EVALUATION OF POTENTIAL CARBON DIOXIDE SEQUESTRATION AND ENHANCED OIL RECOVERY IN THE NORTHERN MALAY BASIN AREA

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A project report submitted in partial fulfillment of the requirements
for the award of the degree of
Master of Engineering (Petroleum)

School of Chemical and Energy Engineering
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JANUARY 2019

To my parents and family,
Thank you for everything
To my lecturers,
Thank you for the knowledge that has been passed on to me
To my friends,
Thank you for not giving up on me.
I dedicate this work to all of you.

ACKNOWLEDGEMENT

First and foremost, I would like to thank my family, especially my parents, for helping me, guiding me, giving me their emotional supports and also for not giving up on me during my downturn days.

Next, I would like to thank my supervisor, Prof. Dr. Radzuan for accepting me as his student, and for giving me ideas and guidance towards completing this project. I would also like to thank all the lecturers from the Petroleum Engineering Department for guiding me and teaching me throughout these 4 semesters of my study. Without their guidance, I will not be able to finish my course of program.

Lastly, I would like to thank my seniors and peers for helping me and acknowledging my hard work in completing this program.

Thank you.

ABSTRACT

The topic of climate change has been increasingly debated around the world as of date. One of the main causes of climate change is the increase in global warming, which is directly caused by the rise in the amount greenhouse gases (GHGs) in the atmosphere, which mostly comprises of carbon dioxide (CO_2) gas. One of the ways in order to lessen the amount of CO_2 gas in the atmosphere is through CO_2 sequestration. This study aims to evaluate the potential of CO_2 sequestration in the Malay Basin. By utilizing a set of field data and a static model that is obtained from previous studies of **Field N** in the Northern Malay Basin Area, a reservoir simulation dynamic modelling is done by using the Roxar-Tempest VIEW™ ver. 8.3 software. The main objectives of the simulation are to determine the amount of gas that can be stored in **Field N** in the Northern Malay Basin area through the CO_2 sequestration and enhanced oil recovery (CO_2–EOR) process using dynamic modelling, and also to determine the amount of oil production in **Field N** using the CO_2–EOR process using dynamic modelling. The outcome of this research are as follows; i) The amount of CO_2 gas that can be stored in **Field N** through CO_2 injection process is about 137 Mscf; (ii) The total amount of oil production of **Field N** through the process of CO_2–EOR ranges from 190 MMstb to 230 MMstb; (iii) The amount of oil production through the process of CO_2–EOR has an increment of about more than 20% as compared to both the natural depletion and water injection simulation; and (iv) As the gas injection rate increases, the amount of CO_2 gas that can be stored also increases. It was deduced that for the CO_2–EOR process, the injected CO_2 gas behaves in a way that it follows the *multiple contact miscibility* process, in which that it sweeps the residual oil towards the producing wells.

ABSTRAK

Topik perubahan iklim semakin diperdebatkan di seluruh dunia sehingga kini. Salah satu punca utama perubahan iklim adalah kerana peningkatan pemanasan global, yang secara langsung disebabkan oleh kenaikan jumlah gas rumah hijau (GHG) di dalam atmosfera, yang sebahagian besarnya terdiri daripada gas karbon dioksida (CO_2). Salah satu cara untuk mengurangkan jumlah gas CO_2 di atmosfera adalah melalui proses penyerapan dan penyimpanan gas CO_2 ini. Kajian ini adalah bertujuan untuk menilai potensi penyerapan dan penyimpanan gas CO_2 di kawasan Malay Basin (Lembangan Melayu). Dengan menggunakan satu set data dan satu model statik yang diperoleh daripada kajian yang pernah dilakukan sebelum ini di **Field N** di Utara Malay Basin, simulasi dinamik model reservoir telah dilakukan dengan menggunakan perisian Roxar-Tempest VIEW™ (ver. 8.3). Objektif utama simulasi ini adalah untuk menentukan jumlah gas CO2 yang boleh disimpan di **Field N** di kawasan Utara Malay Basin melalui proses pemencilan CO_2 dan perolehan minyak tertingkat (CO_2-EOR) menggunakan pemodelan dinamik, dan juga untuk menentukan jumlah pengeluaran minyak di **Field N** menggunakan proses CO_2-EOR menggunakan pemodelan dinamik. Hasil kajian ini adalah seperti berikut; i) Jumlah gas CO_2 yang boleh disimpan di **Field N** melalui proses suntikan CO_2 adalah berjumlah sebanyak 137 Mscf; (ii) Jumlah pengeluaran minyak di **Field N** melalui proses CO_2-EOR berjumlah dari 190 MMstb hingga 230 MMstb; (iii) Jumlah pengeluaran minyak melalui proses CO_2-EOR meningkat sebanyak lebih dari 20% berbanding dengan simulasi semulajadi dan suntikan air; dan (iv) Apabila kadar suntikan gas meningkat, jumlah gas CO_2 yang boleh disimpan juga meningkat. Dapat disimpulkan bahawa gas CO_2 yang disuntik bertindak dengan cara ia mengikuti proses *multiple contact miscibility*, di mana ia berjaya membantu menolak sisa minyak di dalam reservoir ke arah telaga pengeluaran.

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LIST OF ABBREVIATIONS

CCS	-	Carbon Capture and Storage / Sequestration
CH_4	-	Methane
CO_2 -EOR	-	Carbon Dioxide Enhanced Oil Recovery
CO_2	-	Carbon Dioxide
EOR	-	Enhanced Oil Recovery
GHG	-	Greenhouse Gases
IFT	-	Interfacial Tension
IPCC	-	Intergovernmental Panel on Climate Change
MCM	-	Multiple Contact Miscibility
N_2O	-	Nitrous Oxide
NASA	-	National Aeronautics and Space Administration
UNFCC	-	United Nations Framework Convention on Climate Change
US-DOE	-	United States Department of Energy
US-SCNGO	-	United States Strategic Center for Natural Gas and Oil
WAG	-	Water Alternating Gas

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The topic of climate change has been wildly debated around the world, ranging from its causes and effects, the mitigation procedures, and also on the hundreds of projects combatting the problem. According to the 1997 Kyoto Protocol treaty, which is an extension of the 1992 United Nations Framework Convention on Climate Change (UNFCCC), emissions of anthropogenic greenhouse gases (GHGs), mainly carbon dioxide (CO_2), are needed to be controlled in order to extenuate the occurrence of global warming. In addition to this, the 2015 Paris Agreement (*Accord de Paris)* was conducted, and it consists of the mitigation of the greenhouse gas emissions, adaptation and finance, which will commence in the year 2020. The main objectives of the agreement are as follows;

> "To maintain the increasing temperature of the earth by 2°C above the pre-industrial levels and to limit the temperature increase by 1.5°C above the pre-industrial levels,

> “To increase the ability to adapt the impacts of climate change in such a way that it will not in any way or form, harm the food production,
>
> “To ensure that the flows of finance are consistent with a pathway towards low greenhouse gas emissions and climate-resilient development”
>
> (*Accord de Paris*, 2015).

It was also stated by NASA (National Aeronautics and Space Administration) that the average surface temperature of our planet has soared up to about 1.1°C since the 19th century, and it is widely caused by anthropogenic greenhouse gas emissions. In 2016, eight of the months of the year (from January to September), were the warmest months that was recorded in the warmest year of date. Since the oil and gas sector have been one of the major contributors for the emissions of CO_2 gas, (Hamilton, 1998), it is vital for us human beings with conscience to at least mitigate the emissions of CO_2, in order for us to lessen the effect of climate change. There are numerous methods of decrease the amount of CO_2 in the world, the most well-known being the process of CO_2 sequestration.

The term CO_2 sequestration refers to the process of CO_2 capture and storage (CCS). Dated back since 1972, the process was first used as a method to enhance oil recovery (EOR) (Richey, 2013). There are basically three different kinds of the CO_2 sequestration process: terrestrial, geologic, and mineralization. In this study, the geologic sequestration process is examined. Geologic sequestration is the term that is used for permanently storing the captured CO_2 gaseous in subsurface structures such as oil reservoirs, basins, basalt formations and also aqueous saline formations. Most of the geological media that is ideal for CO_2 storage are located in sedimentary basins (eg: deep saline aquifers, coal beds). However, a screening process should be done in order to ensure the safety and longevity of the potential CO_2 storage.

Enhanced Oil Recovery (EOR) is referred to as the tertiary process of oil recovery operations, the first two being (i) Primary Recovery (natural depletion), and (ii) Secondary Recovery (waterflooding, gas injections). EOR consists of processes such as injecting miscible gaseous (eg: CO_2, etc.), chemical injections, and also thermal injections in order to displace the amount of oil left in the depleted reservoirs (Willhite, 1998). EOR will be done when the first and secondary recovery becomes economically unfeasible. The process of Carbon Dioxide – Enhanced Oil Recovery or (CO_2–EOR) on the other hand is the process of which CO_2 gas is injected into the reservoir for storage, and also for sweeping the depleted oil left in the reservoirs. It was reported that the amount of oil recovery that has been obtained through CO_2–EOR purposes to be around 179000 BOPD, and is still increasing up until now. According to the Global CCS Institute, the CCS Readiness Index (CCS-RI), Malaysia has a CCS-RI of about 32%, which falls just a few steps from South Korea which ranks at about 38% (***Figure 1.1***). The countries with good CCS-RI numbers are Canada, the United States and also Norway, all of which has a value of around 68% – 72%. China, the Netherlands, Denmark, Germany and Japan come in latter with good CCS-RI numbers, all of which are ranked at more than 50%.

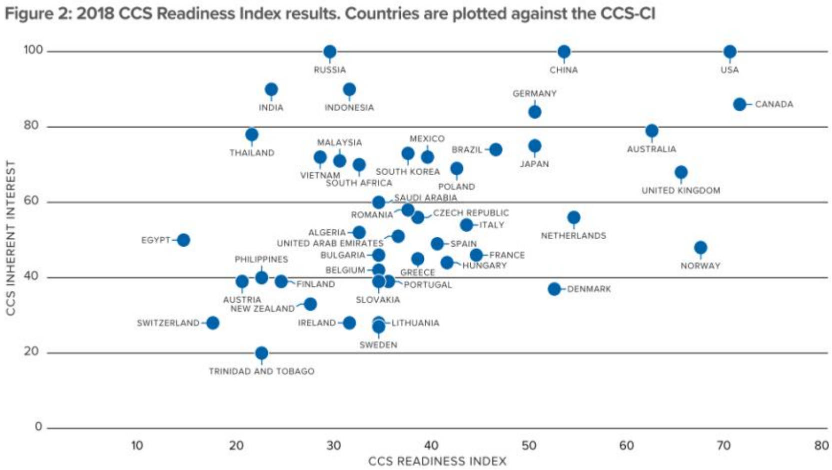

***Figure 1.1**: Carbon Capture and Storage – Readiness Index (CCS – RI) globally (Global CCS Institute, 2018)*

As of now, Malaysia has been known as one of the highest oil-producing countries in the world, and that most of the sources are from sedimentary basins. A previous study has shown that there are 14 identified sedimentary basins in Malaysia that was found to be quite ideal for potential CO_2 storage. The first four basins that have the highest score obtained through selective screening and ranking processes are the Malay Basin, Central Luconia Province, West Baram Delta, and lastly the Balingian Province. It was stated that the Malay Basin warrants extra attention as it is ranked as the basin which has the most potential for offshore CO_2 storage. The different evaluation criteria for the screening process are as follows (modified from Bachu, 2003): Tectonic setting, faulting intensity, reservoir seal pair, depth, size, geothermal, hydrogeology, maturity, hydrocarbon potential, onshore/offshore, accessibility, infrastructure and also climate.

Table 1.1*: List of Ranking or Sedimentary Basins in Malaysia*

Rank, R	Basin, k	Score
1	Malay Basin	0.8113
2	Central Luconia Province	0.7356
3	West Baram Delta	0.7041
4	Balingian Province	0.6938
5	Sabah Basin	0.6864
6	East Baram Delta	0.6260
7	Straits of Melaka	0.6200
8	Penyu Basin	0.5554
9	Tatau Province	0.4938
10	West Luconia Province	0.4553
11	Tinjar Province	0.4200
12	Northeast Sabah Basin	0.3543
13	Southeast Sabah Basin	0.3370
14	North Luconia Province	0.2659

(Hasbollah et al., 2015)

In this study, a detailed evaluation of potential CO_2 sequestration and enhanced oil recovery in the northern Malay basin area were conducted.

1.2 Problem Statement

Carbon dioxide sequestration mainly utilizes the injection of CO_2 gas into a depleted reservoir. An example of this project was located in a depleted gas reservoir in North Italy. The difference in between its physical and chemical properties and changes in the reservoir were simulated to investigate its effects on the reservoir's total storage capacity (Calabrese, 2005). A CO_2 injection process is supposedly effective in reservoirs with a depth of more than 2500ft, as the CO_2 gas will be in its supercritical state, with API oil gravity more than 25° and the remaining oil saturation of more than 20%. During the process of CO_2 injection, the CO_2 gas will react with the formation rocks available, such as in dolomite formations, of which, in turn, will affect the permeability of the composition due to the rocks dissolution and precipitation of reaction products. There are several factors affecting the rate and the interactions between the CO_2 gas and the rock formations, such as the pressure, temperature and the brine composition of the rock formations, the CO_2 gas injection rate, and also the overall injection scheme. A previous study had shown that in a CO_2 gas injection with dolomite formations, the temperature, injection and flow rate doesn't have major impacts on the permeability of the dolomite core sample; the damage that was done towards the permeability of the sample was mostly done by the calcium carbonate ($CaCO_3$), and the precipitations obtained as a resultant of the reaction between silicate minerals in the dolomite and the CO_2 gas injected.

In 2016, a theoretical storage capacity assessment of the Malay Basin was done using the volumetric method for CO_2 gas capacity calculations in deep saline formations (*Hasbollah, 2016*). The method that was used was proposed by the U.S. Department of Energy (US-DOE), and it was planned for external use in assessing the potential of CO_2 storage in reservoirs at both regional and national scales. The following equation is the volumetric formula that was used in order to calculate the CO_2 gas storage resource mass estimate, Gco_2, for geologic storage in saline formation (by considering the boundary conditions of saline aquifers are open);

$$Gco_2 = A_t \; x \; \phi_t \; x \; h_g \; x \; \rho \; x \; E_{saline} \quad (1)$$

Where;

A_t = Total geographical area of the basin being assessed for CO_2 storage,

ϕ_t = Total porosity in volume in net thickness,

h_g = Gross thickness of the saline formation,

ρ = Density of CO_2 at the formation temperature

From the study, it was stated that the amount of CO_2 storage capacity estimation for the Malay Basin was at about 84 Gt and it was located in Groups D and E (***Figure 1.2***) sediments, which are located at a depth of 1000 m to 1500 m, and fulfils the requirement for a safe CO_2 storage unit which requires an average porosity of 17% and a permeability of 40mD (*Kartikasurja, 2008*).

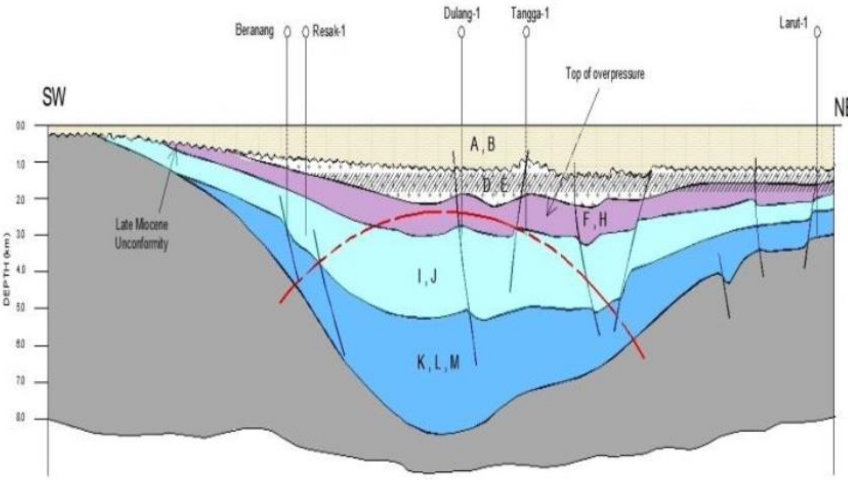

***Figure 1.2**: Potential injection site for CO_2 storage in Malay Basin (Hasbollah & Junin, 2016)*

Since the study that was done by *Hasbollah* on the calculation of Gco_2 utilizes theoretical generalized data, thus, in this study, an experimental CO_2 gas storage capacity assessment will be done by running a 3-D dynamic modelling with data samples obtained from a previous study that was done in **Field N** in the Northern Malay Basin Area. The amount of CO_2 gas stored in the field will be calculated from the amount of CO_2 gas injected and the amount of CO_2 gas produced from the field. The storage capacity assessment will be done by running a 3-D dynamic model of **Field**

N in the Northern Malay Basin area using the Roxar–Tempest VIEW™ software.

1.3 Objectives of the Study

The objectives of the study are as follows:

i. To determine the amount of CO_2 gas that can be stored in **Field N** in the Northern Malay Basin area through the CO_2 – EOR process using dynamic modelling
ii. To estimate the amount of oil production in **Field N** using the CO_2 – EOR process using dynamic modelling

1.4 Scopes of the Study

The scopes of the study which are based from the objectives are as follows:

i. Studying the amount of CO_2 gas that can be stored in **Field N** in the Northern Malay Basin area through the CO_2 – EOR process using dynamic modelling
ii. Studying the amount of oil production in Field N through the CO_2 – EOR process using dynamic modelling

iii. Comparing the amount of oil production in **Field N** through Primary Recovery, Secondary Recovery and through CO_2 – EOR simulation

iv. Examining the effects of different rates of CO_2 gas injection towards the amount of CO_2 gas stored and the amount of oil produced in **Field N**.

1.5 Significance of the Study

This study highlights the major problem that the world is facing right now, which is the ever-existing climate change. Thus, one of the ways in order for us to contribute in combatting the phenomenon is by mitigating the CO_2 gas emissions through the process of CO_2 sequestration. As Malaysia has already ratified both the UNFCCC and the Kyoto Protocol treaty, thus, it is quite vital for us to conduct and in depth analysis towards the ‘readiness’ of Malaysia in CO_2 sequestration. In this study, a continuation of assessing the Malay Basin as a potential for long term CO_2 storage was done. By running a dynamic model of a particular field located in the Malay Basin in Malaysia, we can theoretically analyse the technical aspect of CO_2 sequestration and also the future of CO_2 – EOR process. This study was also done so that it could provide a basis for policy makers on the future planning of CO_2 capture and storage, not only in Malaysia but also worldwide.

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