
**FINAL YEAR PROJECT II**

# COMPARISON OF WATERFLOOD ULTIMATE RECOVERY FOR OIL AND WATER WET RESERVOIR

**14816 | MOHD IZUHAN SHAH BIN OTHMAN**

**SV :** DR. SYED MOHAMMAD MAHMOOD

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MOHD IZUHAN SHAH BIN OTHMAN
14816

Dissertation submitted in partial fulfilment of
the requirements for the
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(Petroleum)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
32610 Tronoh
Perak Darul Ridzuan, Malaysia

**CERTIFICATION OF APPROVAL**

# Comparison of Waterflood Ultimate Recovery for Oil And Water Wet Reservoir

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Mohd Izuhan Shah Bin Othman
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A project dissertation submitted to the
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Approved by,

_____

( Associate Professor Dr Syed Mohammad Mahmood)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

## CERTIFICATION OF ORIGINALITY

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

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MOHD IZUHAN SHAH BIN OTHMAN

# ABSTRACT

Current trends nowadays shows that the crude price's degrades at a significant measure until 'forced' some of the oil and gas giants revised and restructure their capital and operational expenditures. Yet if we rewind back before the price has been reduced, the condition was highly favourable for mass exploration and recoveries programmes due to amount of expected profit that the companies may gain. Recovery activities are in controlled manners now, yet that doesn't mean that the studies about it have to be stopped, it must continuously in progress so that it may be applied during field's profitable season. In conjunction to that, this paperwork entitled The Comparison of Waterflood Ultimate Recovery For Oil and Water Wet Reservoir. Waterflooding is a common technique used for Improved Oil Recovery (IOR). The purpose of the method is simple, to sustain the reservoir pressure hence improve the recoveries. Many factors able to influence the sweeping efficiency, but in this paper, the focus will be more on relations between recoveries and wettability. In reservoir rocks, there are two types of wettability; the oil-wet and water-wet. The wettability possibly depends on rock's surface chemistry, i.e. clayed layer, carbonates or silica (sandstones). Another popular factor to validate the type of wettability is by determining the fluid contact-angle on rock surface. Moreover, it was proved in past literatures made by fluid scientist, therefore it is irrelevant to be mentioned again in this paper. Hence, the comparisons were made by analysis of past research papers and books which majority of it were written based on professional field experiences.

# ACKNOWLEDGEMENT

Alhamdulillah, all praise to The One and only God, Allah SWT for permitting me for able to do the project and solve all the challenges that I faced along the completion timeframe.

Secondly, I would like to express my sincere gratitude to all parties who has contributed along the process of my Final Year Project which entitled Comparison of Waterflood Ultimate Recovery For oil and Water Wet Reservoirs. I also want to take this opportunity to thank to Petroleum Engineering Department for giving me opportunity to experience to complete this project as my learning process and get more information and knowledge about the subject matters.

Special thanks goes to my dearest Project Supervisor, Associate Professor Dr Syed Mohammad Mahmood for the continuous support, assistance, facilitation and guidance in acquiring knowledge throughout my project.

My sincere thanks also to Universti Teknologi PETRONAS (UTP) for giving students an opportunity to expose ourselves in the real working project. Apart from that, it is important to us to handle the project by ourselves which definitely encourage student to be more independent in the future.

Last but not least, I would like to thanks to all fellow families, classmates and friends from other disciplines of studies which sometime they sit together and with me and share their thoughts on certain issues that puzzled me for some time. Finally, thanks to everyone who has contributed directly or indirectly in completing this task.

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# 1.0 INTRODUCTION

## 1.1 Background & Theories

There are phases in Exploration and Production (E&P) project which are acquisition of right, exploration, appraisal & development, production and abandonment. The exploration period is very important because all reservoir investigation data were obtained from this session through various methods such as seismic surveying, core evaluation, log analysis, and many more. Then the results were re-analysed during appraisal phase in order to evaluate its economical significant during that particular time with that particular technological advancement. If it is reliable, then the field will be developed and prepared for production phase.

Regarding hydrocarbon production performance, it was estimated or forecasted in both phases mentioned. Hence, it is approximately known when the primary recovery will last, when the secondary recovery can be started and feasibility of executing expensive Enhance Oil Recovery (EOR). At the end of the day, the estimation will be correlated with the real time results during actual operation, thus some changes have to be made in order to meet the expected ultimate recovery.

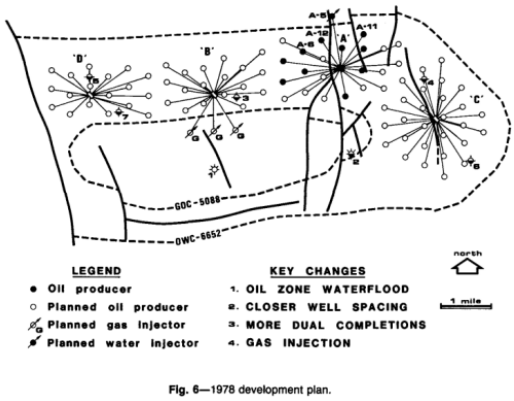



Fig. 6—1978 development plan.

**Figure 1 :** Tapis Field Development Plan Schematic's.

**Source: OnePetro**

To support the statement, in a brief field development plan paper entitled Exploration, Development and Reservoir Engineering Studies for the Tapis Field Offshore Peninsular Malaysia by Heacock et al (1983) from Esso Production Malaysia Inc. (EPMI) states about the future injection outlines that possible to be executed if the field reaches its IOR and EOR feasible stage. The plan was done on 1978 as in Figure 1.

In oil production, it is divided into 3 phases of recoveries; primary, and tertiary. First, in Oil & Gas production phase, mostly were based on natural pressure differential between the subsurface and wellbore. After perforated, the pressure drives the fluid tremendously into the wellbore and travels up to the surface facilities. The payzone pressure drops as the fluid is producing. Hence, as time goes by, the fluid won't able to flow in high velocity.

To solve that problem, most of the steps taken was by injecting water, but it is also depends on the content of the reservoir, suitability is a great concern in order to make sure that the ultimate recovery and flooding operation economically sensible for the company. To add, Gulick, et.al from Society of Petroleum Engineers (SPE)

mentioned that one of the cheapest and most popular methods restoring and maintaining reservoir energy is to inject water into the reservoir. This more than 70 years old method is still effectively practicable until now and widely used in many platforms worldwide.

Of course, in dealing with reservoir conditions, there are many factors that may affect the success rate of upstream operation. Therefore it is important to understand the reservoir rocks and fluid properties. From various presence of parameters found, this paper is deeply interested with the wettability of reservoir rocks and how it closely related with waterflooding performance.

There are some other factors of fluid-surface interaction that may influence the reservoir rock surface's wettability. The factors are the interfacial forces between two immiscible fluids and capillary action which is the interaction of liquid on solid surfaces (Dandekar, 2006). The statement signifies that in the reservoir, the two (2) liquid elements, the oil and water can also adhere/attach with the rock surface. The distinctive wettability behaviours are commonly called as water-wet and oil-wet.

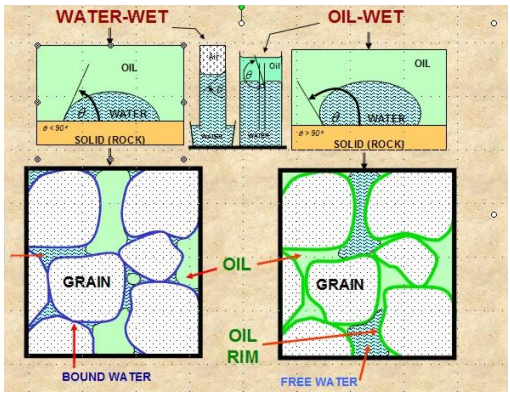



**Figure 2 : Schematic of Wettability (Crain, 2013)**

How to determine whether it is water-wet or oil-wet reservoir?

From laboratory analysis, the acceptable theory made was, if the contact angle, θ is close to 0°, the rock is considered to be "strongly water wet". While if the contact angle, θ close to 180°, the rock is considered to be "strongly oil wet" (Crain, 2013). Yet actually there are a lot of theories out there, the mentioned one is one of the fundamental theories obtained. Specific wetting behaviour also prone on specific type of rock, that is the reason why different reservoir has different production performance and fluids connate saturations.

## 1.2 Problem Statement

One of the cheap IOR applications in the industry is water flooding or some says water injection. Yet, identifications of success factors are important in order to sustain an economical and profitable execution.

Thakur (1998) from Chevron mentioned in his paper entitled The Role of Reservoir Management in Carbonate Waterfloods, one of the factors that can affect the waterfloods' recovery is the reservoir rock wettability. Plus he adds, more favourable production exist from high water-wet reservoir rather than oil-wet reservoir, nevertheless the oil-wet reservoir still have the potential to be flooded efficiently. That's why a structured test and simulation has to be done right after the company have the field's core sample and data.

In addition, Professor Willhite from University of Kansas states that a both fluid and rock property contributes in the wettability of the reservoir. His data concluded that the ability of changing wetting phase was due to heterogeneity of surface element surrounding the pores solid surface and the favourable liquid injection. For example let say initially the rock surface is water-wet and the flooded liquid was also a water-based, hence in doesn't change the wetting behaviour of the surface but this helps in pushing the hydrocarbon to the facilities via imbibition. But the other way around happen if the initial wetting phase is oil-wet. This phenomenon can affect the field's expected ultimate recovery.

## 1.3 Objectives

The objectives of doing this project are:

1) To investigate the waterflood ultimate recovery on oil-wet reservoir.

2) To investigate the waterflood ultimate recovery on water-wet reservoir.

## 1.4 Scope Of Studies

It is important to set the scope thus clearing the goal of this project/study. Plus, the author also found the title itself is a combination between two (2) disciplines in Petroleum Engineering which are;

- The oil recovery (Ultimate).
- Rock properties (Wettability)

Based on The Reservoir Engineering Aspect of Waterflooding, the author Mr. Forrest F. Craig, a manager of petroleum at Amoco International Oil Company mentioned that in the reservoir, it was generally considered that most of the formations are preferentially water wet. This is due to natural cause of sandstone deposition which commonly occur in aqueous environment and only later that, hydrocarbon migrate in the conduits. While the carbonate formation, the water play its part for porosity development and then the oil move into it. Yet Mr Nutting found that the hydrocarbon producing carbonate formations are oil wet based on his research paper entitled Some Physical and Chemical Properties of Reservoir Rocks Bearing On The Accumulation and Discharge of Oil published by American Association of Petroleum Geologist.

Therefore, we can simply make a conclusion that;

- Generally water-wet = Sandstone.
- Generally oil-wet = Carbonates.

**Figure 3: Sandstone (http://www.offshore-technology.com/projects/galoc-oil/galoc-oil2.html, 2015)**

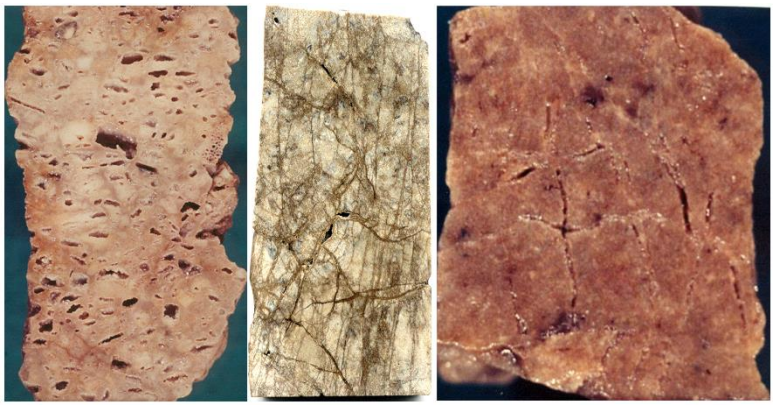


**Figure 4 : Carbonates Cross-Section (http://www.intechopen.com/books/metal-ceramic-and-polymeric-composites-for-various-uses/inversion-of-physical-properties-for-determining-the-microstructure-of-natural-composites , 2015)**

Furthermore, the author feels that wettability is naturally occurs in the subsurface, it is a reality in every upstream operation have to face, hence it will be more interesting to study of rock type (sandstone and carbonates) in order to see the wettability influence on oil recovery.

There are few assumptions have to be made in order this research follows the scope. Based on Dake, 2002 in his book entitles Fundamentals of Reservoir Engineering, the list of assumptions are as below;

1. Water is displacing oil in water wet reservoir.
   Note: to fulfils the title of this project, hence ***author decided to look on water displacement on oil in both water-wet and oil-wet reservoir***.
2. The displacement is considered as incompressible. (only involves liquid)
3. The displacement is considered to be linear.

Based on Latil, 1980 of his book entitled, Enhanced Oil Recovery which also touches about water injection. The author agrees to take his research as an immiscible liquid (Water-Oil) displacement in a homogenous reservoir. This assumption may be sort of theoretical but it is also have high benefit since to ideal case research, every parameter are put in extremities to prepare with any unavoidable things that may happen during on-field application.

# 2.0 LITERATURE REVIEW

## 2.1 Waterflooding

Gulick et. al from Society of Petroleum Engineers mentioned that, the history of waterflooding dated as early as 1865, but this method becomes widespread in the 1950's. He adds, water injection was implemented to restore oil production rates or in some opinions, to maintain its production drive like happened during primary recovery.

Plus, his research team also adds, an early start to waterflooding will speed up the recovery process and thereby improve the economic performance of the field. They stated this kid of strategy has been a successful at very large offshore fields in the past. How early it is meaning to say before the field reach its bubble point, hence if it is started after the oil becoming gas, then it would be quite uneconomical to push the production at the optimum rate.

In PetroWiki website published by Society of Petroleum Engineering (SPE) stated that waterflooding is inexpensive, generally available in large quantity, and effectively made production wells that were near the water injection wells flow.

## 2.2 Wettability

### 2.2.1 Definitions

Obtained from PetroWiki, it says that wettability is a measurement of the wetting phase adhered on the formation. While in Schlumberger's Oilfield Glossary explained the wettability in the preference of a solid to in contact with one liquid or gas. It can be determined by measuring the contact angle of crude and formation water on silica or calcite crystal. Of course this kind of measurement are done in laboratory and for the time being it is uncertain to execute it on field but it is able to be deduced by observing field's relative permeability graph.

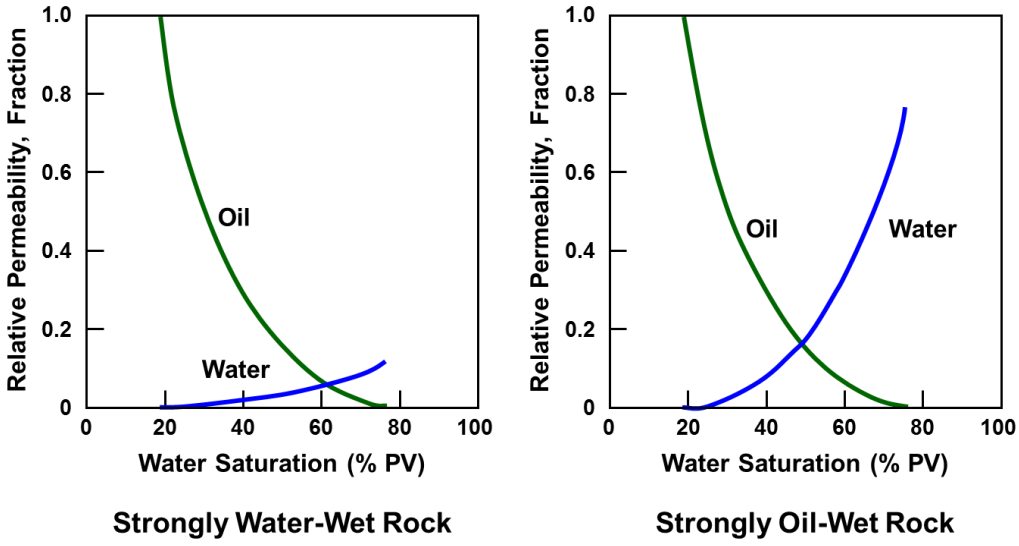



**Figure 5 : Relative Permebility Graph (TAMU,2014)**

## 2.2.2 Factors That Effects Wettability

Dandekar(2006) do explained in his book entitled Petroleum Reservoir Rock and Fluid Properties which is wettability are dependent on interfacial tension, while capillary pressure depends on both wettability and interfacial tension yet relative permeability relies on interfacial tension, wettability and capillary pressure. This four(4) fundamental aspect of rock & fluid properties plays a vital part in the success of oil and gas production as the relationship as in Figure 3 below.

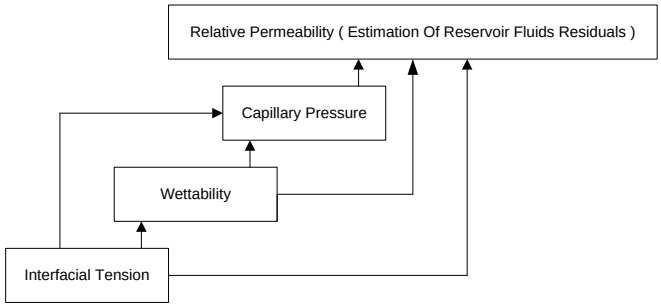



**Figure 6 : Relationship Concept of Major Rock & Fluid Properties**

## 2.2.3 Mechanism to Change Wettability Behaviour.

Salathiel from Esso Production Research Company stated in his paper entitled Oil Recovery by surface Film Drainage In Mixed-Wettability Rocks which is wettability of mineral surfaces may be altered not only by absorbed monolayer of surface active components, but also by much thicker layer of deposited organic substances. He adds, several workers have reported the formation of stable film on solid surfaces when they stand in contact with certain crude oil. This is very interesting because from a consultation with an expert in the Universiti Teknologi PETRONAS, Dr. Syed Mohammad Mahmood, a lecturer from Petroleum Engineering Department

mentioned that a heavier hydrocarbon do have the ability to displace the wetting phase on the rock, hence forms a layer on the pore surface.

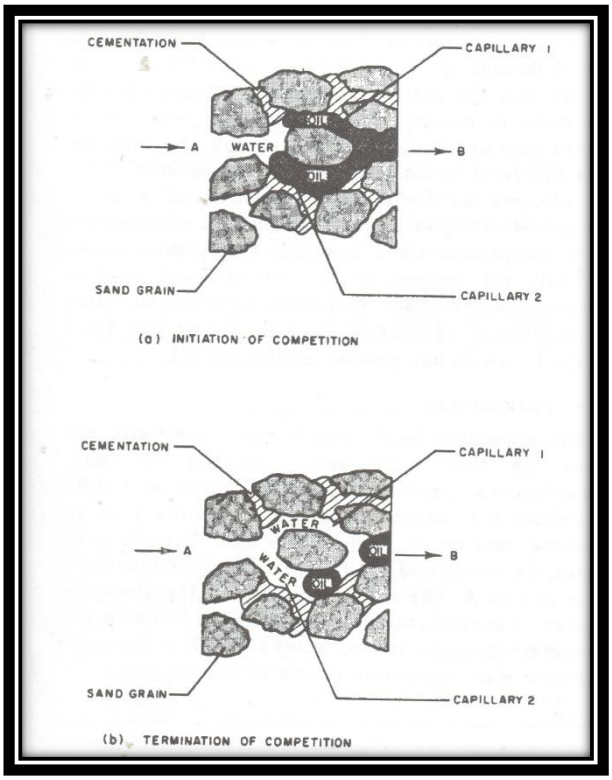



**Figure 7 : Model of Wettability Changing Via Floodwater Properties Alteration (SPE,2003)**

Another method is by altering the floodwater's chemical features to reduce the wetting fluid's interfacial tensions and capillary pressure. Mr Abrams from Shell Company (1974) made an experiment to observe the influence of fluid viscosity, IFT and flow velocity on residual oil saturation lest via waterflood. The experiment was done by injecting flood water of varied properties into core samples hence the residual oil left was observed. The efficiency model were illustrated as in Figure 4, the purpose is clear, to achieve the best flood water solution which can give maximum hydrocarbon displacement by altering the targeted wetting hydrocarbon's IFT on pore surface.

# 3.0 METHODOLOGY

Based on a book entitled “Introduction to the Philosophy of Methodology” , the author, K.E Howell(2013) described methodology as a general research strategy that was identified, thus outlines the way in which a research project is to be undertaken. The methods, described in the methodology, define the means or modes or mechanism of data collection or, sometimes, how a specific result is to be sorted or calculated.

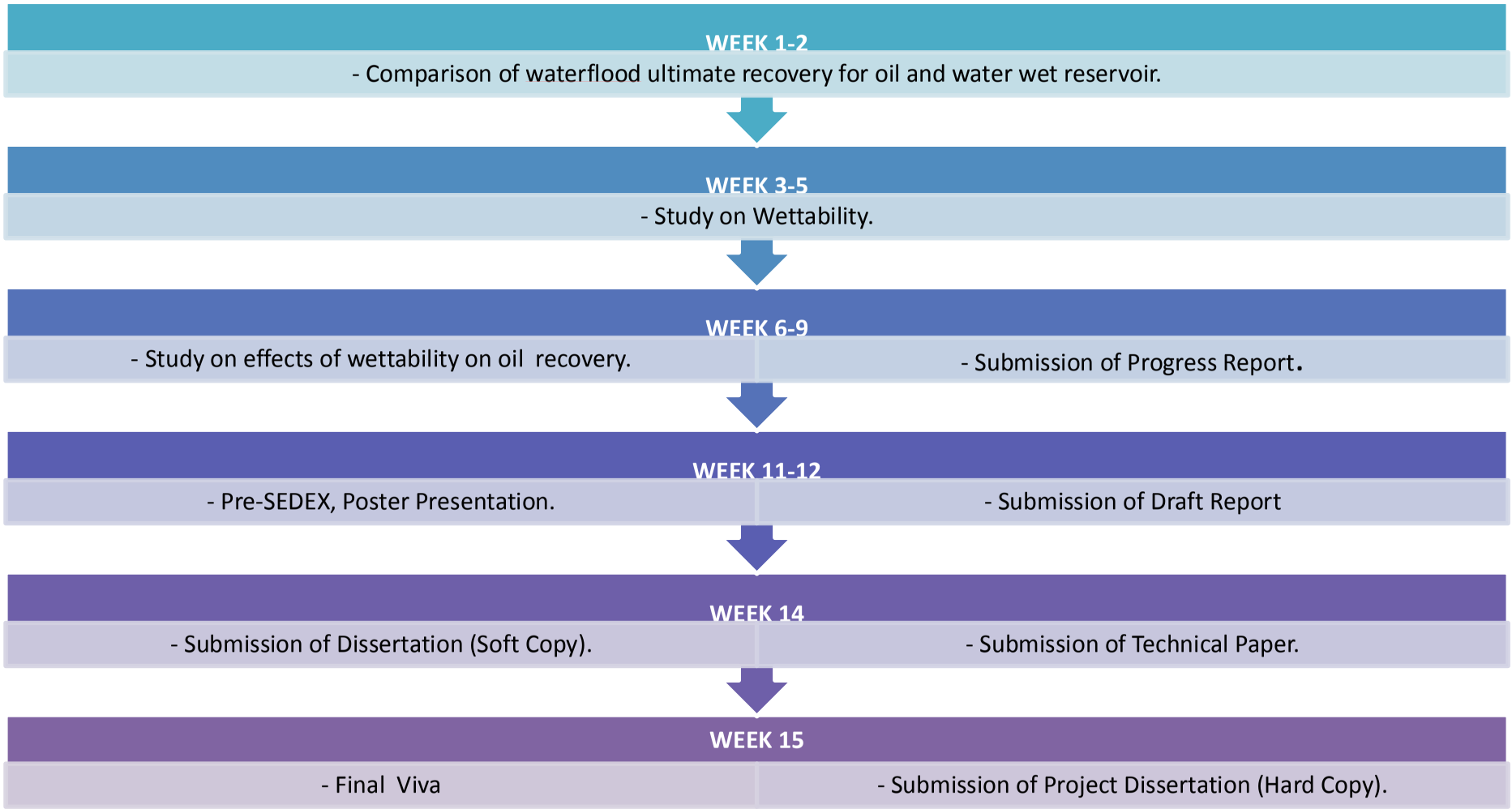
Therefore, the concept of this research’s methodology is prone to be as steps of acquiring knowledge based on paper works available in offline or online resource centre. Below are the steps taken :

i. **Consultation with Supervisor.**
   Engage with the supervisor which also an expert with the subjects.

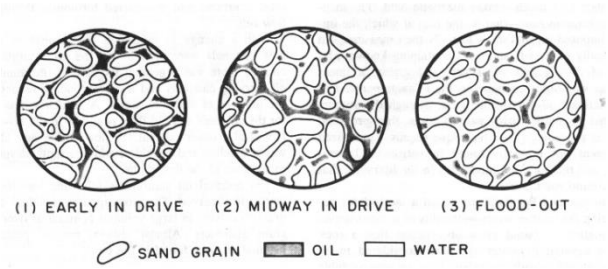
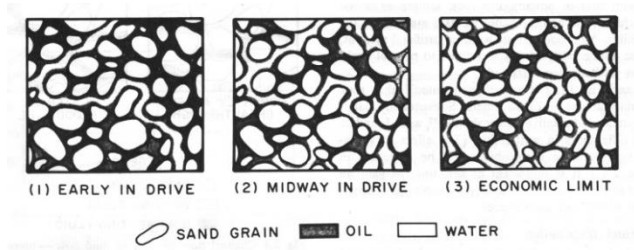
ii. **Paper Review.**
   Waterflooding have a very long history in the upstream industry, thus there are many re-investigations and researches had been done in order to study its behaviours and improve its efficiencies. Fortunately, there are abundance of reading materials in the net and library for author to read and reviews.

iii. **Comparing.**
   Comparing both predicted ultimate recovery based on the information obtained. Plus to come out with comparative analysis based on effects of wettability type on recovery. If possible, this paper will come out with some data of information with graph

## 3.3 KEY MILESTONE

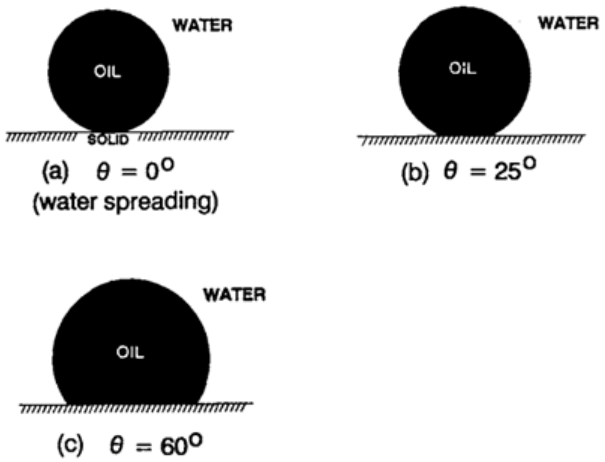
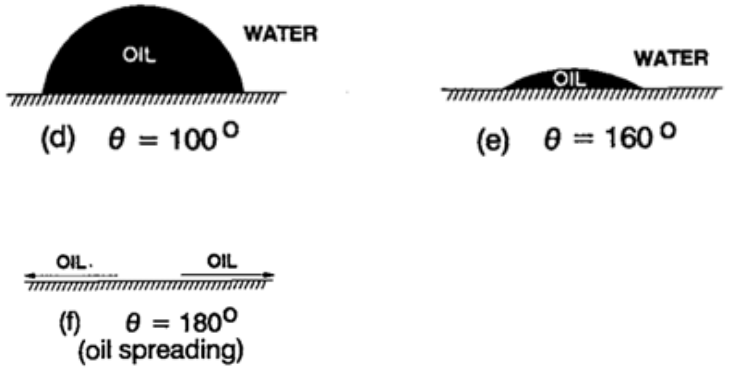


## 4.0 RESULTS & DISCUSSION

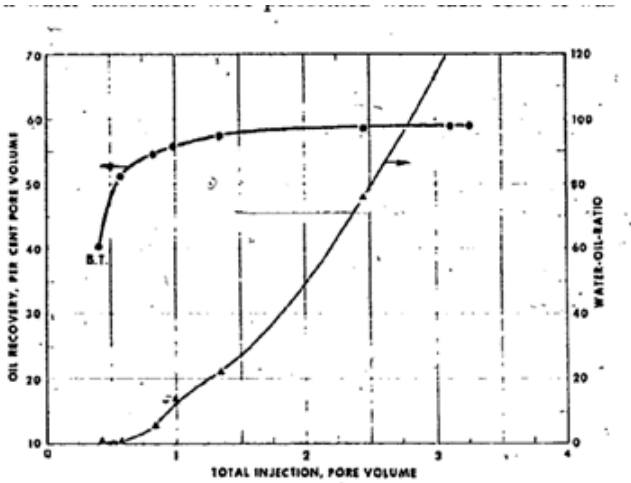
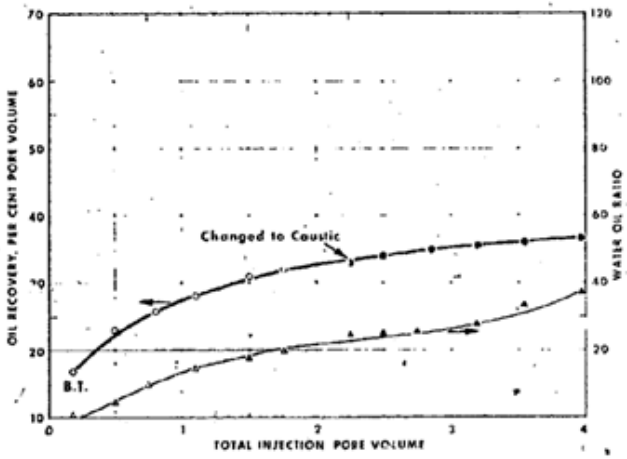
| | Water-wet Rock | Oil-Wet Rock |
|---|---|---|
| Flow Pattern |  *Figure 8 : Flow Pattern* *Source Book : The Reservoir Engineering Aspect of Waterflooding* |  *Source Book : The Reservoir Engineering Aspect of Waterflooding* |

Dandekar had emphasised a point where he state that wettability is a key parameter that affects the petrophysical properties of reservoir rocks. The petrophysical characters of reservoir rocks are consist of formation lithology, porosity, water saturation, both relative & effective permeability and not to forget, the wettability. Consequences of the features mentioned are on the business key profit gainer which is the hydrocarbon recovery.

From the table above, the flow pattern here we can see, the graphical illustration by Mr. Forrest Craig from SPE regarding waterflooding on rocks that contain respective wettability. It is obviously shown that the water displace better in water wet rock compared to oil-wet rock, the irreducible oil was minimised significantly.

| | | |
|---|---|---|
| Angle of Contact |  **Figure 8 : Angle of Contact of Water Wet** ***Source Paper : Wettability and Its Effect on Oil Recovery*** |  **Figure 9 : Angle of Contact of Oil on Oil-wet Rock** *Source Paper : Wettability and Its Effect on Oil Recovery* |

Secondly, author found that microscopically the effect imbibition effectiveness was also affected by the angle of contact of oil on rock surface. The oil affinity is between 100 degree to 180 degree of contact, the rock is oil-wet while if the oil affinity is between 0 degree to 60 degree, the rock is preferentially water-wet. This matter was due to the surface chemistry of the rock that result its preference towards certain liquid.

| | | |
|---|---|---|
| Laboratory Result |  FIG. 1—PERFORMANCE OF 0.5N NaOH FLOOD IN WATER-WET CORE 12-3A.<br>**Figure 10 : Spontaneous Imbibition Lab Result**<br>*Source Paper: Certain Wettability Effects In Laboratory Waterflood* |  FIG. 3—PERFORMANCE OF WATERFLOOD FOLLOWED BY NaOH FLOOD IN OIL-WET CORE 6-1 (ROOM TEMPERATURE, NO REVERSAL IN WETTABILITY).<br>*Source Paper: Certain Wettability Effects In Laboratory Waterflood* |

Last but not least , from a laboratory test made by Mr. Necmettin Mungan from AIME to see the wettability effect in laboratory waterflood. The method of experiment applied was similar like Amott Test whereby spontaneous imbibition is the principle mechanism. It was found that, the Oil-wet cores would imbibe about 10%-pore volume oil and then 8 to 11%-pore volume water. While in water-wet cores, the flooding shows a recovery about 40-41%-pore volume. Hence, it is true based on the evidence mentioned in literatures, waterflood recovery are significantly more in water-wet reservoir compared to oil-wet reservoir.

# 5.0 CONCLUSION & RECOMMENDATION

## 5.1 Conclusion

In conclusion, Waterflooding is a relevant method of sustaining the oil recovery despite of any injection technique. It is cheap and reliable for a long term of the operation. Yet considering there are many factors that may affect the efficiency, pre-execution core test is a must. Hence, the author of this project have achive the objective outlined in earlier page.

## 5.2 Recommendation.

Author would like to recommend few things for future improvement. Most of the suggestions are more into experimental method. Firstly, the author feels that this project would be more successful if there is opportunity to execute the core-flooding experiment. Hence the result would be more realistic hence able to provide more empirical evidence to proof the literatures.

Secondly, it is highly recommended to do some other laboratory measurement such as Amott test or United States Bereu of Mines (USBM) microscopic test, Nuclear-magnetic Resonance Test, Dye adsorption or others. With a very limited time frame, it is suggested to execute Amott test compared to others. This test is done to see the wettability of rock in microscopic scale. It involves the measurement of the amount of fluids which spontaneously imbibed by a wetted-rock sample. It is also an industrial standard of comparing wettability of various core plugs.

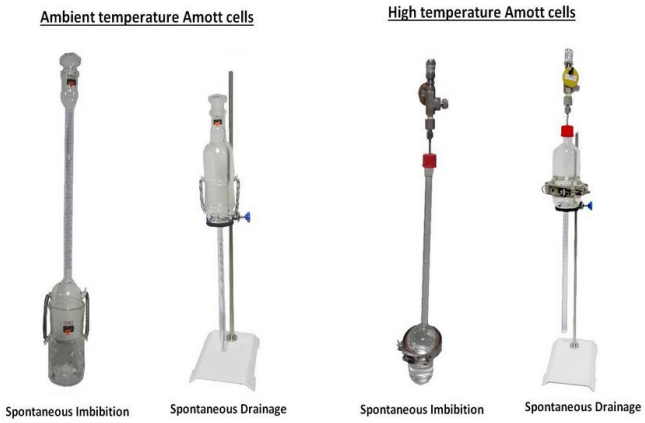



**Figure 11 : Amott Test Laboratory Set-up**

The Ammot Test result then will be calculated with formula below in order to find the rock's wettability index. The wettability index then that nearest to 0.1 and are often further reduced to weak, moderate or strongly wet to certain fluid.

$$\text{Index} = \frac{\text{SpontaneousWaterImbibition}}{\text{TotalWaterImbibition}} - \frac{\text{SpontaneousOilImbibition}}{\text{TotalOilImbibition}}$$

$$= \frac{AB}{AC} - \frac{CD}{CA}$$

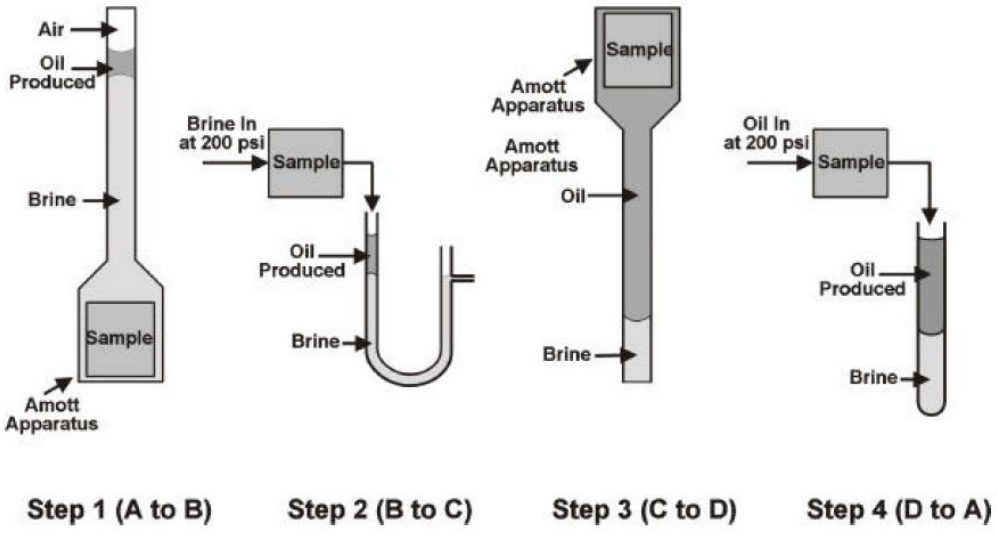



**Figure 12 : Amott Wetting Technique (Dr.Paul Glover, Leeds University)**

Thirdly, he would like to recommend an enhanced study regarding surface chemistry of porous media and its influence in setting the wettability of the rock. From paper entitled " Surface Energy and Wetting Behaviour of Reservoir Rocks" by Mr. Naveed et.al greatly emphasised that an accurate description of the surface chemistry of the reservoir rock-fluid system is necessary to understand the attractive forces between various fluid phases. This rock-fluid interaction results the fundamental nature of wettability and wetting behaviour of fluids on the reservoir rock's surface. This information is needed because after the behaviour is determined, later on a mitigation research and plan can be done by altering the wettability of the rock thus increasing its recovery.

Last but not least, author would highly recommend for research of wettability with by including more other variables such as capillary effect, interfacial tension, reservoir fluids, the floodwater salinity and temperature of flood water so with that, researcher are predicted to come with more holistic finding with the oil recoveries. The inclusive experiments results then may benefits the industry.

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# APPENDIX

## The FYP1 Gantt Chart

| DETAIL / WORK | WEEK (FYP1) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Selection of Project Topic | | | | | | | | | | | | | | |
| Search acticles | | | | | | | | | | | | | | |
| Submission of Extended Proposal | | | | | | | | | | | | | | |
| Continue work | | | | | | | | | | | | | | |
| Proposal Defence | | | | | | | | | | | | | | |
| Continue work | | | | | | | | | | | | | | |
| Submission of Interim Draft Report | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | |

The FYP2 Gantt Chart

| DETAIL / WORK | WEEK(FYP2) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Project Work Continues | | | | | | | | | | | | | | | |
| Submission of Progress Report | | | | | | | | | | | | | | | |
| Project Work Continues | | | | | | | | | | | | | | | |
| Pre-SEDEX | | | | | | | | | | | | | | | |
| Submission of Draft Report | | | | | | | | | | | | | | | |
| Submission of Dissertation (Soft bound) | | | | | | | | | | | | | | | |
| Submission of Technical Paper | | | | | | | | | | | | | | | |
| Oral Presentation | | | | | | | | | | | | | | | |
| Submission of Project Dissertation (Hard bound) | | | | | | | | | | | | | | | |