WATER FLOODING PERFORMANCE IN OIL RESERVOIR

By

GEHAD MOHAMMED AHMED NAJI 15745

FINAL REPORT

Submitted to the Petroleum Engineering Programme

In partial fulfillment of the requirement
For the degree
Bachelor of Engineering (Hons)
(Petroleum Engineering)

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2015

CERTIFICATION OF ORIGINALITY

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

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Gehad Mohammed Ahmed Naji 15745

ABSTRACT

The objectives of the final year project are to study and investigate the forces in the reservoir model and how these forces can be used to design the water flooding performance toward oil recovery enhanced. And to evaluate how the water injection rate can affect the oil recovery for reservoir. It is a beneficial to the gas and oil industries of company to have and test the potential for the techniques of oil recovery, and low cost which are cheap and easy to control like water flooding.

The problem in water flooding is that, oil companies still looking for researches on force which available in the reservoir and how it can be designed the water flooding that can lead to be a good oil recovery at lower cost. Precisely, approximately maintenance and design the requires of water flooding to understand the oil viscous can be displaced by the water, and how can optimized the oil recovery.

Subsequently, the scope of this project to get the result for water injection into the lab core plug with containing free gas in crude oil at different injection rate of water flooding. The replies for different compared of water floods in ordered to search the mechanisms through which water injection can be recover the crude oil. The evaluation of the parameters is the effect of capillary force, effect of injection water rate, ration of mobility and instability. These researches of this project focus on the effect of evaluating of water injection rate towards recovery of crude oil by water flooding. In respect of obtaining the data, the writer use research and identifying the methodology and understand the notion of water flooding in oil reservoir.

This project will find the result for injection of water into laboratory core sample which contains free gas crude oil at different rate of water injection. Therefore, if we have lower injection rate of water flooding is better than higher injection in terms of oil recovery which can lead to increase the profit of oil as well as the company's revenue.

ACKNOWLEDGEMENT

Alhamdulilah. Thanks to Allah SWT and all praise is to Allah, the most gracious and the most merciful, who through his grace and mercy, whom with his willing giving me the opportunity to complete this final year project which is title Waterflooding performance in oil reservoir. This project would was prepared for petroleum engineering department. This final year project based on the methods that given by university.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Crude oil in the reservoir is a type of oil which has low viscosity, low permeability and low porous that can be flow easily. crude oil has viscosity range 31.1 °API (less than 870 kg/m3).Based on reservoir conditions, oil can be dissolved in the gas, but some of the oil can be recovered by using energy which coming from solution gas of crude oil [1].There are some common characteristic of crude oil properties which are, lower specific gravity, high hydrogen to ratio of carbon , low content of asphaltenes, low residues of carbon, and low nitrogen, so many countries are contain a significant of crude oil deposit.

Waterflooding performance in reservoir is using to increase the production rate and it has low viscosity in a crude oil field because it's not so expensive and easy to control. Therefore, there are some parameters which can develop the waterflooding performance in crude oil reservoir to make it more efficient.

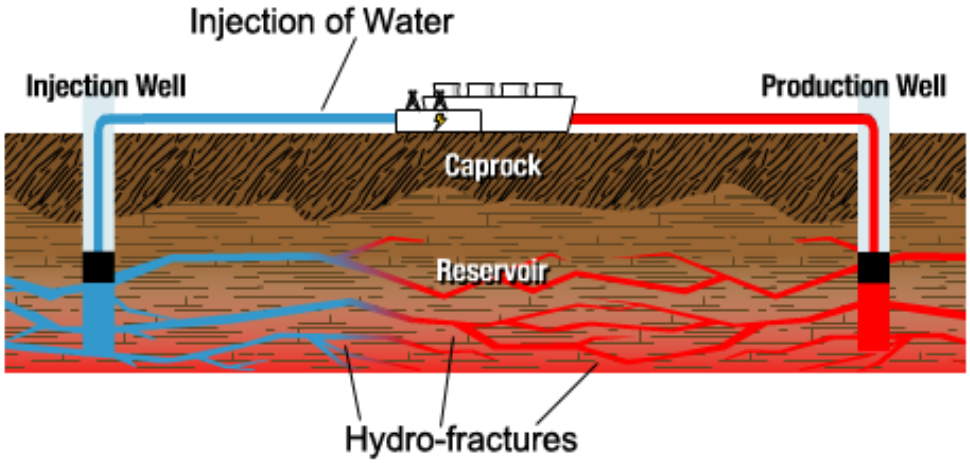


Figure 1: water injection technique in crude oil

Source: ***https://www.google.com.my/search?q=waterflooding+crude oill***

1.2 Problem Statement:

Majority of study according to water flooding performance in crude oil reservoir. It focuses into the effect of flow rate due to water flooding in crude oil. This study will care about the benefit to the oil and gas company to have a low cost. The technique of oil recovery has inexpensive of relatively and it's easy to control.

Oil companies still looking for researches about the forces which available in reservoir and how it can be designed the water flooding that can lead to be a good oil recovery at lower cost. Precisely, approximately maintenance and design the requires of water flooding to understand the oil viscous can be displaced by the water, and how can be optimized the oil recovery.

This project will find the result for injection of water into laboratory core sample which contains free gas crude oil at different rate of water injection. Therefore, if we have lower injection rate of water flooding is better than higher injection in terms of oil recovery which can lead to increase the profit of oil as well as the company's revenue.

1.3 Significant of the project:

There are some limited documented of experience for water flooding in the crude oil reservoir [3-6] but, totally the mechanism recovery of viscous oil by water flooding has not explored. The recovery of water flooding is known to be the low for the high oil viscosity because the mobility adverse ratio between water inject and oil. Water flooding is still applied in many crude oil fields because of field operators and relatively inexpensive have a many years of experience of designing and controlling the water flooding.

Therefore the final year project is hopefully can increasing the level of research about the mechanism for the recovery of viscous oil by waterflooding and can contributing to the oil company to get high oil recovery.

1.4: The objectives:

- To study and investigate the forces in the reservoir model and how these force can be used to design the water flooding performance toward oil recovery enhanced.
- To evaluate how the water injection rate can affect the oil recovery for reservoir.

1.5: The scope of study

The scope of this project to get the result for water inaction into the lab core plug with containing free gas in crude oil with viscosity of 1.5 cp at different injection rates of water flooding. The importance of water flooding is to investigate the mechanisms of water injection towards crude oil reservoir recovery.

So the evaluating of parameters can affect the oil viscosity and rate of water injection, and the ratio of mobility. This project is considered to examine the affects the rate of water injection due to the crude oil reservoir of water flooding performance.

1.6 Project Relevancy

The oil cost of water flooding in crude oil is hundreds of millions of dollars at petroleum industry each year. The optimum solution an important part of all water flooding design for balancing cost with capability of waterflooding in production of crude oil. An understanding the forces that are present in the reservoir and mechanism by which crude oil can be recovered by water injection to insure that, the success in crude oil and increasing the recovery and high oil production.

Oil Company still looking for researches about the forces which available in reservoir and how it can be designed the water flooding that can lead to be a good oil recovery at lower, therefore, the author try to solve this problem by using the final year project as a medium in these applications.

1.7 feasibility of the project

This project is feasible to be conducted within the short time given due to the following factors:

1.7.1 Availability of equipments

This project is required three equipments in the laboratory experiments which are Sohxlet Extractor, POROPERM machine and relative permeability system. Those equipments are available at Academic Building (15-02-08) Universiti Tecknologi PETRONAS.

1.7.2 Availability of chemical and materials

The required materials and equipments for experimental works are provided at UTP laboratory facilities

Chapter 2

Literature Review

2.1 Water Flooding Mechanism

Water flooding performance is the methods of improved the injection of water into the reservoir to clear the quantities of the oil that left after primary recovery (reservoir natural drive). The water injection usually involves by water flooding through wells especially the removal of oil and water from the wells of production. So the mechanism of secondary recovery which involves the water injection into reservoir during injection wells to preserve the pressure of reservoir and drive the oil into production wells. The methods of Enhance oil reservoir (EOR) are very important because the fraction of the oil is very small that lead to be produced by the drive of natural reservoir (primary means). The range for initial recovery is between 5 per cent to 20 per cent.

Water flooding methods become the first secondary methods which applied to reservoir-meets both this criteria. These criteria will help to increase the recovery oil in the reservoir with lower cost.

There are two methods for inject water which are (CAPEX) and (OPEX). The capital cost (CAPEX), it will handle the water injection and production water for surface facilities, with lower cost compared to other method for EOR.

The operating cost method (OPEX), which indicates for water flooding criteria, with lower cost compare to other (EOR) methods [2].

Water flooding has advantages like a proven technical for conventional oil; however there is a room to improve. The enhancement for water flooding will be critical for productivity continuity for a big number of reservoirs through Saskatchewan. However for the EOR technology will more recover of oil from the reservoir. Therefore, the knowledge behind water flooding must advanced to the oil industry.

The next approaches are starting developed and to control the moving oil in the reservoir. In many applications, the viscosity of water is less than the oil reservoir, therefore tends to start flowing through the reservoir by the easiest road. So there are

many ways to increase the viscosity of water and start to flow into the areas where the oil concentration is higher. Produce of oil and researches are not working to find the good practices of water flooding to increase the recovery and to be a successful. Many opportunities of investment compete for attention of oil companies.

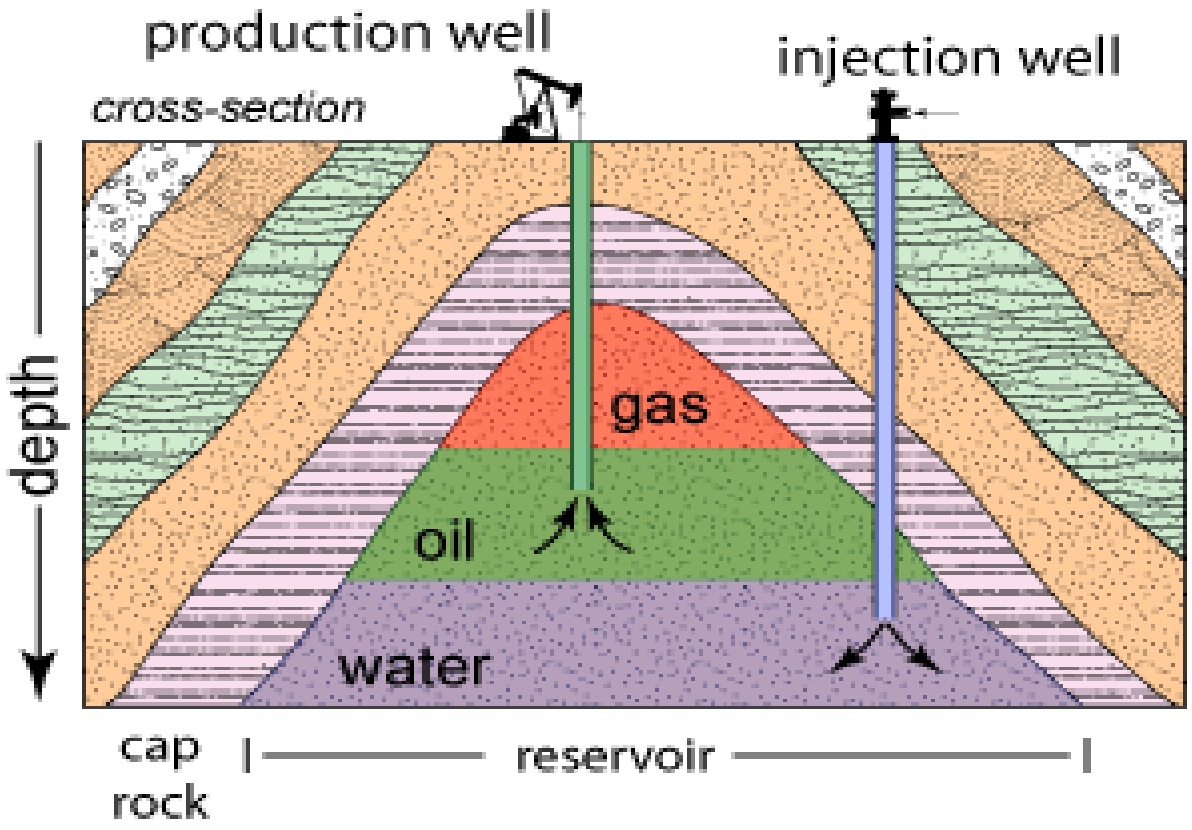


Figure 2: Waterflooding.

2.2: Crude oil

The crude oil in reservoir is a complex mixture of various components. It depends on chemical composition and geographic origin.[3]. It's refers to (light) means that the density or the specific gravity is low compare to the crode oil. Therefore, the API gravity of crude oil has been calculated as higher than 31.1° API, it means that the specific gravity (SG) is less than 0.933.

Therefore, crude oil of transportation, production, and refinery are not present in the reservoir when you compare to the crude oil. More than forty countries having same kind of oil reservoir .in Sudia Arabia having the same amount of congenital oil of reservoir. Actually crude oil is closely to the light crude oil. But the differences between them are the heavy crude oil can't be flow easily. The light crude oil is very important with increasing the number of operators in our industry because of expanding their plants or getting involved in the marketing around the world.

Fields of crude oil can be producing for one hundred and more years, same as one field has been discovered in California in the 1800s. There is some fields have been estimated in Canada, those field can be produced for more than hundred years.

Figure 3: crude oil.

2.3: Waterflooding in crude oil reservoir

The lowest price that has been proven by water flooding is to increase the oil recovery and to maintain the production from oil reservoir. The oil of conventional, the theory of water flooding has been documented well [4]. The application of crude oil is not a case concept same water relative permeability or oil doesn't have same meaning in the system of crude oil, which the area of flow rate of oil and water may have difficulties at all.

So the practitioners still to be applied the same theoretical of understanding or idea to their field. There has been a limited experience of documentations for water flooding in crude oil reservoir, however, in general the mechanisms of viscous oil recovery through water flooding which has not explored yet.

The recoveries of water flooding are low when the viscosity of oil is high instead of the mobility adverse ratio between the water and the oil which injected to reservoir. However water flooding is still applied in many fields of crude oil reservoir, due to cheap and the operator of the field have experience controlling and designing the water flooding.

Several of previous realization is focused on oil or the ratio of water mobility and how can be related to the instability of migration waterfront. The study of these analyses is focusing on the stability of advance waterfront, and how it can be the mobility ration related the recovery of oil.

The mobility ratio (M) is defined as a ratio of relative permeability to water times oil viscosity to relative permeability to oil multiplied by water viscosity.

2.4: IMBIBTION

When the fluid of multiple immiscible is present in the system of porous media happened, the fluids of distribution at equilibrium is umpired by capillary forces [6]. The capillary forces are compete with viscous forces when the water inject into the water wet porous medium, that can be determine the pathways during the travel of water. So, imbibitions are very important phenomenon during the injection of water.

The factors that are controlling imbibitions, like wattability of the rock, permeability, viscosity and displaced fluid, and initial oil saturation and water in the rock. Wattablilty is the most important factors in imbibitions, which can contact the angle in the YOUNG-LAPLACE equation [5].

LI and HORNE [10] had shown the capillary pressure that is expected to decrease the rock with high permeability, as that will be related to the average pore size which located in the rock. Rock permeability is the important parameter for the effect of imbibitions. So, the expected of the rate of the imbibitions is to be lower consolidated rock.

ZHOU et al [11] has found that both the final recovery and the imbibitions rate due to effected by initial water saturation, which can be indicate the water to exist in the smaller extent to the smallest pores by bypassed larger pores. So, the imbibitions of the rate are related to fraction of pores at any saturation given. In the crude oil system the relationship between the water saturation and capillary pressure in the rock is defined poorly. As capillary force still be significant in the parts of water flooding.

The process of capillary drive, the rate of imbibitions can show by.

$$\frac{dR}{dt} \propto \frac{1}{\sqrt{t}}$$

The oil production rate is expected to be the highest at first, and decreases with the time. During the injection at early times into the crude oil, so the water is having low viscosity crude oil however, the forces of viscous are expected to become over capillary pressure.

In conclusion, the rate of imbibitions is decreases with the time, increasing oil viscosity and permeability. The studied of imbibitions shown that, can't be expected to hold in the oil sands. Thus can led to the assumption of common, that imbibitions and capillary forces negligible in the system of crude oil.

2.5 Permeability

Permeability is the measurement or ability of the rock to transmit fluids, usually permeability is measured in milidarcies or darcies. This term was defined by Henry Darcy. HERNY DARCY showed the common mathematics of the transfer heat, which modified to describe the fluid flow in porous media. The formations which can be transmit fluid easily, like sandstones, which described the permeable and tend to get many well-connected pores. Shale's and siltstones as a impermeable formations are tend also to be a mixed grain size or finer and less interconnected pores [7].

The absolute permeability is a measurement of the permeability which conduced when the phase or a single fluid is present in the rock. The effective permeability is the ability to transmit fluid through the rock when the other fluids are presents in the reservoir same the effective permeability of gas. The calculation of the relative permeability allow for different ability of the fluid to flow, since that more than one fluid is present it's totally inhibits flow.

2.6 Breakthrough.

Breakthrough is a description of the reservoir condition which can isolate the fluid or separated from the production of the fluid, which gains access for producing wellbore [8]. These terms are most applied to gas and water breakthrough, which the gas and or water injected to maintain the reservoir pressure by using wells injection, breaks through to more or one of the wells producing.

Breakthrough of water is the production of the water from underlying water. The process should avoid since there is no value of water production [9]. Water produced also can be change the topside and the well environment it also requires treatment and can handling to reduce the pollution. The operator will accept the high water cut in the situation where the price of oil is high. So, the early breakthrough of water will be occur in the bad formation, thin layer of oil, bad well position, higher production zone and heavy production of oil.

The production of water of designed well for oil production will support us a new environment in the topside and in the well equipment too. Although the formation of water has no oxygen, but it can may change the level of CO2, H2S, chloride ions and

others. In conclusion, breakthrough of water from seawater supporting the pressure can cause increasing in H2S. So if this project can take longer time of production of crude oil before the breakthrough. It will reduce the problem of high water cut like scale, corrosion and cracking.

Chapter 3

3.0 METHODOLOGY

The methodology is the tools that can describe materials and methods which applied to many field and it can collect the necessary data of study. This chapter is covering the work flow with project activities, Gantt, materials, and effective of apparatus.

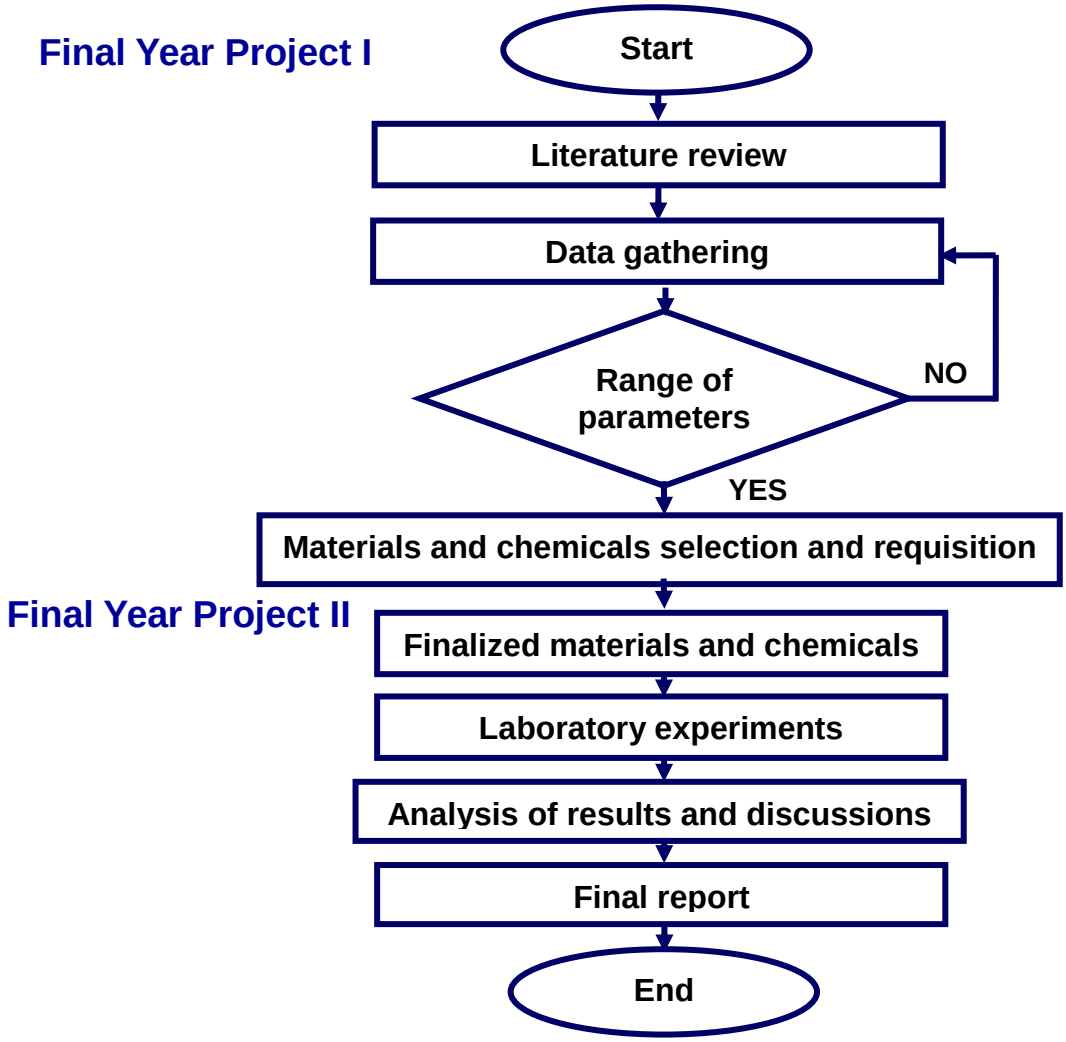


Figure 4: Project Flow Work

3.1 The procedure of identification.

The project is divided into two parts which are Final Year Project 1 and Final Year Project 11 figure 4 shows that project according to the sequence to make sure the project goes smoothness and efficiency.

This project is begin with the literature review on water flooding mechanism, crude oil , water flooding in crude oil , imbibitions, permeability and breakthrough which are the parameters of this final year project. As well, the basic review on the lab work regarding to studies of high viscous oil of water flooding with several of water injection rate.

All the information which gathered by this project in a proper documentation. The review and analysis detail on the previous works already conducted to see the finalizing of this area of study. But the design of the lab experiment will completed during of the second part of this project.

The lab experiment of water flooding performance for core plug of low crude oil viscosity of 1.5 cp at the varying injection of water rates which will be using by Soxhlet Extractor[13]. For PROPERM instrument, and the machine of Relative Permeability which available at academic building 15. So the Soxhlet apparatus used to clean and extract the core sample from the water, oil and other materials. The PROPERM instrument is used to determine the properties of core sample sized at pressure like permeability and porosity. Then at the end of this experiment of water flooding for different injection rates and different of core plug viscous by using the RPS machine. Later on from obtain the result we can find and analysis the study of investigate the forces in the reservoir model and how these force can be used to design the water flooding performance toward oil recovery enhanced. And to evaluate how the water injection rate can affect the oil recovery for reservoir.

3.2 The experiment work of Methodology

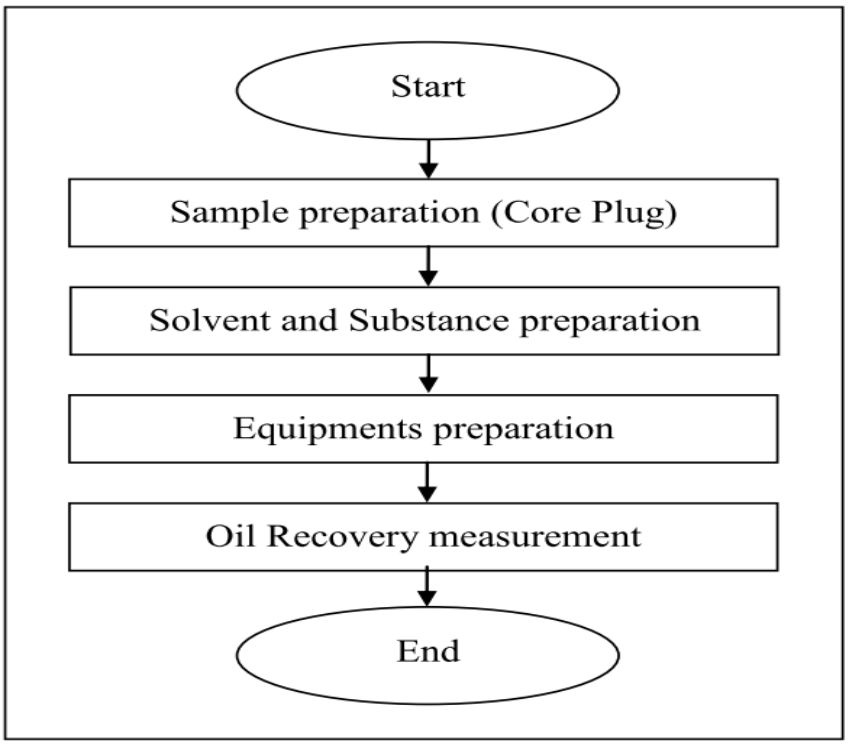


Figure 5: The experiment of methodology

3.3 Lab works related to core plug of water flooding.

3.31 The cleaning of core plug by using Soxhlet Extractor

Soxhlet extractor is required only where the compound of desired has limited solubility in the solvent. If the compound of desired has solvent in a significant solubility then the filtration of the sample can used to isolate the compound from the substance of insoluble. The Soxhlet Extractor developed onto the flask of containing the solvent extraction. Then the Soxhlet is equipped with the condenser.

The solvent s reflux by heated. The vapour of the solvent moves up a distillation arm, and flood into the housing of the chamber the thimble of solid. The condenser is ensure that for any solvent vapour cools, and falling drops back down into the housing of chamber the solid material. The solid materials fill slowly with a worm solvent. The chamber emptied automatically by a arm of siphon side, and the solvent running back to the distillation flask when the Soxhlet chamber is already full.

After extracting the solvent is removed, usually by means evaporator of a rotary, yielding compound of extractor. So there is no any soluble portion remains in the thimble of the extracted solid, and is typically discarded.

3.4 Experimental Activities

3.4.1 Materials & Equipment

- Soxhlet Extractor
- Core Samples
- Brine
- Core flooding

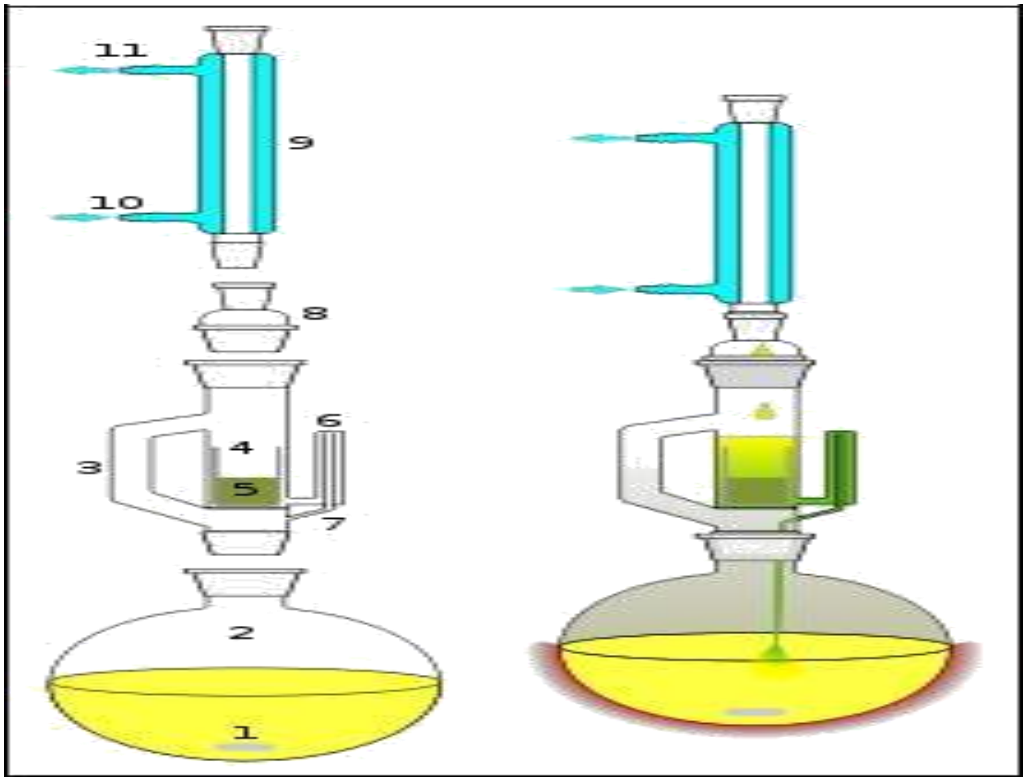


Figure 6: Soxhlet Extractor

1. Stirrer Bar.
2. Still pot.
3. Distillation Path.
4. Thimble.
5. Core Plug.
6. Core Plug.
7. Siphon Top.
8. Siphon Exit.
9. Expansion Adapter.
10. Condenser.
11. Cooling Water in Cooling Water Out.

Therefore the easiest way to understand the equipments of Soxhelt Extractor is used to clean the core sample from the water, oil and any materials. The Soxhlet apparatus is based on a mantle of heating to boil the solvent, the sample of chamber and cooled water system to condense the vapors of solvent. The core sample is placed into the chamber of sample. Therefore, the solvent is heated and vaporized [12]. The solvent is removes the components of solvent from the core after the solvent fill the chamber.

Figure 7: Soxhlet Extractor.

3.4.2 Determination of permeability and porosity by using POROPERM MACHINE

Figure 8: POROPERM Machine.

The POROPERM Machine is a porosimeter and permeameter which used to determine the properties of the core samples at confining pressure. Besides that, the direct measurement of properties, the machine offers calculation and reporting facilities by windows operating software. The measurements are including of a gas permeability, core length, pore volume and diameter. So, the calculated parameters are included of Klinkenberg corrected permeability, Klinkenberg slip factor, inertial coefficient, sample porosity, sample bulk volume, grain density and grain volume.

3.4.3 The water flooding for different viscosity of cores plug.

Figure 9: Relative Permeability System (RPS)

Relative permeability system (RPS) TEMCO- RPS-800-10000 HTHP test can be used for flow testing of permeability and relative permeability of the core samples, on site conditions of pressure and temperature. Tests that performed with the system with include the initial oil saturation, secondary waterflooding, tertiary waterflooding, relative permeability and permeability. Oil, brine or any other fluids can be injected through and into the core sample. Firstly, make sure the core flooded with the brine water (0.02 wt% of NaCl) until one hundred saturation of water (Sw). this method can achieved when the volumes of inlets and outlets are equals. After that, the core will be flooded with high oil viscosity until it reached the (Swcr) critical water saturation. This method also can achieve when 100% of oil flow at the

outlet. Let the core stable by put the core holder for 3 days. Then flood the core with the brine water (0.02 wt% of NaCl) with different rate injection until 90% of water cut. Therefore, we can be able to calculate the recovery factor of the different core. Therefore, the tables below need to be calculate and filled during the experiment. I conduct four runs experiment for different viscosity at different rate of injection.

Table 1 : Properties of Core Plug.

Core Name	X
Porosity (%)	x
Permeability (air,mD)	x
Permeability (infinite,mD)	x
Diameter, cm	x
Length, cm	x
Volume Bulk, cc	x
Volume Pore, cc	x
Volume Grain, cc	x
Grain Density, g/cc	x
Bulk Density, g/cc	x
Dry Weight, gm	x

Table 2: Recovery

Experiment / run	viscosity (cp)	brine water rate of injection (mL/min)	OOIP (mL)	Critical Water Saturation (S_{wc})	Volume Displace (mL)	Residual Oil (S_{or})	Recovery Factor
1	1.5	0.5	x	x	x	x	x
2	1.5	1	x	x	x	x	x
3	1.5	2	x	x	x	x	X
4	1.5	3	x	x	x	x	X
5	1.5	4	x	x	x	x	X

Table 3 : Recovery per pore volume injection.

Experiment / run	viscosity (cp)	brine water rate of injection (mL/min)	Recovery Factor
1	1.5	0.5	X
2	1.5	1	X
3	1.5	2	X
4	1.5	3	X
5	2	0.5	X
6	2	1	X
7	2	2	X
8	2	3	X

3.5 project activities

It will be updated until first August.

Table 4: Activity Tracking.

No	Subject / Activities	Status /expected completion
1-	Design laboratory works	Completed
2-	Booking of laboratory	Completed
3-	Preparation of core plug and oil	Completed
4-	Experimental work commences	Completed
5-	Data analysis	Completed
6-	Preparation of progress report	Completed
7-	Preparation of paper/jour	Completed
8-	Preparation of seminar	Completed
9-	Preparation of poster	Completed
10-	Preparation of final report	Completed
1	Preparation of oral presentation	Completed

3.6 Key Milestone:

No	Subject / Activities	Date
1-	Design laboratory works	15-25 May 2015
2-	Booking of laboratory	18-20 May 2015
3-	Preparation of core plug and oil	23-25 May 215
4-	Experimental work commences	28 May – 25 July 215
5-	Data analysis	27 June – 30 July 2015
6-	Preparation of progress report	26-30 June 2015
7-	Preparation of paper/journal	23 June-2August 2015
8-	Preparation of seminar	1-4August 2015
9-	Preparation of poster	1-14 July 2015
10-	Preparation of final report	16June -3 August 2015
1	Preparation of oral presentation	4-17 August 2015

Table 5: Key Milestone

3.7 Gantt chart I

Table 6:Gantt chart FYP1

NO	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project														
2	Preliminary Research Work - Conducting online research - Literature review														
3	Submission of Extended Proposal														
4	Proposal Defense - Preparation for presentation														
	Lab Reservation to conduct the testing - Purchasing Chemicals														
5	Project work Continues														
6	Submission of Interim Draft														
7	Submission of Interim Report														

Deliverability
Work Progress

3.8 Gantt chart II

Table7: Gantt chart FYP2

Task/Activity	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Design laboratory works	■	■													
Booking of laboratory	■	■													
Preparation of specimen		■													
Experimental work commences			■	■	■	■	■	■	■						
Data analysis							■	■	■	■	■				
Preparation of progress report										■					
Preparation of paper/journal										■	■				
Preparation of seminar												■	■		
Preparation of poster												■	■		
Preparation of final report									■	■	■	■	■		
Preparation of oral presentation														■	■

3.9 Tools and Equipment

Table 8: tools and equipment

Apparatuses	**Quantities**
Core plug for sandstone type	1
POROPERM system machine	1
RPS machine	1
SOxhlet Extractor	1
Beakers	4
Measuring cylinders	7
Chemical	**Quantity**
Crude oil	1000cc
Water Brine 0.02 wt %	3000cc

3.10 Experimental Procedures and Details

3.10.1 Core Cleaning

It should be cleaned and saturated the cores samples properly before the displacement test can carried out to start measuring the relative permeability and the oil recovery to insure every runs are not affected by impurities inside the core sample and also to insure that, there is no air inside the cores. Therefore the core must be clean thoroughly.

Procedure:

- The Soxhlet Extractor method is used to extract and dissolve the oil and brine from the rock core sample by using the solvents.
- Sample cleanliness is determined from the solvent colour that periodically from the extractor which should be clear. The samples are cleaned by solvent of refluxing and placed in the extractor.
- Heated the solvent and vaporized in the flasks of boiling and cooled at the top by using condenser. The cooled of the solvent liquid falls into the sample chamber. The clean solvent is soaks the core and fills the chamber. The dirty solvent which used to clean the core siphons into the boiling flask with redistilled it again when the chamber is full.

3.10.2 Dry core properties

Chemicals and Apparatus

- Nitrogen Gas
- Oven
- Helium Porosimeter

Procedure:

- Measurement of air permeability and porosity must be done before saturated the core.
- After the process of cleaning, the core samples are puts into the oven to dry every residues of toluene which can be still entrapped in the spaces of the pore.
- Using nitrogen, Porosimeter gas is filled into the chamber of the core to completely saturate the sample.
- By using the suitable pressure and setting up the pressure for reading purposes, the air porosity will stabilize and the values of absolute permeability will obtained.

3.10.3 POROPERM Machine.

Chemical and Apparatus.

- POROPERM Machine.

Procedure:

- First, measure the weight, length, and diameter of the cores plug.
- By using the POROPEM machine device, put the core plug in the core holder in the machine and the confining pressure is applied up to 1000 psi.
- Display the characteristic and graphs of the core plug automatically by using the computer system.
- Record the permeability and porosity reading in the result section.
- Saturate the core plug by using distilled water in the desiccators at least 6 hours.

3.10.4 Relative permeability system (RPS Machine)

Chemicals and Apparatus.

RPS machine.

Procedure:

- Using the air gun to clean all the tubing and make sure it's free from any foreign fluid.
- Prepare the equipments for the core holder: put the core plug inside the confining tube latex.
- Repeated of the brine 2.0 wt%. poured it into the external pump then close. The vent of air is pressured to the pump to the brine in to the accumulator B.
- Crude oil is heated in the oven at 100 dgreeC , slowly pour into the accumulator A.
- INJECT THE BRINE SOLUTION UNTIL PERMEABILITY READING STABILIZED.
    - The purpose of this step is to determining the absolute permeability or initial permeability.

- Inject crude oil.
    - To measure the amount volume of the oil that has been saturated.
    - To calculate the irreducible water saturation of Swir.
    - To displaced the water when the oil is pumped into the core, until there is no oil coming. Like more oil is pumped.

- Inject brine water solution
    - To determine how much oil is remains and how much oil volume has been saturated. This is remaining oil saturation, Sor.
    - To measure manually the recovery of crude oil.
    - The experiment repeated by using three different type of brine water injection rate (0.5 mL, 1 mL,2MmL,3 mL) for two different types of oil viscosity (1.5cp and 2cp)

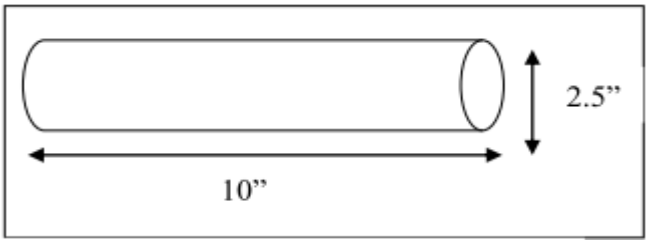


Figure 10: Core holder illustration

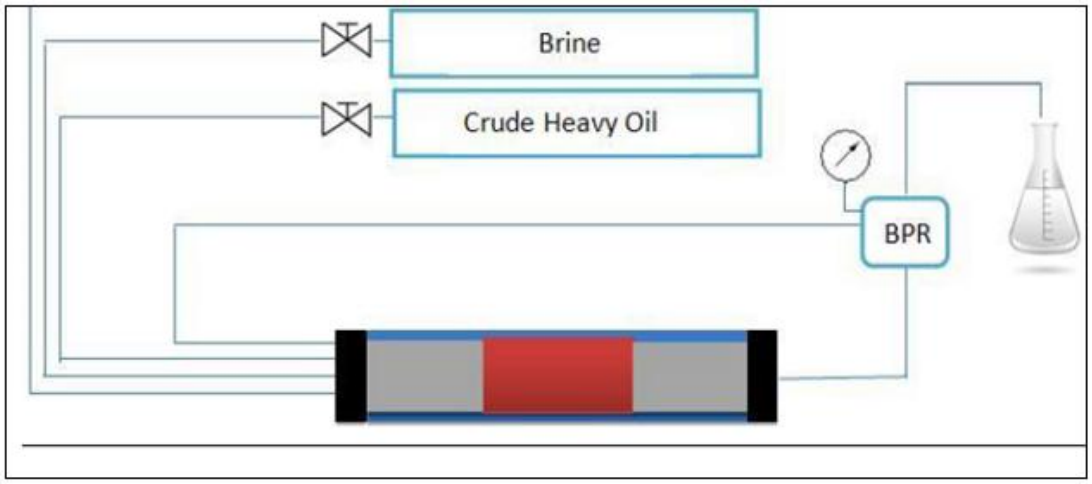


Figure 11: RPS machine equipments

Then the entire three channel or pipes would connected to the holder of the core with contained the saturated the core plug with the distilled water with volume 80.76cc. This measurement is gained from this formula: $\pi r^2 L = \pi \times (3.801/2)^2 \times 7.31$.

So, we need to model the waterflood by saturated with the water since the experiment is focusing on the woterflooding or secondary recovery. Then we inject the brine at low rate 0.5 ml/min to stabilize the model.

There would be pressure gauges to calculate the pressure reading at end of each the cylinder model. There is BPR equipment at the end of the line, which will be controlling the inlet and outlet pressure. The author used in this experiment the following data.

Inlet pressure = 2000 psi

Outlet pressure= 2500 psi

For the whole of my experiment the temperature is kept at a fixed for 100 degree C and repeated at 100 degree C. at the end of the cylinder would be beakers of the volumetric to calculate or to measure the crude oil sample being recovered. The experiment is contained by changed the brine water injected rate. The whole calculation is done manually by using the excel, putting the formula in spreadsheet of the excel such as Swc, OOIP, Sor, Volume displacement and RF like tabulated below.

run 1 (0.5 mL/min)

Name of the cores	x

Porosity (%)	x
Permeability (air,mD)	x
Permeability (infinite,mD)	x
Diameter, cm	x
Length, cm	x
Volume Bulk, cc	x
Volume Pore, cc	x
Volume Grain, cc	x
Grain Density, g/cc	x
Bulk Density, g/cc	x
Dry Weight, gm	x

OOIP (mL)
x

Volume Displace (mL)	
before breakthrough	x
after breakthrough	x
total volume displace	x

Recovery Factor
x

Figure 12: Calculation in Excel.

- OOIP = pore volume *(1-Swi)
- Volume displacement = measured oil displaced during water flooding
- Recovery factor = volume of oil displaced / OOIP

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Analysis and Data Gathering

In data analysis and data gathering, I show all findings for my experimentation result that shows the effect of water injection rate of crude oil water flooding towards recovery. So, it will cover the explanation part (discussion) which is relate to the literature review and results of this experiment.

4.1.1 Core Plug information obtained from, POROPERM machine and manual caliper.

After each running of water flooding towards the core plug by using the relative permeability system (RPS) machine, the data was collected and the information of the core like porosity, diameter and permeability also taken to insure that the accuracy of the recovery calculation is already obtained. The author runs the machine for twenty minutes during every run and reading the tabulated data for the oil injection; the machine is stopped when there is no brine water coming with the oil. Then the author inject the brine water to get the recovery factor, the machine is stopped when there is no oil coming out. The tabulated data as below from the POROPERM machine.

Table 9: Run 1

First run (0.5 ml/min)

Core Name	B1
Porosity (%)	12.836
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.275
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

Table 10: Run 2

second run (1.0 ml/min)

Core Name	B1
Porosity (%)	12.836
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.275
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

Table 11: Run 3

Third run (2.0 ml/min)

Core Name	B1
Porosity (%)	12.836
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.275
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

Table 12: Run 4

Forth run (3.0 ml/min)

Core Name	B1
Porosity (%)	12.836
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.275
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

Fifth run (4.0 ml/min)

Core Name	B1
Porosity (%)	12.865
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.284
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

Table 5: Run 5

Figure 13: POROPERM Machine at Core Analysis Lab (Building 15-02-08).

4.1.2 Waterflooding of crude oil with different injection flow rate by using RPS machine.

After we put all the information above (like, length, viscosity and diameter) into the RPS machine. By using the computer control the author would be ruining the crude

oil recovery process. As below is showing the input in the control panel on the screen of the computer.

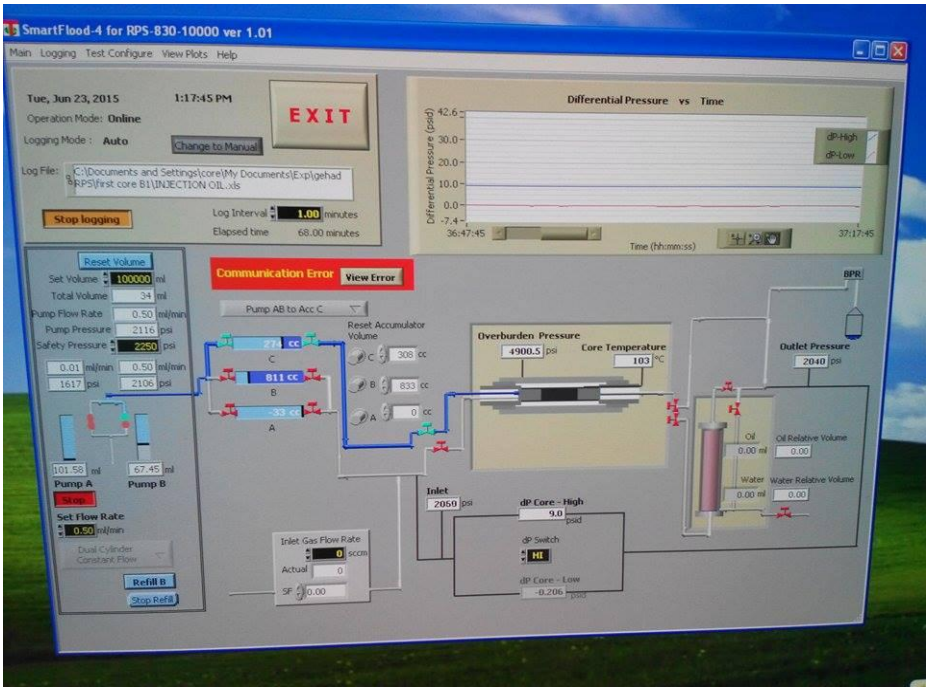


Figure 14: Clarification of RPS machine on-screen control panel

After insert all data in the RPS machine like the information of core plug, outlet pressure, inlet pressure, overburden pressure, temperature and other data, laboratory technician and author ran the machine. It takes a period of time to stabilize the pressure at the initial of water flooding.

As the case in the methodology previously, we record all the data and tabulated in the excel spreadsheet. Therefore, below is the picture of example which indicates the first crude oil that has been produced during water flooding.

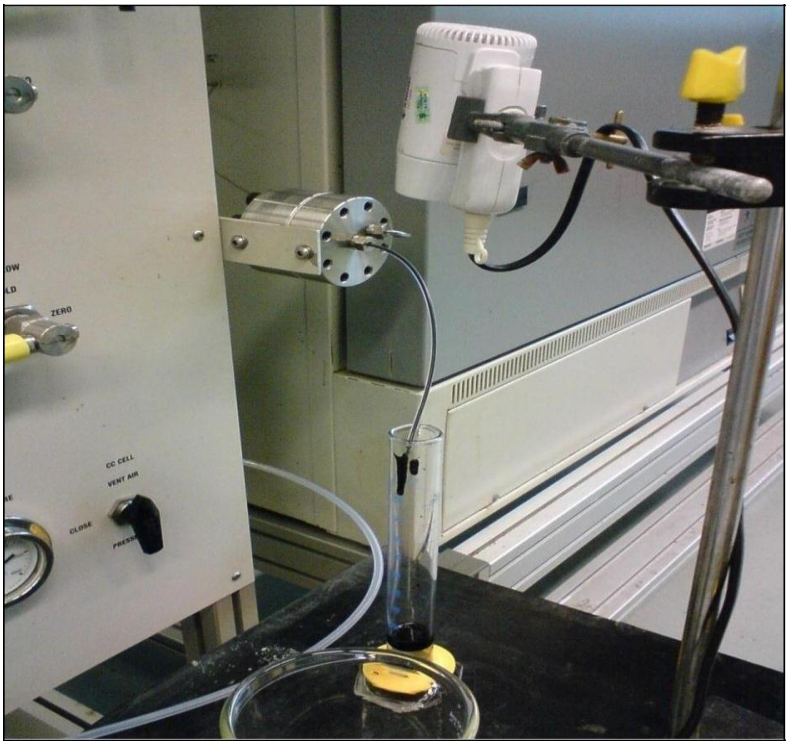


Figure 15: Crude oil produced at the outlet of RPS machine

4.1.3 Findings of crude oil water flooding with the different injection rate.

This data is recorded for the four runs of water flooding I tabulated as shown below.

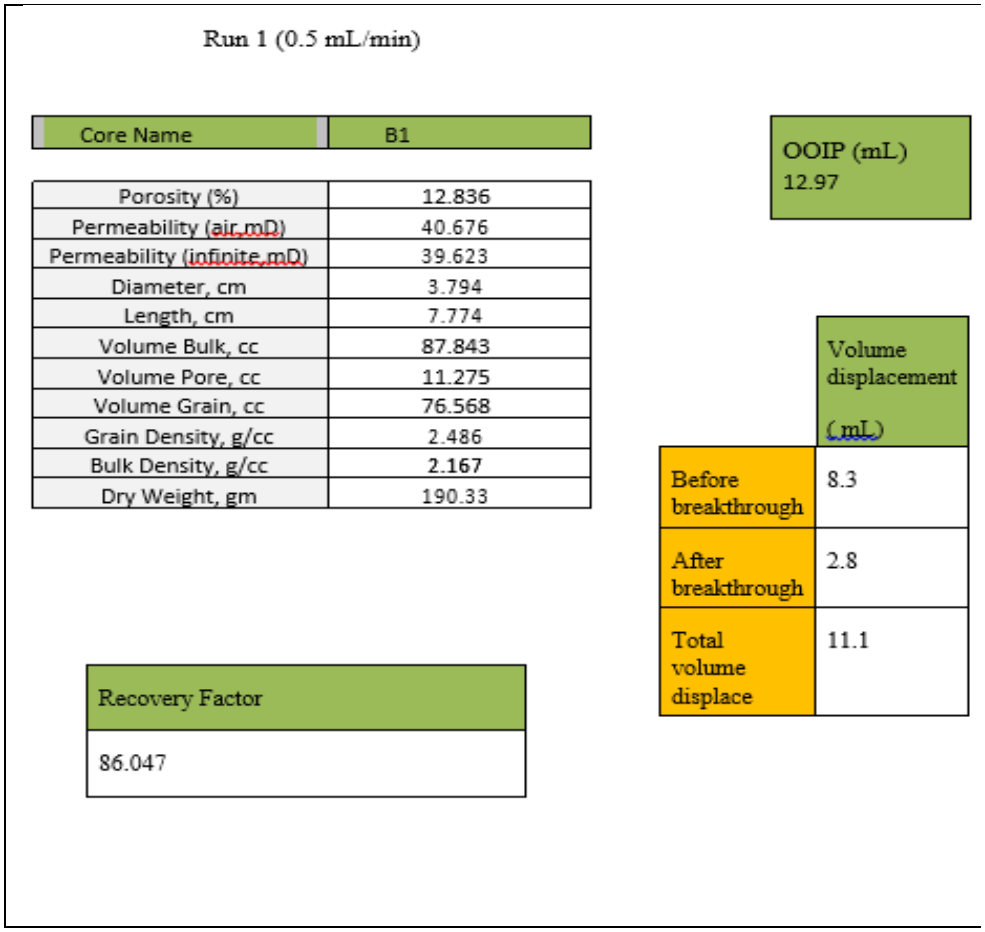
Therefore, the calculation of this formulated in the excel spreadsheet.

Table 14: The RPS machine in the insulated temperature of 100 degree C at 36.2cp viscosity

Experiment / Run	viscosity (cp)	brine water rate of injection (mL/min)	OOIP (mL)	Critical Water Saturation (S_{wc})	Volume Displace (mL)	Residual Oil (S_{or})	Recovery Factor FR
1	1.5	0.5	12.90	0.2686	11.1	1.87	86.047
2	1.5	1	12.70	0.2986	9.46	3.21	74.488
3	1.5	2	12.60	0.3142	9.09	3.46	72.143
4	1.5	3	12.90	0.2770	8.37	4.56	64.884
5	1.5	4	12.87	0.2813	7.92	4.95	61.538

Referring to the result in the table above, it can be shown the following:

1) The first column is to indicate for the four runs of crude oil water flooding.
2) The second column is to indicates the type of viscosity which are 1.5cp
3) The third column is shown that the rate of injection for brine water from 0.5mL/min up to 3.0 mL/min
4) The forth column and others column shows the amount of crude oil being displaced during inject the brine. It can be shown that the crude oil can able to displace for viscosity of 1.5cp successfully, but it cannot be displaced further when using 2 cp of crude oil. The author decided to try it again in the future for the 2cp with different temperature, because it may failed for the 2cp of crude oil. This aimed to reducing the viscosity of the crude oil. It will solve the problem in the first experiment.


Run 1 (0.5 mL/min)

Core Name	B1
Porosity (%)	12.836
Permeability (air,mD)	40.676
Permeability (infinite,mD)	39.623
Diameter, cm	3.794
Length, cm	7.774
Volume Bulk, cc	87.843
Volume Pore, cc	11.275
Volume Grain, cc	76.568
Grain Density, g/cc	2.486
Bulk Density, g/cc	2.167
Dry Weight, gm	190.33

OOIP (mL)
12.97

	Volume displacement (mL)
Before breakthrough	8.3
After breakthrough	2.8
Total volume displace	11.1

Recovery Factor
86.047

Figure 16: : Example of calculation in Excel Spreadsheet

We can use the same spreadsheet for the other five run. All of the equation is already

explained in methodology part. The author takes all the data and changes it into graph. Because we need to ensure it easy to understand the relation between the rates of injection towards recovery and the others parameter which are included in the excel format. Therefore, below are the graph based on the data for 5 run of crude oil waterflooding:

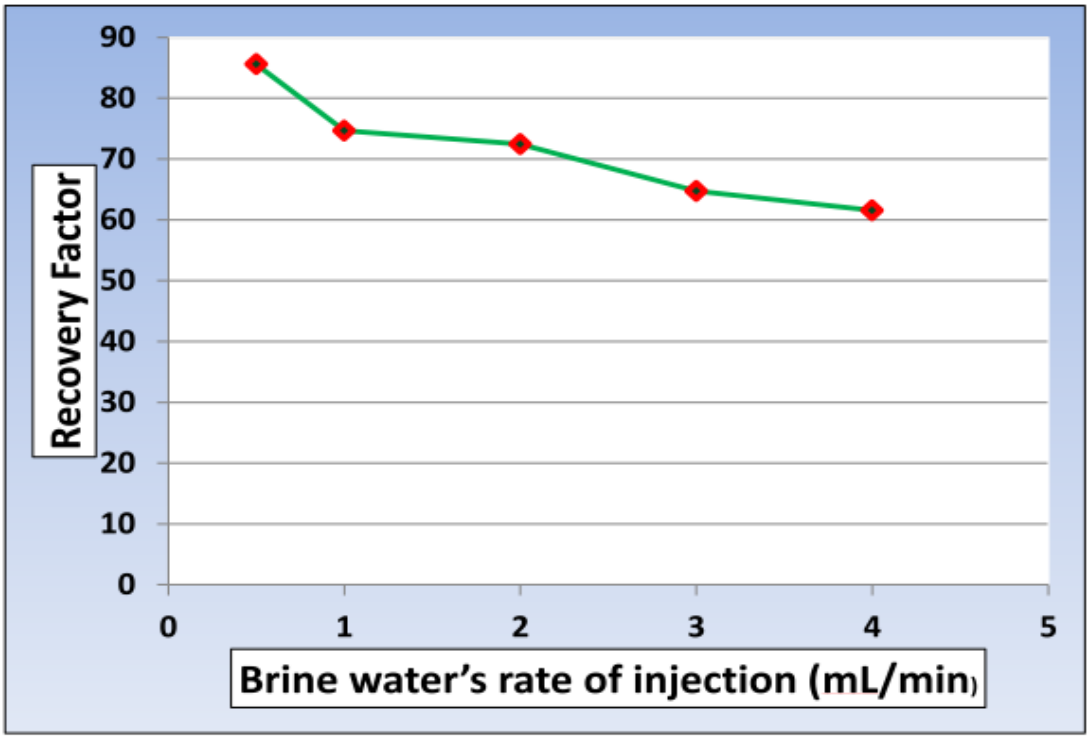


Figure 17: Brine water rate of injection (mL/min) vs Recovery Factor

According to the table above, it can be seen that:

- For brine water first run with 0.5 mL/ min, it shows the optimum recovery factor of 86.047%and suddenly drop when the injection being increase up to 1 mL/min
- The last injection run of 4 mL/min shows the lowest recovery factor of 61.54 %compared to the others lower injection of rate.
- It shows clearly that the recovery factor is decreasing with the increasing of brine water rate of injection (mL/min).
- Therefore, it also clearly indicate that recovery is high when the decreasing of brine water rate of injection (mL/min)
- The recovery is high due to waterflooding of linear core sample which is

small in size, short in length, small in diameter.

- Therefore the lowest injection rate is the best.

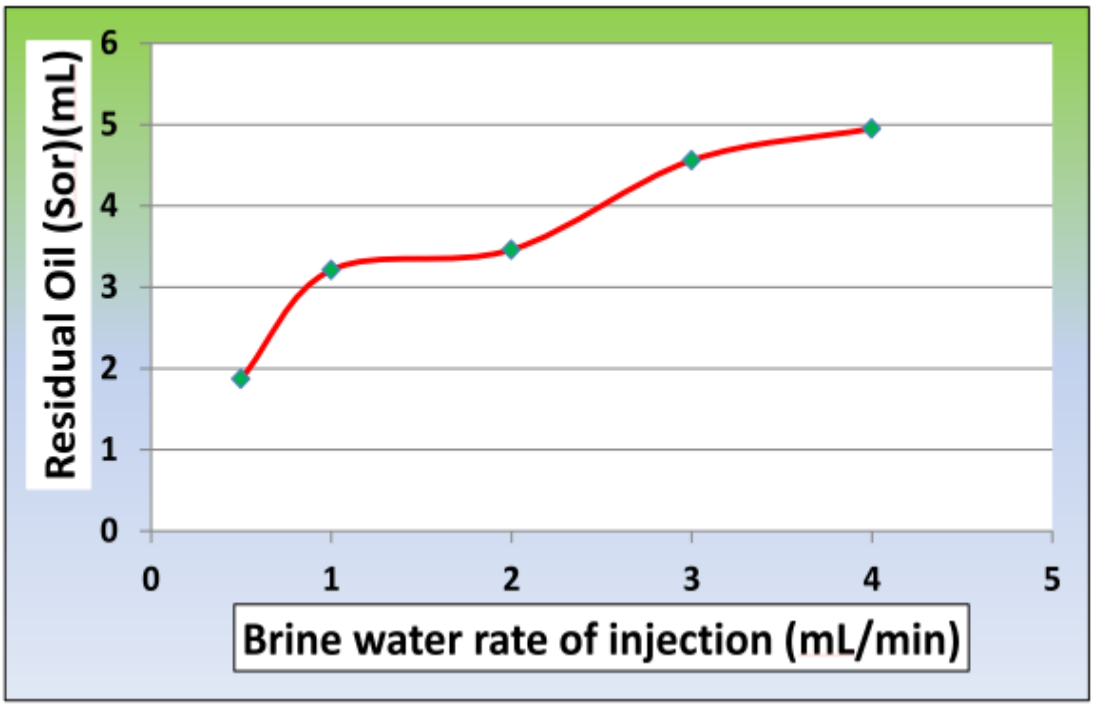


Figure 18: Residual Oil (Sor) vs. Brine water's rate of injection (mL/min)

According to the table above, it can be seen that:

- For the first injection brine water with 0.5 mL/ min, it shows the lowest residual oil which is 1.87 mL.
- The fifth injection of 4 mL/min shows the highest residual oil which is 4.95 mL.
- It shows clearly that the residual oil is increase with the increasing of brine water rate of injection (mL/min).
- So , it also clearly indicate that residual oil is high when the increasing of brine water's rate of injection (mL/min)
- Therefore the highest slope is between 0.5 mL/min and 1.0 mL/min. Therefore it indicates that 0.5 mL/min and 1.0 mL/min is the point where the significant residual oil is occurring.

4.2 Discussions:

While the theory which has been discussed before in the literature review section. It cased that from the conventional theory that the viscosity of crude oil will lead to poor mobility ration. For the lab of core flooding, the residual oil and capillary bypassing is one of the major mechanisms responsible for trapping oil.

Therefore there is potential for fingers to grow for smaller diameter core, thus in the field, the effect of instability can do more pronounced better than the system of a linear core. The theory of the instability shows that Isr=1,000, which the displacement rate can be determine the finger properties and during of the high injection rate in an unstable system, the wavelength of the finger will be short. Therefore for low condition of rate, the wavelength of finger is few fingers and it will be long from the porous medium. Hence, it more recommended performing water flooding and it is more slowly under unstable condition.

The instability theory normally based on the balance of forces. The displacement will be stabilized if the combined forces of capillarity and gravity are greater than the viscosity of the force, in the displacement of higher viscous fluid. If the reverse is true, the displacement will be unstable, and then the degree of instable depends on the rate of the injection, all will being equal.

Therefore, theory of instability does not describe clearly how much oil is displaced at later times after occurred of water breakthrough. By pointing or referring to the experiment which has been done by the author, it shows that, the low injection rate will produce higher recovery due to low saturation, that means water brine pushing the oil slowly until it remove the whole portion of oil. Therefore, it a good result for industrial to inject water at low rate of injection as to avoid the early water breakthrough and stabilizes the condition to produced high recovery.

CHAPTER 5

5.0 CONCLUSION

5.1 Conclusion:

According to the literature review, there was some limited experience in the documentation for water floods in crude oil reservoirs, however in totally, the mechanism of oil viscous recovery by water flooding did not explored yet.

The recovery of water flood is known to be lower for higher oil viscosity because the adverse of mobility ratio between the water and oil that injected to the reservoir. Therefore water flooding still applied in many crude oil fields since that it is not expensive and they have years of experience of controlling and designing the water flooding. The challenge is to study and investigate the forces in the reservoir model and how these forces can be used to design the water flooding performance toward oil recovery enhanced at low rate.

The present work is aims to study and investigate the forces in the reservoir model and how these forces can be used to design the water flooding performance toward oil recovery enhanced at low rate. The final of this study is toevaluate how the water injection rate can affect the oil recovery for reservoir. During the begging of the project, the focus was on the literature reviews about the matter, which it shows the important of instability, mobility ratio and the parameters of imbibitions during the water flooding.

Therefore, the author proved that the effect of oil recovery due to the water injection in different flow rate, which indicate that, the low rate of injection will produce higher recovery during the experiment procedure. The finding of this experiment not only high recovery, but the low OPEX and CAPEX also for the industrial company that they can buy or use low pressure of valves and low horse power of pumps.

5.2 Recommendation:

The author can see some of the improvement for RPS machine during the experiment, which we can put the heater at the outlet of the RPS machine since the outlet lead to increase the crude oil viscosity and is not properly heated. It can lead to wrong measurement of the recovery when it will stuck at the tube of outlet and restrict the flow of crude oil.

For the industrial practitioner, therefore it is advisable to do water injection of crude oil at lower rate, which has been proven by this experiment that it can increase the oil recovery. This is very important since the application of this experiment can increase the revenue and profit of Oil Company.

The author would like to give recommendation or to recommend to UTP to provide a lot of core samples with assortment in porosities and permeability since it would help the student better of their projects and to make more reliable for their experiment. Due to the expensive of the core, therefore, it is very hard for students to buy or to order a core samples.

CHAPTER6

REFRENCES

1-) An Estimate of Recoverable crude Oil Resources of the Orinoco Oil Belt, Venezuela" (in en). USGS. 11 January 2010. http://pubs.usgs.gov/fs/2009/3028/pdf/FS09-3028.pdf. Retrieved 23 January 2010.

2-) Benefit flow from wateflooding, http://goliath.ecnext.com/coms2/gi_0199-3251219/Benefits-flow-from-waterflooding-oil.html retrieve on 22 Oct 2010.

3-) Heavy Oil, http://www.slb.com/services/industry_challenges/heavy_oil.aspx retrieves on 21 Oct 2010.

4-) MOORE, T.F. and SLOBOD, R.L., the Effect of Viscosity and Capillarity on the Displacement of Oil by Water; Producers Monthly, Vol.20, pp. 20-30, August 1956.

5-)BENTSEN, R.G., A New Approach to Instability Theory in Porous Media; SPE Journal, Vol. 25, No. 5, pp. 765-779, October 1985.

6-) GREEN, D.W. and WILLHITE, G.P., Enhanced Oil Recovery; SPETextbook Vol. 6, Society of Petroleum Engineers, Richardson, TX,1998.

7-) Term of permeability, http://www.glossary.oilfield.slb.com/Display.cfm?Term=permeability retrieve on 20 Sept 2010.

8-) Term of breakthrough, http://www.glossary.oilfield.slb.com/Display.cfm?Term=breakthrough retrieve on 27 Sept 2010.

9-) Exprobase, http://www.exprobase.com/Default.aspx?page=250 retrieve on 22 Oct 201

10-) LI, K. and HORNE, R.N., Generalized Scaling Approach for Spontaneous Imbibition: An Anaytical Model; SPE Reservoir Evaluation & Engineering, Vol. 9, No. 3, pp. 251-258, June 2006.

11-) ZHOU, X., MORROW, N.R. and MA, S., Interrelationship of Wettability, Initial Water Saturation, Aging Time, and Oil Recovery by Spontaneous Imbibition and Waterflooding; SPE Journal, Vol. 5, No.2, pp. 199-207, June 2.

12-)Soxhlet, F. Die gewichtsanalytischeBestimmung des Milchfettes, Polytechnisches J. (Dingler's) 1879, 232, 461.

13-)Laurence M. Harwood, Christopher J. Moody. Experimental organic chemistry: Principles and Practice (Illustrated edition ed.). pp. 122–125. ISBN 978-0632020171.

14)PETERS, E.J. and FLOCK, D.L., The Onset of Instability During Two-Phase Immiscible Displacement in Porous Media; SPE Journal, Vol. 21, No. 2, pp. 249-258, April 1981.

15) Rodriguez H. A., Vaca P., Gonzalez O., and De Mirabal M. C., "Integrated study of a crude oil reservoir in the Orinoco Belt : A field case simulation"

16) Energy Information Administration (2001) "Venezuela Offers Full Market Value to Encourage Foreign Investment in Oil"

17)Orinoco Crude Oil Belt, http://www.eoearth.org/article/Orinoco_Heavy_Oil_Belt,_Venezuela retrieve on 16 Sept 2010

18)DONG, M. and DULLIEN, F.A.L., Effect of Capillary Forces on Immiscible Displacement in Porous Media; paper SPE 56676 presented at the SPE Annual Technical Conference and Exhibition, Houston,

19)CHATZIS, I., MORROW, N.R. and LIM, H.T., Magnitude and Detailed Structure of Residual Oil Saturation; SPE Journal, Vol. 23, No.2, pp. 311-326, April 1983.

20)SARMA, H.K. and BENTSEN, R.G., An Experimental Verification of a Modified Instability Theory for Immiscible Displacements in Porous Media; Journal of Canadian Petroleum Technology, Vol. 26, No.4, pp. 88-99, July-August 1987.

21)FISCHER, H., WO, S. and MORROW, N.R., Modeling the Effect of Viscosity Ratio on Spontaneous Imbibition; paper SPE 102641 presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, 24-27 September 2006.

22) Waterflooding, http://oilgasglossary.com/waterflooding.html retrieves on 21 Oct 2010.

23)TeamOfWaterflooding
http://www.glossary.oilfield.slb.com/Display.cfm?Term=waterflood retrieve on 19 Sept 2010.

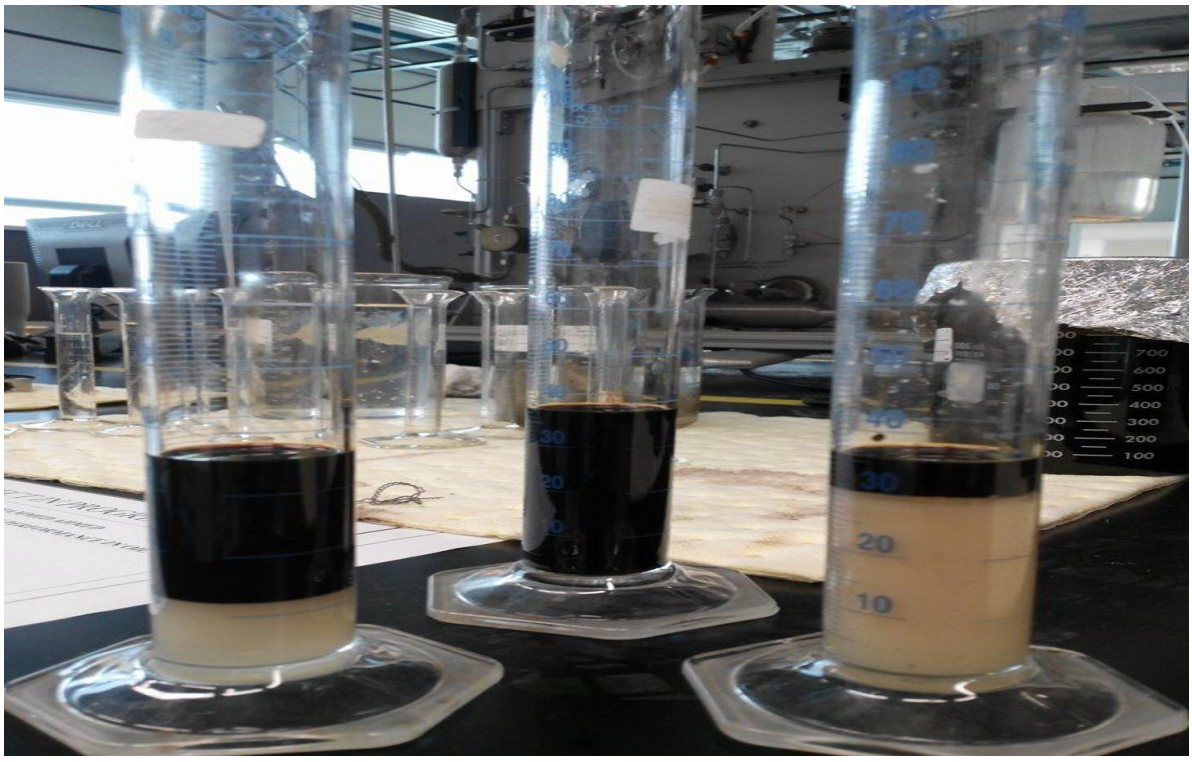
24) Benefit flow from wateflooding, http://goliath.ecnext.com/coms2/gi_0199-3251219/Benefits-flow-from-waterflooding-oil.html retrieves on 22 Oct 2010

APPENDIXS

Appendix 1: simple picture of density measurement

Picture of density measurement

Appendix 2: Picture of crude oil water flooding



Picture of crude oil water flooding