The Impact of Temperature on the Effectiveness of Surfactant to Change the Wettability

By

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ABSTRACT

Utilization of surfactants is one of the methods for wettability alteration of reservoir rock, from oil wet into water wet by reducing the interfacial tension. Studying of wettability alteration mechanism using surfactants has been emphasized by researches. Later on, many researchers have focused on surfactants capability of tolerating on a condition created by increasing temperature to increase their ultimate recoveries. However the wettability of porous media is difficult to observe directly during the injection of the surfactant process. Many differ in opinion among researchers for the exact temperature on the effectiveness of surfactant and contact angle to recover the oil. Therefore, experimental study needs to be performed to observe the changes in contact angle at the optimum temperature.The objective of this experimental study is to investigate the impact of different temperatures, ranging from $50^{\circ}C$-$120^{\circ}C$ on the surfactant's performance in altering the wettability of a rock. In this study, sessile up method for contact angle measurement have been made using Berea sandstone core sample, Dulang crude oil in the presence of Sodium Dodecyl Sulfate (SDS) surfactant at pressure 200 psia and constant salinity of 5000ppm. The experiment is being conducted using the Interfacial Tension 700 (IFT700) tool and measured the contact angle. The changes in contact angle when temperatures are increasing have been evaluated. The contact angle is found to decrease from 110° to 48° as the temperature increase. The wettability has been enhanced and changed from oil wet to water wet means contact angle decreasing as temperature increases, leading to increase the oil recovery.

CERTIFICATION OF APPROVAL

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Zahidah Abdul Rahim

A project dissertation submitted to the
Petroleum Engineering Programme
University Teknologi PETRONAS
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Bachelor of Engineering (Hons) Petroleum Engineering

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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 originality work contained here have not been undertaken or done by unspecified sources or persons.

(Zahidah Abdul Rahim)

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CHAPTER 1

1 INTRODUCTION

1.1 Background of Study

Wettability is defined as the "tendency of one fluid to spread on or adhere to a solid surface in the presence of other immiscible fluids" (Tarek Ahmad, 2001). When these immiscible fluids are in contact, the active forces are exists. This existence of these forces gives rise to fundamental properties such as interfacial tension and wettability. Because of these attractive forces, the wetting phase tends to occupy the smaller pores of the rock and the nonwetting phase occupies the more open channels. For a water wet reservoir, water occupies the small pores and most of the rock surface is in contact with water. When the rock has no strong preference for either oil or water then it is an intermediate wet reservoir. In an oil wet reservoir, oil covers most of the rock surface and small pores. The wettability of reservoir rocks to the fluids is important in that the distribution of the fluids in the porous media is a function of wettability (Dandekar, 2006).

Many different methods have been proposed for measuring the wettability of a rock/fluid system. They consist of quantitative methods such as Contact angles, imbibitions and forced displacement (Amott) method and United States Bureau of Mines (USBM) method. Quantitative methods are direct measurement methods, where the wettability is measured on actual rock samples using reservoir fluid samples and the reported the wettability in terms of wettability index, signifying the degree of water, oil wetness, or intermediate wetness. The contact angle measures the wettability of a specific surface, while the Amott and USBM methods measure the average wettability of a core (Anderson, 1986) .Primarily the ability of surfactant to reduce the interfacial tension (IFT) and altering wettability it is viable option being explored today. The surfactant comes from the term surface-active agent.

1.2 Problem Statement

1.2.1 Problem Identification

Wettability of porous media is difficult to observe directly during the injection of the surfactant process. Many differ in opinion among researchers for the exact temperature on the effectiveness of surfactant and contact angle to recover the oil. Previous study on wettability alteration showed that, advancing angle measured was decreasing during surfactant injection (135°-139°) compared to initial advancing angle (152°) measured before surfactant injection (Xu *et al.,* 2005) .Contact angle decreases as temperature increases (Standnes and Austad, 2000). Decreasing trend IFT from 40.1 mN/m at 28°C to 35.7 mN/m at 70°C as the temperature increase for 0.005Mole Stearic Acid (SA) in n-decane/water system (Hamouda and Karoussi, 2008). Therefore, experimental study needs to be performed to observe the changes in contact angle as the temperature increases.

1.2.2 Significant of the project

This project is very important in order to observe the changes in contact angle as the temperature increases during surfactant injection in the core sample surface. The changes of contact angle will be measured throughout the experiment process. This study will investigate a relationship between two dependent variables which are temperature and contact angle. There has been considerable effort to study surfactant ability in order to recover the remaining oil. Surfactant can be used to create ultra low IFT between surfactant bank and remaining oil thus increase the remaining oil mobility (Salehi *et al.*, 2006). This project may help to bring out the idea on how this relationship of these two dependent variables will increase or decrease the recovery efficiency of a reservoir utilizing surfactant injection as an EOR option.

1.3 Objective

The objective of this project is to study experimentally the impact of temperature on the surfactant ability to change the wettability.

1.4 Scope of Study

There are extensive areas of studies for the effect of temperature on the effectiveness of surfactant to change the wettability. In this project, the study will be looking into measurement of the initial wettability on the core samples saturated in brine without surfactant. Then, this study focuses on changes of the contact angle by apply a variation of temperature on the surfactant as well as to perform better wettability in core sample. This involves knowledge in wettability, measurement on contact angle, and the effective of temperature on better wettability changes.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Studies on temperature effect on wettability alteration using surfactant by IFT and/or Contact angle measurement.

Hamouda and Karoussi (2008) studied the effect of the temperature on oil recovery by measured the interfacial tension (IFT) and contact angle. In order to examine the trend and the effect of these ions in salt water, the IFT measurements are performed with 0.005Mole concentration of stearic acid (SA) in n-decane /water containing 0.1Mole concentration of Sodium Sulfate or Magnesium Chloride. Indeed interfacial tension experiments show the expected decreasing trend IFT from 40.1 mN/m at 28°C to 35.7 mN/m at 70°C as the temperature increase for 0.005Mole concentration of Stearic Acid (SA) in n-decane/water system.

Standnes and Austad (2000) measured the advancing and receding contact angles as a function of temperature for modified calcite surfaces with 0.005Mole concentration of Stearic Acid (SA) dissolved in decane. The result showed that the contact angle decreases with temperature which is indicate that the calcite surface is becoming more water- wet as a function of temperature.

Hjelmeland and Larrondo (1986) studied that temperature can have an effect in reducing the IFT between crude oil and an aqueous sulfonate system. The result showed that temperature was found to have a large effect on the wetting characteristics. At low temperature, the solid phase exhibited oil-wet behavior, whereas at higher temperatures it exhibited water-wet behavior.

Wang and Gupta (1995) reported that contact angle measurements at reservoir conditions. Their experimental results included contact angle measurements for crude oil-brine-quartz system over a pressure range of 200 to 3000 psig and temperature range of 72.5°F to 200°F. The quartz mineral surface was used to represent the sandstone. The result showed the contact angle decreases as the temperature increasing.

2.2 Studies on wettability alteration using surfactant

Wu *et al.*, (2008) studied the application of surfactants on the mechanisms responsible for enhanced oil recovery from carbonate reservoirs. This study used naphthenic acids dissolved in decane as a model oil to make calcite surfaces more water-wet. Results indicate this flotation test is a useful rapid screening tool to identify better EOR surfactants for carbonates.

Xu *et al.*, (2005) studied the wettability altering capability of the surfactants. In this experiments, the fractured Yates dolomite reservoir, Yates crude oil, synthetic brine and an anionic ethoxy sulphate surfactant have been used. The experiment has been conducted at Yates reservoir conditions of 700 psi and 82° F. The contact angles have been measured using the Dual-Drop Dual Crystal (DDDC) technique. The results showed that the advancing angle measured was decreasing during surfactant injection (135°-139°) compared to initial advancing angle (152°) measured before surfactant injection.

Zhang *et al.*, (2006) investigated the controlling mechanisms and variables of improved the oil recovery using surfactant. He found the use of alkaline surfactant is able to alter wettability of calcite from intermediate-wet to water-wet. The presence of sodium carbonate also significantly reduces the anionic surfactant adsorption.

Jarrahin *et al.*, (2010) studied on a wettability alteration of reservoir rock using surfactants. In this experiment, model oil is prepared by adding Stearic Acid in n-heptane. Calcite surface as solid surfaces was saturated in 2 different conditions which are with stearic acid in n-heptane and without Stearic Acid in n-heptane and aged for 2 days. Afterward, a drop of water was placed on the calcite surface. The results showed the contact angle decreases from 110° to 28°.

Kolev *et al.*, (2002) carried out experiments on detachment of oil drops from glass substrates in solutions of an anionic surfactant. In this experiment, it use surfactant C14/C16-alfa-olefin-sulfulate (AOS) sodium salt with a concentration was 0.3molar Mole and dissolved in 0.1Mole concentration of Natrium Chloride (NaCl), deionized water to form surfactant solution. Pure hexadecane was used as the oil phase and dry glass slides used as substrates. Then, a drop of hexadecane was placed on the upper side dry glass slide. Afterwards, the surfactant solution was carefully poured into the vessel until completely immersing the oil drop in the solution. Consecutive video frames of such drops are digitized and the time dependencies of the contact angle are determined. All experiments were carried out at the ambient room temperature, $22^{\circ}C$. The experimental images of a drop at different stages of spontaneous detachment shows as Figure 2.1 below. It is visible that initially the drop has an approximately spherical shape. With elapsed time the contact angle decreases and the drop becomes slightly elongated under the action of buoyancy. At the final stage (t= 878s) a neck is formed. Next, the drop detaches very fast.

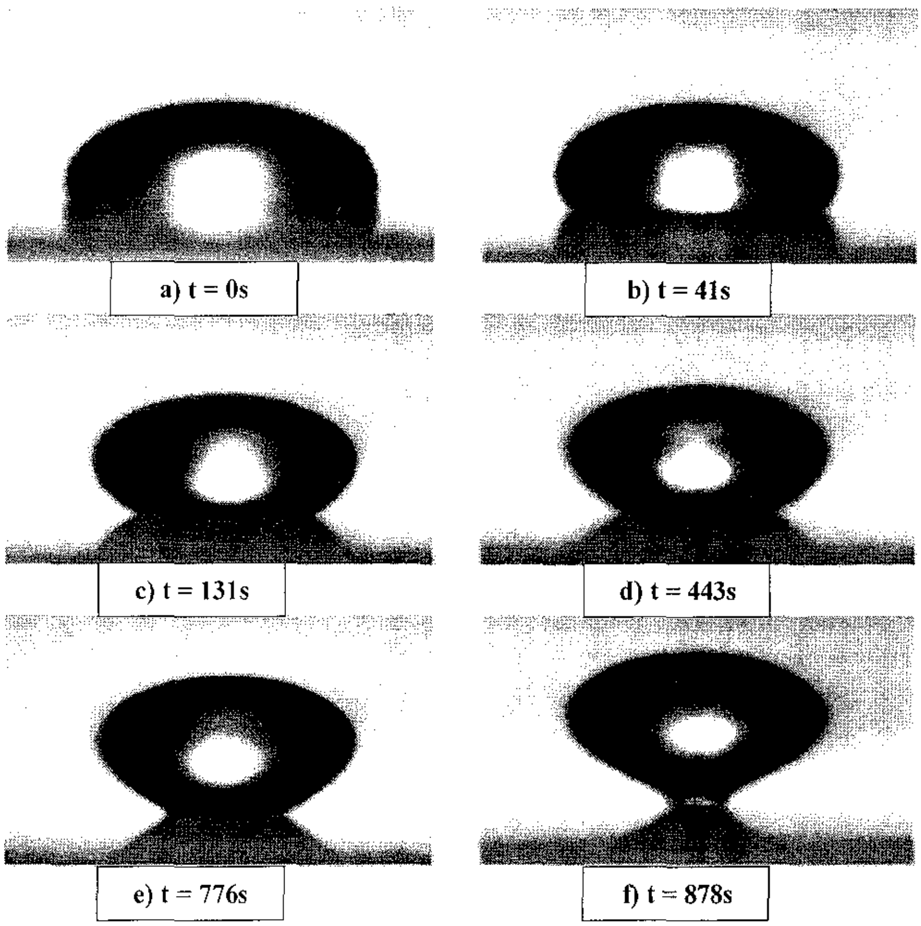


Figure 2.1 : Consecutive images of the process of detachment of a hexadecane drop from a glass plate immersed in solutions of anionic surfactant (Kolev *et al.*, 2003)

Vijapurapu and Rao (2003) studied effect of brine dilution and surfactant addition on spreading and adhesion behavior of Yates crude oil on dolomite surfaces. Spreading and adhesion have been characterized through measurements of oil-water interfacial tension (IFT) and contact angles. Surfactant has ability to alter wettability in addition to reducing IFT. They saturated the core sample in the brine with different surfactant concentrations (0ppm, 500ppm, 1500ppm, 3500ppm) .For the Yates reservoir rock-fluids system, an Ethoxy Alcohol surfactant altered the strongly oil-wet nature (advancing angle of 158°) to water-wet (advancing angle of 39°) at a concentration of 3500 ppm.

2.3 Studies on wettability measurement method

2.3.1 Contact angle measurement

The contact angle is the angle at which a liquid and vapor interface meets a solid surface. The contact angle is specific for any given system and is determined by the interactions across the three interfaces. Most often the concept is illustrated with a small liquid droplet resting on a flat horizontal solid surface. The shape of the droplet is determined by the Young's relation. When a droplet of liquid rests on the surface of a solid, the shape of the droplet is determined by the balance of the interfacial liquid/vapor/solid forces. The contact angle plays the role of a boundary condition (Retrieved from http://en.wikipedia.org/wiki/Contact angle). It can write an equation that must be satisfied in equilibrium (known as the Young Equation):

$$\gamma_{LG} \cos \theta_c = \gamma_{SG} - \gamma_{SL}$$

where : γ_{LG} = liquid-gas interfacial tension

θ_c = contact angle

γ_{SG} = solid-gas interfacial tension

γ_{SL} = solid-liquid interfacial tension

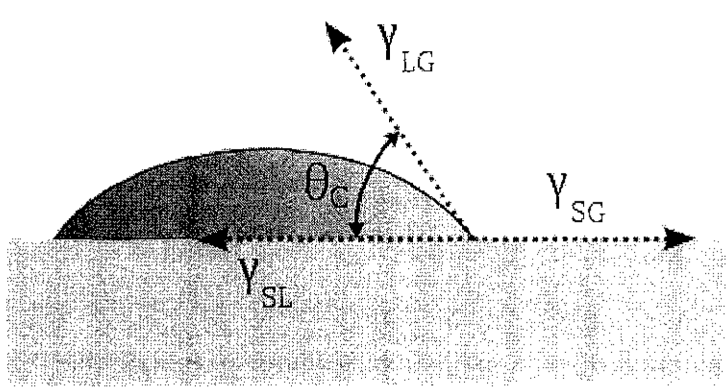


Figure 2.2 : A contact angle of liquid sample (Retrieved from http://en.wikipedia.org/wiki/Contact angle)

The common methods of contact angle measurement employed in petroleum industry are sessile drop method. This methods required the mineral crystal to be tested is mounted in a contaminant free test cell made of inert mineral. Sessile drop method only need a single flat, polished mineral crystals. Quartz and calcite crystals are commonly used in place of sandstone and limestone respectively. Figure 2.3 showed the sessile drop measurement. In this case the water droplet was surrounded by oil. For a water wet, the surface is in contact with water and the contact angle was less than 90°. In an oil wet, the surface is in contact with less water and the contact angle was more than 90° (Retrieved from http://en.wikipedia.org/wiki/Contact angle).

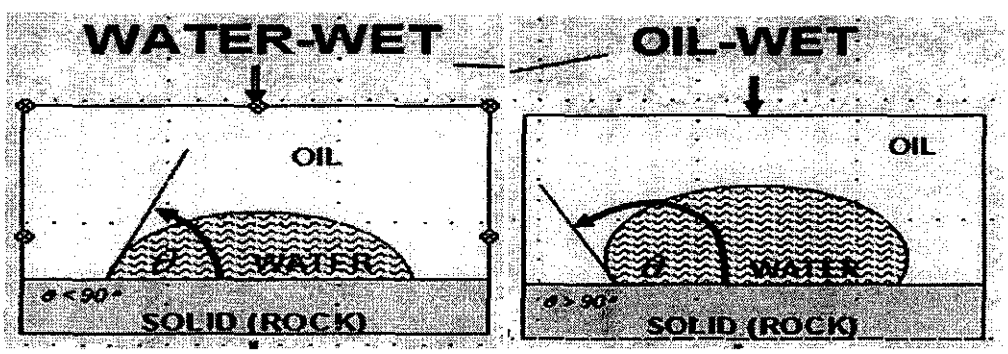


Figure 2.3 : Contact angle wettability (Retrieved from http://en.wikipedia.org/wiki/Contact angle)

Sometimes the contact angle was measured differently when the oil droplet was surrounded by water which is measured the contact angle of water (more dense fluid) not the oil. From Figure 2.4, for strong oil wet, the surface is in contact with oil and the contact angle of water was more than 90°. In a less oil wet, the surface is in contact with more water than oil. So the contact angle was less than 90°.

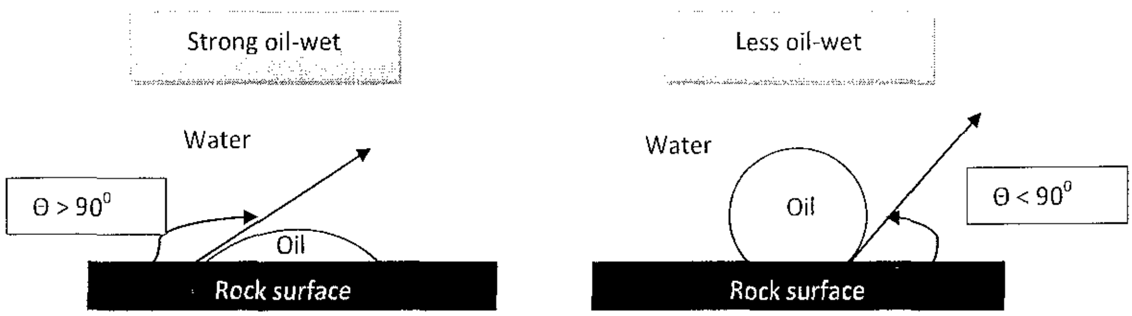


Figure 2.4 : Oil droplet surrounded by water

2.3.2 Amott method

Amott method is one of the most widely used empirical wettability measurement s for reservoir cores in petroleum engineering. The method combines two spontaneous imbibitions measurements and two forced displacement measurements. This method recognizes the fact that wetting fluid will generally imbibe spontaneously into a core, displacing the nonwetting fluid. The wetting fluid is forced to imbibe some more by using centrifugal (Anderson, 1986). The most important parameters to be measured in Amott method are:

- Amount of oil displaced by spontaneous imbibitions of water, $V_{osp.}$
- Amount of oil displaced by force imbibitions of water, $V_{ot.}$
- Amount of water displaced by spontaneous imbibitions of oil, $V_{wsp.}$
- Amount of water displaced by force imbibition of oil, $V_{wt.}$

The parameters measured above are used in the following calculation of displacement by water ratio δ_w and displacement by oil ratio $\delta_{o.}$

$$\delta_w = \frac{V_{osp}}{V_{wt}} \qquad \delta_o = \frac{V_{wsp}}{V_{ot}}$$

2.3.3 USBM method

USBM method was developed by Donaldson *et al* (1969) and also designed to measure the average wettability of a core sample. The entire wettability test is conducted in a centrifuge apparatus which used to place the core sample and displaced the fluid. The wettability of the core sample was determined if the $I_{USBM} > 0$, the core is water-wet and when $I_{USBM} < 0$, the core is oil-wet. Whereas a near zero value of I_{USBM} it indicates neutral wettabilty (Dandekar, 2006).

CHAPTER 3

3 METHODOLOGY

3.1 Research methodology

3.1.1 Reagent Selection

The following reagents are used in this experiment:

a) Salt solution (brine) of 5000ppm from chemical engineering lab is prepared by dissolving 5g of natrium chloride, NaCl in 1 liter distilled water.
   Increasing in oil recovery from laboratory coreflood studies is achieved by waterflooding using low salinity water, compared with injection of high salinity water. The reasons for this improved oil recovery are thought to be due to effective wettability changes, controlled removal of clay constituents or intentional injection of water containing low concentrations of total dissolved solids into the reservoir. Normally, salinity of less than 5000ppm is implemented (McGuire *et al.*, 2005)

   Webb *et al.*, (2008) compared the high and low salinity of the injection brine to the crude oil for waterflood recovery. The injection brines were simulated the formation brine for high salinity waterfloods (salinity of 15,000ppm to 200000ppm) and low salinity brine(less than 5000ppm) for low salinity corefloods. All brines, both high and low salinity were used for waterflood tests. As the results, it has proven that low salinity of injection brine improved the waterflood characteristics.

b) Dulang Crude oil

c) Anionic surfactant (Sodium Dodecyl Sulfate) supplied by Chemical Engineering laboratory.
   Sodium Dodecyl Sulfate with two different surfactant concentrations for 0ppm and 500ppm is dissolved in brine was prepared. The experiment was repeated

for the 1500ppm and 3500ppm surfactant concentration to investigate the affect of surfactant concentration to the changes in contact angle.
Table 3.1 showed according to amounts listed to produce surfactant solution. This range of concentration is chosen because it is used in the field operations (Ayirala, 1996).

Many studies use the same range of concentrations in their experiments. For example, Vijapurapu and Rao (2003) studied effect of brine dilution and surfactant addition on spreading and adhesion behavior of Yates crude oil on dolomite surfaces. Spreading and adhesion have been characterized through measurements of oil-water interfacial tension (IFT) and contact angles. They saturated the core sample in the brine with different surfactant concentrations (0ppm, 500ppm, 1500ppm, 3500ppm) .For the Yates reservoir rock-fluids system, an Ethoxy Alcohol surfactant altered the strongly oil-wet nature (advancing angle of 158°) to water-wet (advancing angle of 39°) at a concentration of 3500 ppm.

d) One sandstone core sample

Berea sandstone core sample is sliced to provide surfaces for contact angle measurements in this experiment. Berea sandstone is widely familiar by petroleum industry since the past 30 years for the purpose of studying surfactant efficiency. Jadhunandan and Morrow (1995) were studied that wettability can be varied in Berea Sandstone by changing the condition for adsorption from crude oil.

3.1.2 Surfactant Solution Preparation

Four surfactant solutions over constant salinity of 5000ppm of each surfactant concentration are prepared by dissolving Natrium Chloride (NaCl) and surfactant, Sodium Dodecyl Chloride (SDS) in distilled water according to amounts specified in Table 3.1 and Figure 3.1 below:

Table 3.1 : Amount of Surfactant concentration, SDS, NaCl, and distilled water

Surfactant concentration, ppm	0	500	1500	3500	Total amount
Sodium Dodecyl Chloride , g	0	0.5	1.5	3.5	5.5
Natrium Chloride, g	5	5	5	5	20
Distilled water, liter	1	1	1	1	4

Figure 3.1 : Surfactant Solution Preparation

3.1.3 Core Properties Measurement

The core sample properties were measured using poro perm (CoreEval 30) device. Firstly, measured the dimension of the core and then left the core dried in the oven at 60°C for 1 day. Porosity and permeability was determined as shown in Table 3.2 below:

Table 3.2 : Core Properties Measurement

Core properties					dimensions		
	Porosity, %	Grain Density, (g/cc)	Kair,(md)	K∞,(md)	L,(mm)	D,(mm)	Weight,(g)
Initial reading	14.3	2.67			51.24	38.08	131.907
Reading 1	14.605	2.647	20.062	17.098			
Reading 2	14.773	2.652	20.24	17.183			
Reading 3	14.853	2.655	20.432	17.212			
Reading 4	14.844	2.654	20.317	17.567			
Reading 5	14.897	2.656	20.315	17.655			
Reading 6	14.929	2.657	20.385	17.527			
Average	14.817	2.654	20.292	17.374			

3.1.4 Core Slicing/ Trimming

The core trimming device is used to cut the core sample into thin slices. Four slices of core were cut with diameter of about 1mm and were made to provide solid surfaces for the contact angle determination with drop of oil using sessile up orientation.

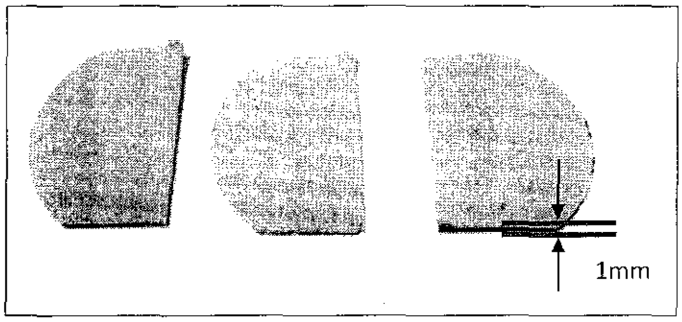


Figure 3-2 : Core Slicing

3.1.5 Saturation Duration

The saturation duration of published studies of surfactant effect on rock wettability, range from one day to ten days. All the four core slices are saturated in the surfactant solution of different Sodium Dodecyl Sulfate concentrations (0ppm, 500ppm, 1500ppm, 3500ppm) more than 10 days.

Morrow *et al.,* (1999) performed a study on wettability characterization from spontaneous imbibitions measurements. They saturated the core sample with brine and allowed to equilibrate for ten days. Besides that, Zhou *et al.*, (2000) was studied the interrelationship of wettability, initial water saturation, aging time, and oil recovery by spontaneous imbibitions and water flooding. The dry core samples were vacuumed and saturated with the surfactant solution and left immersed for about ten days to establish ionic equilibrium between the rock constituents and the brine. This Table 3.3 below showed the core slices for each different surfactant concentration:

Table 3.3 : Core Slices with Different Surfactant Concentration

Core Slices	Sodium Sulfate Dodecyl (SDS) concentration, ppm
Core 1	0ppm SDS
Core 2	500ppm SDS
Core 3	1500ppm SDS
Core 4	3500ppm SDS

Figure 3.3 below showed the picture of core when it was saturated with brine more than 10 days:

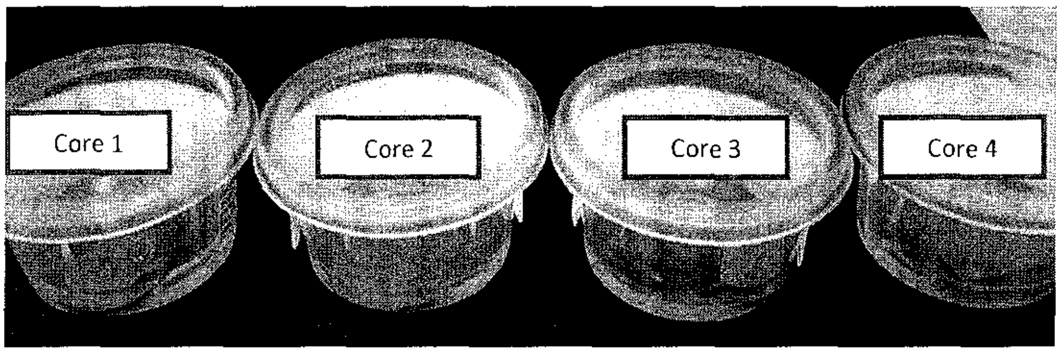


Figure 3.2 : Cores was Saturated with Brine more than 10 days

3.2 Experimental Setup

3.2.1 : Determine Drop Orientation

There are two drop orientations for sessile method namely:

1) Sessile up method or sessile bubble

This orientation is selected from user if oil drop is injected from the bottom, so that oil drop will float up in the brine and rest at the rock slice bottom.

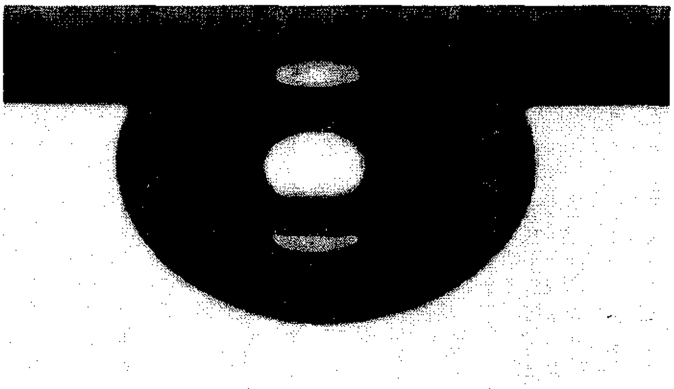


Figure 3.3 : Bubble sitting beneath solid surface captive by other missible

2) Sessile down method or sessile drop

This orientation is selected from user if water drop is injected from the top, so that water drop will sit on the core slice surrounded by oil

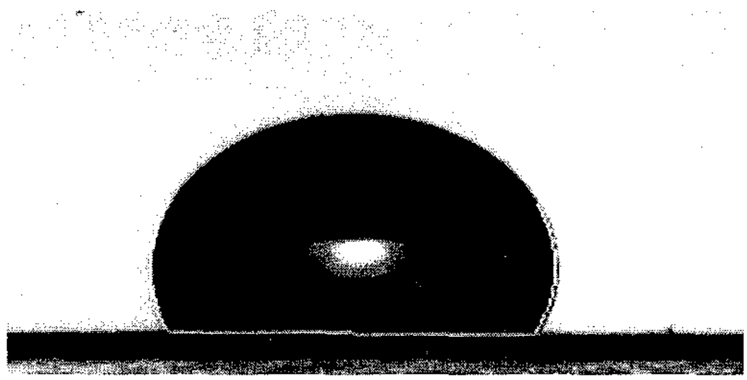


Figure 3.4 : A drop lying on the solid surface

Since the back light is not bright enough to give the view of the water drop surrounded by oil, the first orientation is selected for this experiment.

3.2.2 : Instrument Setup

1) Core slice is mounted on a holder so it may be held in horizontal position. Double sided tape is used to place the core slice on the holder.
2) The core slice holder is placed in the core chamber.
3) Test fluids (oil and brine) are placed in syringes that will be attached to the inlet ports on the device, IFT 700. These ports are connected to the sample chamber through tubing lines.

3.2.3 : Fluid Loading

The software requires some external parameters to be supplied such as needle size (internal/external diameter) and fluid densities.

4) Syringes are attached to the inlet ports.
5) Brine is fed into the chamber until it is full.

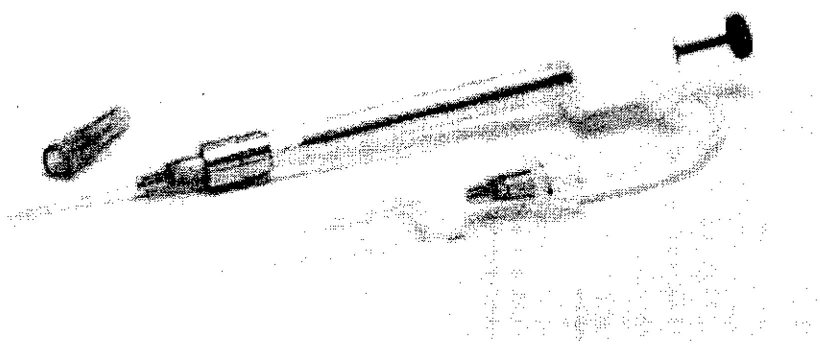


Figure 3.5 : Syringes, Cuvet and Needles

3.2.4 : Drop Dispense

6) Oil drop is formed at the tip of the needle and release
7) That oil drop will float up in the brine and rest at the rock slice bottom.
8) Initial live video image of the sample is obtained. Camera focus is adjusted, so that the tip of the needle image is visibly sharp. The camera viewing angle is adjusted so that the needle image is vertical on the computer screen. Camera focus is adjusted to get a clear image of the oil bubble at the bottom of the core slice.

3.2.5 : Temperature Increasing

9) Temperature was found to have a large effect on the wetting characteristics. In this experiment, the temperatures were increasing for about 50°C, 70°C, 90°C, and 120°C for each of different surfactant concentration respectively.
10) The initial wettability was determined by measured the contact angle of less dense fluid without surfactant (0ppm).

3.2.6 : Aging Time

Aging time is duration of absorption of surfactant solution at the interface to reach equilibrium for contact angle measurement. Measurement of IFT is normally performed when the immiscible fluids are assumed to be in equilibrium. As in the case of liquid-liquid-solid system, the equilibrium between the IFT will also enable the contact angle to be measured. The aging time of IFT studies were presented as shown in Table 3.4 below:

Table 3.4 : Aging time studies of IFT studies

Researchers	Fluid tested for dynamic IFT	Aging time
Hassan *et al* .(1953)	Propane, n-butane, n-pentane, n-hexane, n-octane, i-octane, and benzene against water	2 minutes
Jasper *et al.* (1970)	Benzene and water	5 minutes
McCaffey (1972)	n-dodecane and water	10 minutes
Hjelmeland *et al.* (1986)	Oil and brine	30 sec to 20 minutes

3.3 Contact Angle Measurement

Contact angles are measured by fitting a mathematical expression to the shape of the drop and then calculating manually using simple trigonometry. Where angle θ, is obtained from the inverse of tangent a to b, $\tan^{-1}$ (a/b).

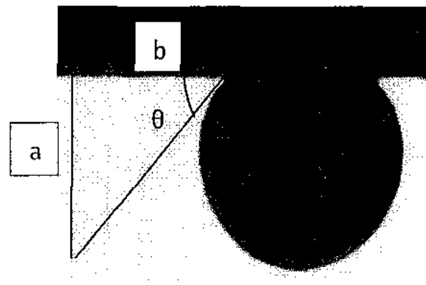


Figure 3.6 : Contact Angle Calculation

3.4 Equipment and tool

In this experiment the device, Interfacial Tension 700 (IFT700) device has been used to measure contact angles at elevated temperature. The picture of the device is shown in Figure 3.8. The central part of this system is core chamber, which has a design rating of 10000 psi at 180°C. The top one inside the core chamber is used to mount the core slice on a holder, while the bottom one has a needle to place on oil drop on the core sample surface. The other accessories are the image capturing system which includes a high-quality digital camera and a light source. It is connected to the computer, monitor and video recorder. The contact angles are measured by a captured of an oil drop shape.

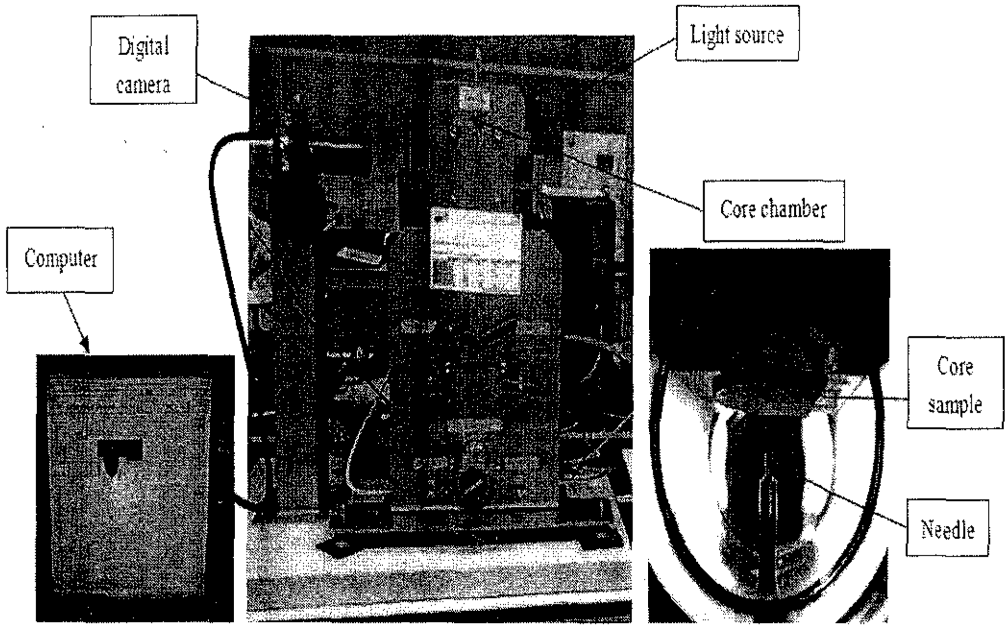


Figure 3.7 : IFT 700

3.5 Key Milestone

Table 3.5 : Key Milestone

	Week (2011)	Milestone
1	February 3-February 13	• Request for Chemicals (Sodium Dodecyl Sulfate, Natrium Chloride) approved by Chemical Engineering Lb Executive. • Laboratory use for chemical solutions preparation application approved by Chemical Engineering Lab Executive.
2	February 14-February 20	• Laboratory and equipment use (IFT 700, poro-perm Core Eval 30, oven, core trimmer) application approved by Mechanical Engineering Lab Executive and Petroleum Engineering Department Technician.
3	February 21-February 28	• Surfactant solution preparation (Natrium Chloride + distilled water + Sodium Dodecyl Sulfate) completed.
4	March 1-March 6	• Core properties measurement (measure porosity and permeability) completed.
5	March 7-March 13	• Core trimming to slice the core as solid surfaces for contact angle measurement completed. • Core slices saturation in surfactant solution for each different surfactant concentration commenced.
6	March 14-March 20	• Mid-semester break • Saturation of core slices continued. • Progress report submitted (March 16).
7	March 21-March 23	• Experimental setup for sessile up on IFT 700 was arranged. • A test run is performed to confirm the operability of the arrangement.
8	March 24-March 31	• Experiment commenced.
9	April 1- April 4	• Result analysis. • Submission Final report(first draft) (April 5)

3.6 Gantt Chart

A series of laboratory tests was conducted during this semester. A result of the tests was an analyzed the core samples wettability by measured the contact angle with varying temperature conditions. Figure3.9 and 3.10 below is Gantt chart showing the timeline to complete the task.

FINAL YEAR 1st SEMESTER (JULY 10)																
No	Detail/ Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Topic selection							Mid-semester break								
2.	Preliminary research															
3.	Submission of Preliminary Report															
4.	Study on fundamental concept of wettability															
5.	Study on effect of temperature on the surfactant															
6.	Submission of Progress Report															
7.	Seminar (optional)															
8.	Study on mechanisms of surfactant and the effect to the wettability															
9.	Preparation for interim report															
10.	Submission of Interim Final Report															
11.	Oral presentation															

Figure 3.8 : Gantt Chart during FYP1

FINAL YEAR 2^{nd} SEMESTER (JAN 2011)																
No.	Detail/ Week	1	2	3	4	5	6	Mid-semester break	7	8	9	10	11	12	13	14
1	Finalizing experiment methodology	■														
2.	Gathering and booking of equipments and reagents		■													
3.	Preparation of SDS-NaCl mixtures			■												
4.	Measurement of core sample properties and slicing of core sample				■											
5.	Aging of core sample in SDS-NaCl mixtures					■	■									
6.	Commencement of experimental work using IFT700 and preparation of progress report								■	■						
7.	Submission of progress report									■						
8.	Experimental work using IFT700									░	░					
9.	Seminar/ Poster exhibition											░	░			
10.	Submission of final report												░			
11.	EDX													░		
12.	Oral presentation														░	

Figure 3.9 : Gantt Chart during FYP2

(Completed: ■ Ongoing : ░)

CHAPTER 4

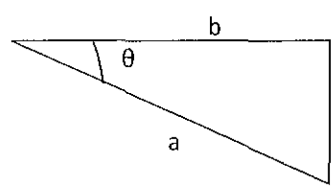
4 RESULTS AND DISCUSSION

4.1 Contact Angle Calculation

Contact angle is measured once the oil drop is in equilibrium with brine, which is after the drop is in static condition. Water wet condition is when contact angle is less than 90°. Thus a smaller value of contact angle indicates a more water wet condition. Likewise, when contact angle is greater than 90° indicates oil wet conditions.

In this experiment, contact angle is calculated manually using simple trigonometry. Where angle θ is obtained from the inverse of tangent a to b, $\tan^{-1}$ (a/b).

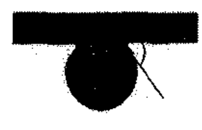
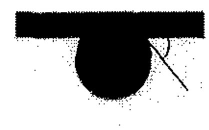
$$\theta = Tan^{-1}\left(\frac{a}{b}\right)$$



4.2 Wettability determination

A visual image at Table 4.1 below shows the result of the reduction in contact angle measurement as temperature and surfactant concentration increases. A plotted graph at Figure 4.1 showed that as the temperature increase the contact angle decreasing. It showed for each different surfactant concentration 0ppm and 500ppm. For 0ppm surfactant concentration contact angle decreases, ranging from 110°-100° and for 500ppm surfactant concentration contact angles decrease, ranging from 77°-55°.This decreasing trend of contact angle with increasing surfactant concentration as temperature increases indicates the wettability has changed from oil wet to become water wet. The wettability has been enhanced and changed from oil wet to water wet means contact angle decrease with increasing surfactant concentration as temperature increases, which is very good because will leading to increase the oil recover.

Table 4.1 : Visual images of oil bubble for contact angle measurement (0ppm and 500ppm surfactant concentration)

Core slice	Sodium Dodecyl Sulfate (SDS) concentration, ppm	Contact angle			
		Temperature ^0C			
		$50^{\circ}C$	$70^{\circ}C$	$90^{\circ}C$	$120^{\circ}C$
1	0 ppm	 Θ = 110 deg	 Θ = 108 deg	 Θ = 105 deg	 Θ = 100 deg
2	500 ppm	 Θ = 70 deg	 Θ = 67 deg	 Θ = 59 deg	 Θ = 55 deg

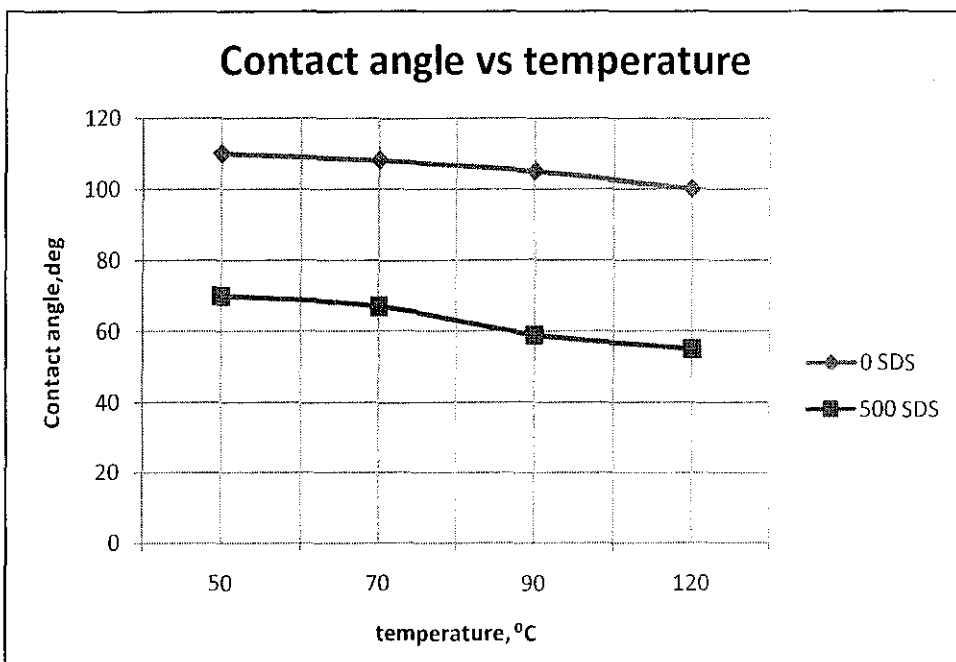


Figure 4.1 : Contact Angle vs temperature for 0ppm and 500ppm surfactant concentration

Temperature was found to have a large effect on the wetting characteristics. As temperature increase, it tends to increase the solubility of wettability altering compounds. Some compounds detached from the surface as temperature increase, hence result in a decrease in contact angle values and gives a good result in achieving good wettability.

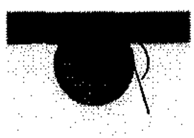
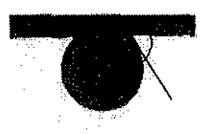
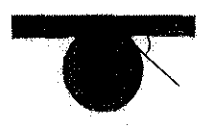
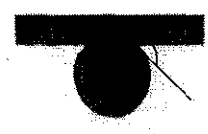
Standnes and Austad (2000) measured the advancing and receding contact angles as a function of temperature for modified calcite surfaces with 0.005Mole concentration of Stearic Acid (SA) dissolved in decane. The result showed that the contact angle decreases with temperature which is indicate that the calcite surface is becoming more water- wet as a function of temperature.

Wang and Gupta (1995) reported that contact angle measurements at reservoir conditions. Their experimental results included contact angle measurements for crude oil-brine-quartz system over a pressure range of 200 to 3000 psig and temperature range of $72.5^{\circ}F$ to $200^{\circ}F$. The quartz mineral surface was used to represent the sandstone. The result showed the contact angle decreases as the temperature increasing.

Hjelmeland and Larrondo (1986) studied that temperature can have an effect in reducing the IFT between crude oil and an aqueous sulfonate system. The result showed that temperature was found to have a large effect on the wetting characteristics. At low temperature, the solid phase exhibited oil-wet behavior, whereas at higher temperatures it exhibited water-wet behavior.

Afterwards, this experiment was repeated for the 1500ppm and 3500ppm surfactant concentration to investigate the affect of surfactant concentration to the changes in contact angle. Table 4.2 showed for the contact angle measurement as the surfactant concentration increasing. It is visible that from plotted Figure 4.2, when increase the surfactant concentration to 1500ppm and 3500ppm the contact angle still showed the decreasing trend as the temperature increases. For 1500ppm surfactant concentration contact angle decreases, ranging from 60°-53° and for 3500ppm surfactant concentration contact angles decrease, ranging from 55°-48°.

Table 4.2 : Visual image of oil bubble for contact angle measurement (1500ppm and 3500ppm surfactant concentration)

Core slice	Sodium Dodecyl Sulfate (SDS) concentration, ppm	Contact angle			
			Temperature °C		
		50°C	70°C	90°C	120°C
1	1500 ppm	 Θ = 60 deg	 Θ = 58 deg	 Θ = 57 deg	 Θ = 53 deg
2	3500 ppm	 Θ = 55 deg	 Θ = 54 deg	 Θ = 50 deg	 Θ = 48 deg

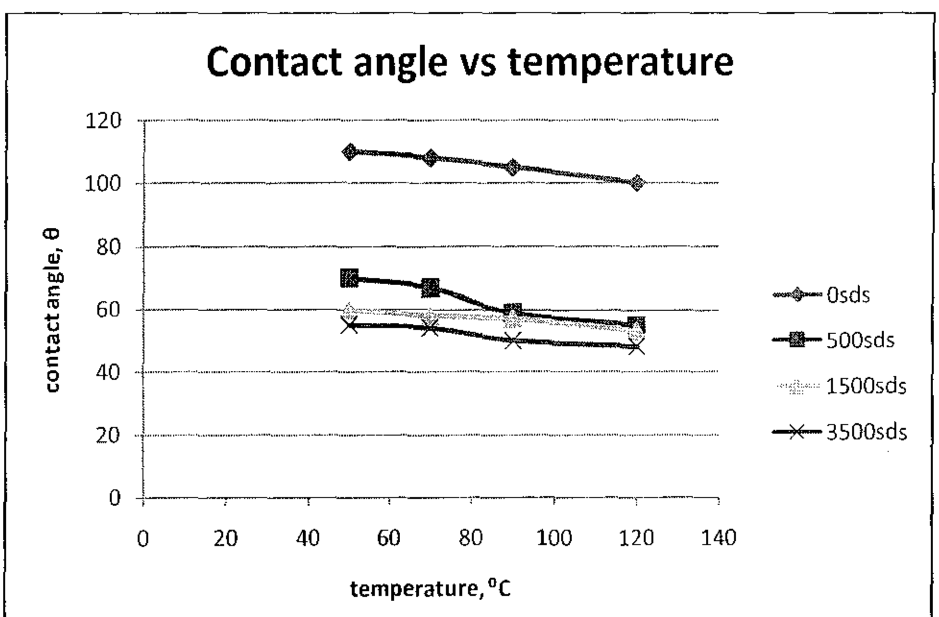


Figure 4.2 : Contact Angle Vs Temperature for ranging from 0ppm-3500ppm surfactant concentration

The purpose of increasing the surfactant concentration is to observe how many changes in contact angle and how affective it's for wettability alteration to become water wet. As expected, higher surfactant concentrations alter the wettability from oil wet to water wet. The decreasing trend of contact angle as surfactant concentration increases it indicates of wettability becoming water wet for each increasing temperature compared to initial wettability.

Alveskog *et al.,* (1998) studied on the influence of surfactant concentration, surfactant adsorption and interfacial tension between oil and aqueous phase. The anionic surfactants were used in the experiments with different concentration of surfactant. The core material was Berea Sandstone. The result showed that increased surfactant concentration results in a change in wettability from oil wet to water wet. The contact angle decreases with increasing surfactant concentration. These correspond to the driving factor which is the higher surfactant concentration the more surfactant absorption and lowered the IFT.

Zhang D.L *et al.*, (2006) investigated the effect of surfactant concentration and understand the controlling of mechanisms involve in surfactant on wettability alteration. The mechanism involved in surfactant are mainly wettability alteration and in IFT reduction. Anionic surfactant (Sodium Carbonate) used in the experiment and both wettability alteration and IFT reduction has been responsible for the increase in oil recovery. When Sodium Carbonate was increased from 0.45 to 1.2 mole concentration, contact angle decreasing ranging from 80° to 40°.

CHAPTER 5

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As conclusions, the experimental result seems more reliable and conclusive. As temperature increase, the contact angle was decreased by increasing the surfactant concentration. The wettability has been enhanced and changed from oil wet to water wet which leading to increase the oil recovery. The result shows that the higher temperature the more absorption of surfactant is works in improving the wettability to water wet condition.

5.2 Recommendations

As recommendation for future works, Dandina Rao (2003) recommended the contact angle is measured using Dual -Drop Dual Crystal (DDDC) technique instead of the using the sessile up method. DDDC technique were resolved the some problem by using sessile up method. Some problem encounter during this experiment is air within the needle is trapped when the test chamber is being filled with brine/SDS which can cause the oil drop created contains smaller air bubble. This problem will affect the shape of oil drop. Besides that, Xu *et al.*, (2005) studied the wettability altering capability of the surfactants. In this experiments, the fractured Yates dolomite reservoir, Yates crude oil, synthetic brine and an anionic ethoxy sulphate surfactant have been used. The experiment has been conducted at Yates reservoir conditions of 700 psi and 82° F. The contact angles have been measured using the Dual-Drop Dual Crystal (DDDC) technique. The result showed that the advancing angle measured was decreasing during surfactant injection (135°-139°) compared to initial advancing angle (152°) measured before surfactant injection.

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