Study of Minimum Miscibility Pressure of Malaysian Light Oil Samples Using Different Type of Gases

By

Rosya Ila Binti Abdul Hamid

Dissertation submitted in partial fulfilment of

the requirements for the

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Mr. Ali F. Mangi Alta'ee)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2012

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.

ROSYA ILA ABDUL HAMID

ABSTRACT

Miscible gas injection recently becomes an imperative method of enhanced oil recovery approach for increasing oil recovery. Successful design and implementation of a miscible gas injection project depends upon the minimum miscibility pressure. The preliminary screening parameters of gas injection including the minimum miscibility pressure (MMP) and type of gas used. Different type of gas injected will give different recovery results due to the unique compositions of oil. The Vanishing Interfacial Tension (VIT) experimental method is used in determines the miscibility efficiency on each type of gas. Basically, in this study carbon dioxide and nitrogen gas has been used in determine MMP for both Angsi and Dulang crude oil. Along the way of this study, factors in determine the MMP can be identified based on the results obtained.

This study has found that carbon dioxide give a better result than nitrogen as injection gas for both light oil samples by providing lower value of MMP. Reservoir temperature, oil composition and type of gases are three main factors that affect in determine the MMP of light oil. The effects of these factors on MMP were discussed in this paper.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Enhanced Oil Recovery (EOR) has been a much discussed topic since 1990s in order to maximize the potentials of reservoir's ultimate recovery. The experienced oilmen during that time discover that a new and significant potential of shifting their focus exploring new fields towards maximizing the production from the existing fields. EOR describes the sophisticated techniques utilized to increase the production or the extraction of oil from the oil field. The main purposes of using EOR are to restore the formation pressure and also improve the oil displacement.

Study by PETRONAS indicates that EOR in Malaysia can boost up recovery up from 4% to 11%. There are many types of EOR methods and two of the methods suitable for Malaysia reservoirs which are gas injection and chemical injection (Terry Knott, 2009). Gas injection can be in three form which are miscible, immiscible or water alternating gas (WAG) injection.

The major types of EOR operations are miscible displacement, chemical flooding and thermal recovery. The application of the techniques depend on the reservoir temperature, pressure, depth, net pay, permeability, residual oil saturation, porosity and oil properties. Gas injection(miscible displacement) is one of the method that widely used in EOR for certain reasons which are,(1)gas injection means to achieve higher oil recovery for deeper reservoirs and particularly deeper offshore reservoir;(2)it is effective to recover residual oils;(3) gas injection can be used to mitigate CO_2emission when combined with CO_2 captured. During gas injection, the gas injection will swell the oil, reduce oil viscosity and achieve miscibility by exchanging components with the oil (Wei Yan, Michael L. Michlesen and Erling H. Stenby, 2012).

Minimum Miscibility Pressure (MMP) is the lowest pressure at which first or multiple contact miscibility can be achieved in the conditions of constant temperature and composition. At this pressure, the interfacial tension between the oil and gas injected is zero and no interface exists between the fluids. Above the MMP, 100% displacement efficiency can be expected on the microscopic scale. The injected gas becomes miscible with oil or in other words gas and liquid to become mutually soluble is when enough light hydrocarbon concentrate in the gas.

Development of oil and gas miscibility requires dynamic processes. There are several types of gaseous that can be used as injected gas such as NGL, carbon dioxide (CO_2), nitrogen (N_2) or flue gas. All of these gaseous become miscible when their density is high or generally greater than 0.5g/cc. Therefore, the gas works best in high pressure. Basically, different gaseous will give different result in determining the value of the MMP between the oil and gas.

The measurement of the MMP is one of the hot topics discussed in oil and gas industry, several correlations, experimental procedures and numerical methods have been proposed in the literature (Abiodun Matthew Amao, Shameem Siddiqui, Habib Menouar and Bob L. Herd, 2012). Experimental methods including Slimtube measurement (Yellig et al., 1980), rising bubbles techniques (Christiansen et al., 1987) and vanishing interfacial tension (Rao, 1997). Numerical methods include single and multiple cell models, 1-D Slim tube simulations (Metcalfe et al., 1973, Neau et al., 1996). Meanwhile analytical methods are based on method of characteristics (Wang, 1998). Empirical methods prediction based on the different correlations (Emera et al., 2005, Emera et al., 2006, Huang et al., 2003).

1.2 Problem Statement

Gas injection is one of the common methods used in enhanced oil recovery phase. During gas injection, MMP is one of the factors to be considered when injecting the gas into the reservoir. MMP in term of gas injection is defined as the minimum pressure at which the injected gas and the contacted oil in place become miscible with each other and result in efficient displacement process. Miscible gas displacements which are carbon dioxide and nitrogen can only be achieved by injecting the gas at a higher pressure than the MMP of the reservoir, in which the MMP must be lower than the reservoir pressure. Each reservoir has their own unique value of MMP due to the composition of the oil. Thus it is important to know the MMP value for oil when injected with different type of gases in determine the lowest possible MMP of the oil.

1.3 Objectives and Scope of study

The objectives of this project are:

- To determine the MMP value of different Malaysian light oil samples at reservoir temperature and varying pressure using different type of gases.
- To determine the best type of gas injection for the light crude oil samples in miscible flooding process

The main objective of this study is to determine the minimum miscibility pressure of Malaysian light oil using vanishing interfacial tension (IFT) technique. In this technique, the MMP for each light oil sample is determine through the extrapolation to zero IFT in IFT against pressure graph. The experiment is carried out by using two different types of gases which are carbon dioxide and nitrogen. The results obtained are compared to the several published correlations.

1.4 Significance of the project

Experimental study in determine the minimum miscibility pressure (MMP) of the light oil samples by using different type of gases is carried out through this project. In this study, it will determine the best gas injection between carbon dioxide and nitrogen for the light crude oil samples. Vanishing interfacial tension methodology is being used in determine the value of MMP for each crude oil

1.5 Relevancy of the project

Gas injection is one the Enhanced Oil Recovery methods that help to increase the production of the reservoir. MMP is one of the criteria in determine the EOR methods that will be used in a reservoir specifically type of gas injection. The type of gas injection used will give different results of MMP since the factors that affect the value of MMP itself are the composition of oil and also the type of gas injected. Therefore, it is important to know which type of gas will give the lowest MMP value for the crude oil.

1.6 Feasibility of the project within the scope and time frame

The early part of this project consists of research by reading technical papers, journals, books and etc. Better understanding of the project is gained when the experiment is carried out and by analyzing the results obtained. In the first planning, this project includes the slimtube experiment as one of the way in determine the value of MMP but due to the lack of time, vanishing interfacial tension (VIT) method is being used as the alternative in determine the MMP value of the crude oil samples. In VIT method, it takes about one week to obtain all the results needed. Meanwhile the MMP values from the published correlations are obtained throughout the period of the project. Therefore, this project is feasible within the time frame required.

CHAPTER 2

LITERATURE REVIEW

A gas miscible process can be used to increase the production or also known as tertiary production. The difference in this methods compare to the other type of EOR methods is the gas injected is not naturally occurring. In this process the gas injected can be carbon dioxide, nitrogen or LPG. So it is important to know the best gas can be used as the injection gas to bring the highest recovery process.

By injectingCO_2, miscibility is achieved by reducing the IFT towards its lowest value, reduces the viscosity and increase the swelling of the oil. Reservoir fluid phase is classified into two broad types according to the pressure and composition diagram (Metacalfe and Yarborough, 1979). At temperature above 120^{o}F, vapor and liquid phase coexist. When the temperature is below 120^{o}F, phase behavior is more complex due to the some mixtures separate into equilibrium vapor and liquid phase, while others separate into two coexisting liquid phases and three coexisting phases. Knowledge of the phase behavior of the particular gas/oil system in slim tube simulation will help in determine the sensitivity to numerical dispersion in that system (Jessen, Stenby & Franklin M., 2002).

The use of nitrogen as the injection gas or displacement fluid has been studied by a variety of investigators. Hudgins et al reported experimental data that showed significant decrease in nitrogen MMP as the amount of dissolved gas was increased for two crudes oil. There is limitation of existing N_2-MMP correlations (Yurkiw and Flock). In the system reviewed by them, injection gas impurities did not change MMP's drastically. They conclude that further study on effects of variation in gas injection composition is needed.

There are various methods to measure MMP. It can be measure experimentally, using slimtube or rising bubble apparatus, numerically using compositional simulator and/or published correlations (Elsharkawy, A.M. et al 1996; Wu, R.S. and Batycky, J.P.1990).

2.1 Definition of MMP

- Lowest pressure at which break point of maximum curvature when recovery of 1.2PV gas injected is plotted against pressure. (Johnson and Pollin,1981).
- Lowest pressure at which gas injection and oil become one phase and miscible displacement is attained. (Jarrel, M.J. et al., 2002, Stalkup, F.I, 1992).
- Interfacial tension between gas and oil diminish approaching miscibility and the interface between the fluids will be eventually disappears at miscibility (Holm, 1978).

2.2 Miscible Displacement

Miscible displacement processes are defined as process where the effectiveness of the displacement results from miscibility between the oil initially in place and fluid injection. Example of displacement fluids are flue gas, carbon dioxide, hydrocarbon solvents and nitrogen.

In immiscible displacement process such as water flooding, generally the microscopic displacement efficiency, E_D, is much less than the unity. When the condition whereby the crude oil in the place contacted with the displacing fluid is trapped due to the wettability condition, relative permeability of oil will be reduced to zero. When it happens, continued injection of the fluid will be ineffective anymore since the fluid will be simply flows around the trapped oil. Capillary forces caused the oil does not move in the flowing stream and prevent from oil deformation.

The limitation of immiscible displacement process is overcome through miscible flooding in which the displaced oil is miscible with zero interfacial tension with displacing oil.

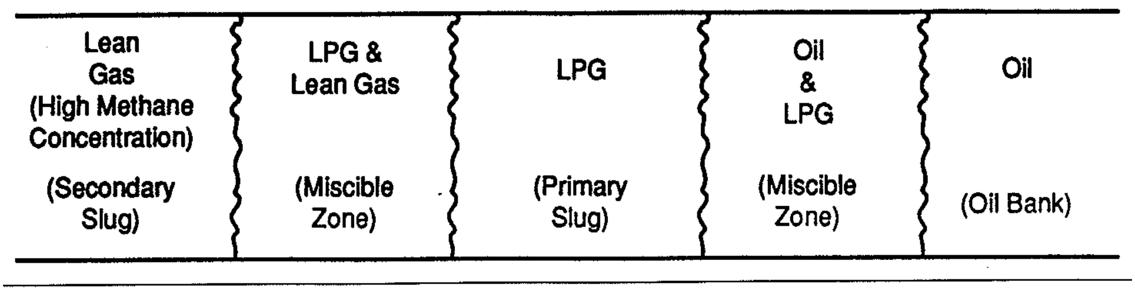


Fig 1. Miscible displacement

Figure 1 shows the miscible displacement process for first contact miscible (FCM) which involves injection specific volume of slug which miscible with the oil. The solvent in the figure is the low molecular weight hydrocarbons (Liquidified Petroleum Gases, LPG). In Multiple Contact Miscible (MCM) case, the oil and injected solvent is not miscible in the first contact but miscible after the modification of the composition of displaced and displacing fluid. Miscibility is dynamically developed as the process continues.

Pseudo ternary diagram always been used in undertanding miscibility for complex hydrocarbon mixtures.

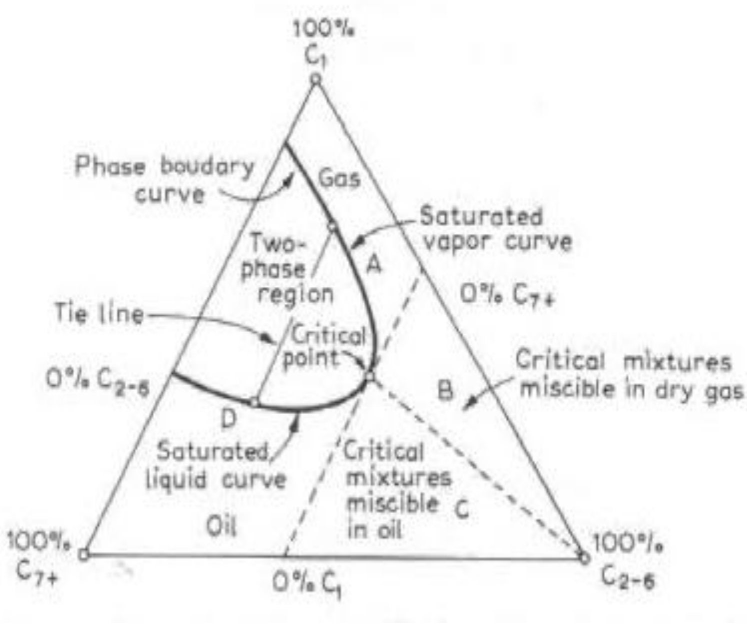


Fig. 2 Pseudo ternary diagram

The diagram shows physical conditions of hydrocarbon at constant temperature and pressure (Clark et al, 1958)

The pseudo ternary diagram consist of 3 components which are methane (C_1), intermediate components (C_2-C_6) and heavy component (C_{7+}). Referring to Figure 2;

- Region A shows all gas phase
- Region D shows only oil (liquid) exist
- Region B and C, at critical condition both liquid and gas exist
- Region B, it shows range of composition at certain pressure and temperature where the mixtures miscible with dry gas.
- Region C, it shows the range of composition whereby mixtures miscible with oil
- Slope of the tie line is determined from the equilibrium ratio.
- If the equilibrium ratio>1, the slope is positive
- If the equilibrium ratio<1, the slope is negative

In miscible gas injection, miscible bank can be formed either by evaporation or condensation of the intermediate hydrocarbon.

1. *Enriched gas or condensing gas drive*

Occur when major transfer of intermediate components by condensation process from gas.

2. *High pressure or evaporation gas drive*

Occur when major transfer of intermediate components by evaporation process from oil.

FCM Process

FCM, First Contact Miscibility process consists of injecting primary slug that is miscible with crude oil followed by secondary slug. Primary and secondary slug ideally miscible between with each other or otherwise the residual saturation of the primary slug will be trapped along the displacement process. It is hard to find reservoir that can be recovered using this process since it needs a really high pressure in order achieve miscibility at first contact with the oil.

MCM Process

MCM, Multiple Contact Miscibility process is where the miscibility is generated through in situ composition changes between oil and displaced fluid. MCM process is classified into vaporization, extraction or condensation. Vaporization or extraction occurs when hydrocarbon components from oil are being transferred to gas injection. On the other hand, when components in gas injection are transferred to oil in order to achieve miscibility, the process will be called condensation.

2.3 Factors Affecting Displacement Efficiency of Miscible Processes

Reasons of failure miscible injection recovery are due to improper pattern, excessive reservoir heterogeneity and insufficient pressure to attain miscibility (Crosby, 1969). In achieving miscibility, sweep efficiency is important.

1. Microscopic Displacement Efficiency (without mobile water)

In secondary recovery, the miscible displacement process takes place when IFT is vanished between oil and solvent. The efficiency of displacement is not totally 100% due to several factors such as dispersion and mixing at the microscopic level and also due to the phase behavior.

2. Macroscopic Displacement Efficiency (without mobile water)

Four major factors that affect macroscopic displacement efficiency are:

- Mobility ratio
- Viscous fingering
- Gravity segregation
- Reservoir heterogeneity

2.4 Carbon dioxide flooding

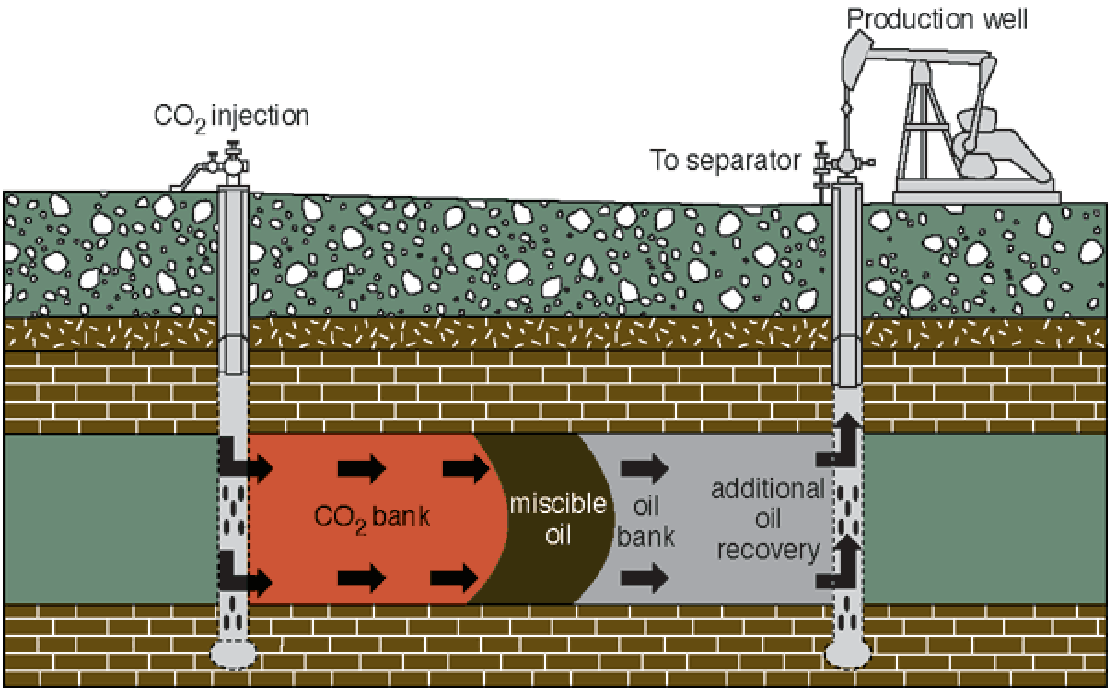


Fig 3 Carbon dioxide flooding process

Advantages of carbon dioxide flooding:

- Reduce oil viscosity and increase mobility ratio
- Reduction in residual oil saturation
- Increase recovery by approximately 25% over water flooding
- Miscibility can be achieved at low pressure
- Aids recovery through solution gas drive
- Miscibility can be regenerated

Disadvantages of carbon dioxide flooding

- Availability of the gas
- Transportation cost
- Corrosion
- Poor sweep and gravity segregation under certain condition
- Viscous fingering
- Can lead to deposition of heavy hydrocarbon

2.5 Nitrogen gas injection

It can enhance oil recovery by several mechanisms which are:

- Pressure maintenance

  To keep pressure above bubble point or dew point

- Immiscible displacement

  Effective if mobility ratio is favorable and the process allow gravity segregation between oil and gas injection to occur.

- Miscible displacement

  Depend on the condition of pressure, temperature and properties of injected gas and oil.

Advantage of inert gas (nitrogen):

i. Low cost
ii. Reliable of supply
iii. Prevent from oil encroachment into the gas cap if gas cap is present
iv. Higher recoveries than water flooding in low permeability reservoir
v. Residual inert gas in abandonment

2.6 Properties of gas injection (Nitrogen and Carbon dioxide)

Under reservoir condition, each type of gas has a different behavior.

- Usually nitrogen is more viscous than carbon dioxide. Hence, the displacement efficiency is higher using carbon dioxide. Up to 4000 psia, the viscosity of nitrogen increase with increment of temperature.
- Nitrogen is less soluble in oil compare to carbon dioxide.
- Nitrogen is recommended to be used as miscible gas injection at elevated pressure.

Physical properties of gas injection

Carbon Dioxide		Nitrogen	
Formula	CO2	Formula	N2
Molecular Weight (lb/mol)	44.01	Molecular Weight (lb/mol)	28.01
Critical Temp. (°F)	87.9	Critical Temp. (°F)	-232.5
Critical Pressure (psia)	1071.0	Critical Pressure (psia)	492.3
Boiling Point (°F)	-109.2	Boiling Point (°F)	320.5
Melting Point (°F)	-69.9	Melting Point (°F)	-345.9
Psat @ 70°F (psia)	852.8	Gas Density @ 70°F 1 atm (lb/ft3)	0.0725
Liquid Density @ 70°F (lb/ft3)	47.64	Specific Volume @ 70°F 1 atm (ft3/lb)	13.80
Gas Density @ 70°F 1 atm (lb/ft3)	0.1144	Specific Gravity	0.967
Specific Volume @ 70°F 1 atm (ft3/lb)	8.74	Specific Heat @ 70°F (Btu/lbmol-°F)	6.97
Specific Gravity	1.555		
Specific Heat @ 70°F (Btu/lbmol-°F)	8.92		

2.7 Factors Affecting MMP

Generally, high MMP is due to the high density and molecular weight of oil. It is also increase along with increment in temperature.

- Reservoir fluid composition

Lighter hydrocarbon components in the oil will result in lower value of MMP and heavier components caused the MMP to be higher. Alston et al. (1985) stated that miscibility is affected by oil composition especially C_{5+}. Meanwhile, types of hydrocarbon in the range of C_5 to C_{30} fractions of the crude oil reported will affect MMP value (Holm and Josendal, 1974).

- Gas composition

Lean gas (methane, nitrogen, flue gas and etc.): in vaporizing gas drives, as it travels through the reservoir, it vaporizes methane through LPG components from the crude oil. When displacing gas sufficiently vaporized hydrocarbon, miscibility will be achieved. It has been reported by Glaso in 1987, even small impurities will effect MMP.

Methane and nitrogen gas is less miscible compare to carbon dioxide. Impurities such as H_2S and Sox will result in lower MMP meanwhile presence of C_1 and N_2 can caused higher value of MMP.

- Reservoir temperature and pressure

Reservoir temperature will effect in determine MMP according to Alston et al. (1985). Higher reservoir temperature will result in higher value of MMP. Miscibility also will be affected by the pressure of the reservoir, as the pressure increase, MMP will be higher.

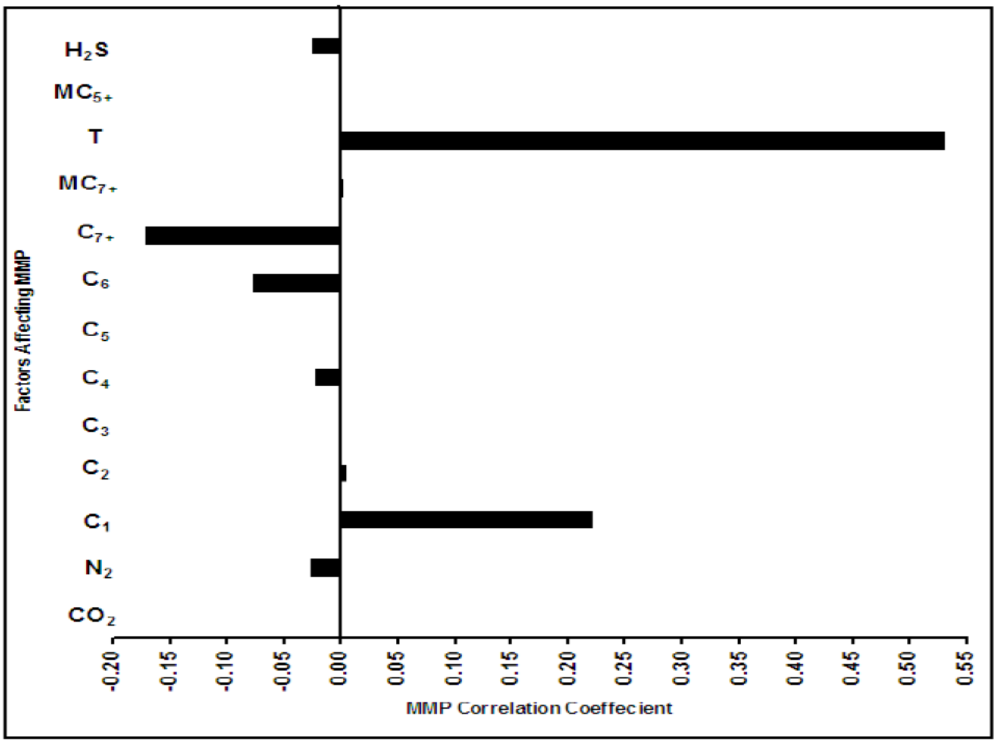


Fig 4 Effect of different variables on MMP (Osamah et al, 2011)

2.8 Experimental Measurement of MMP

1. Slimtube measurement

Slimtube-displacement experiment is the most commonly used approach (Yelling and Metclafe 1980; Holm and Josendal 1982). Slim tube is designed to create an environment where viscous fingering is eliminated or minimized by transverse dispersion (Stalkup F.I.1992). The slimtube is long, usually between 5 to 20 feet and narrow tube packed with glass beads or sand.(Elsharkawy et al.1992). This method comes close to one dimensional displacement. The common criteria in determine the MMP are 80% recovery at gas breakthrough (Holm and Josendal 1974).

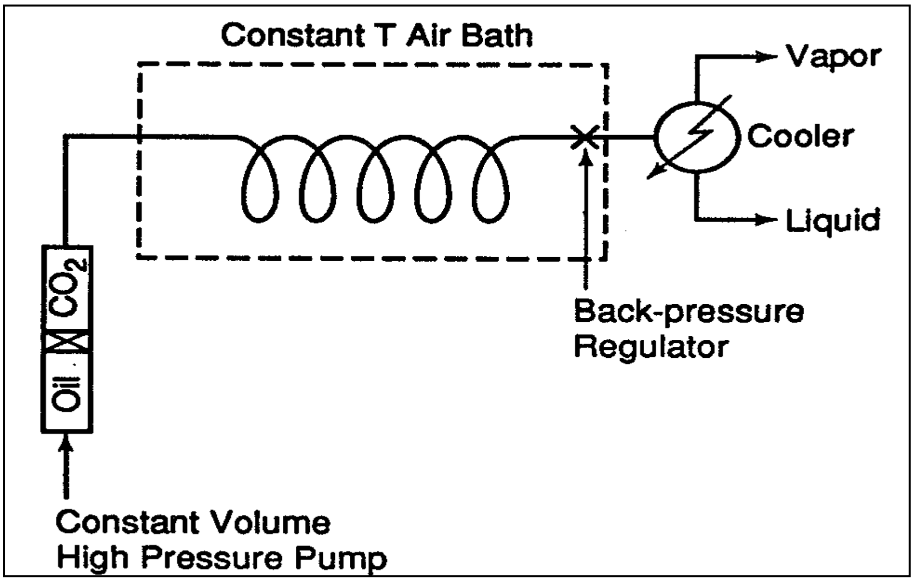


Fig. 5 Schematic of slim tube apparatus

The slim tube is typically consists of a stainless steel tube which packed uniformly with fine grade sand or glass beads. The wall effect is negligible causes the ratio of particle size to tubing diameter is sufficiently small. The tube is coiled horizontally so the gravity effect can be neglected. Pump functioning as to force fluids through the porous medium pack and the pressure is controlled by back pressure regulator. Fluid collection and measurement system are provided at the end of tube.

2. Rising Bubble

Rising bubbles apparatus (RBA) experiment is the basis of a method in determine MMP (Chritiansen and Haines 1987). RBA method is recognized as one of the cheapest method and fast alternative in determines MMP (Christiansen and Haines 1987). The shape and size of the bubbles produce from this technique is pressure dependence. This method requires only small amount of crude oil and gas (Elsharkawy, A.M. et al 1996).

RBA consist of a flat glass tube with high pressure sight gauge in a temperature controlled bath. Behavior can be observed through sight gauge. Above MMP, the behaviors of bubbles are quite distinctive. The bubbles change in shape as it rises and disperse into the oil. Below MMP, the bubble will retain its spherical shape as it rises but the size become smaller due to the mass transfer between oil and gas injected.

3. Vanishing IFT

VIT technique has been reported for rapid and cost effective estimation of MMP (Rao, 1997). It consists of high pressure and high temperature cell filled with injection gas. Then a drop of crude oil will be introduced into the cell through the capillary tube (Rao and Lee 2002). The original experiment has been modified by Ayirala and Rao (2006) whereby the overall composition in the cell is kept constant and the IFT is measured through capillary method and shape analysis of hanging drop.

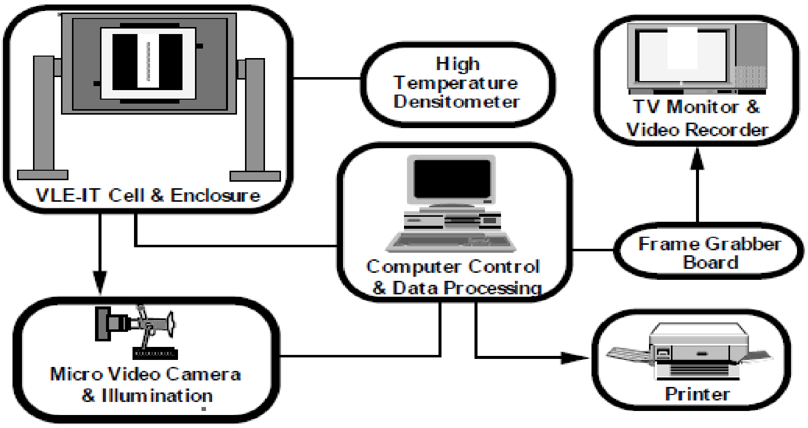


Fig. 6 major components in VIT experiment

Two methods are usually used in the IFT measurements which are drop volume technique and pendant drop technique.

i. Drop volume technique

In this technique it requires running the variable volume chambers of the equipment at slow rates.

$$\text{Volume of a drop, } V_d = flow\ rate \times [\frac{time}{number\ \ of\ drops}]$$

$$\text{IFT, } \sigma = [V_d\ (\rho_1 - \rho_2)g_c.F/r]$$

ii. Pendant drop method

The image of the drop hanging from the tip is captured and analyzed.

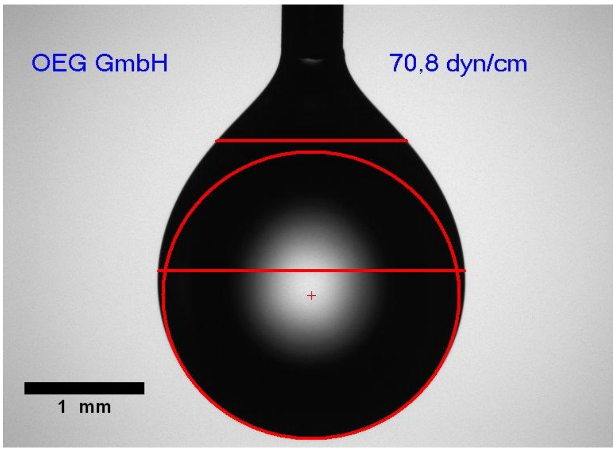


Fig. 7 Image of pendant drop from IFT measurement

Interface profile is constructed from mathematically derived curve that satisfies the Laplace capillary equation.

$$\sigma(1/R_1 + 1/R_2) = \Delta P$$

ΔP = Pressure difference across the interface surface of pendant drop

R_1, R_2 = Two principles radii of curvature

4. Correlation

Empirical methods are the different correlation based prediction methods in determine MMP. Different correlations have been developed by researchers in the literature review in predicting the value of MMP (Yelling and Metcalfe 1980). The correlations usually differ in the parameters that have been used in develop it. The following is the brief explanation on several correlations.

Cronquist (1978) – the correlation is based on three parameters which are reservoir temperature, molecular weight of C_{5+} and mole percent of C_1. it covers wide range of API and temperatures

Johnson and Pollin (1981) – parameters used are oil gravity, average molecular weight of oil, gas composition and temperature. The correlation covers wide range of API, pure and dilutedCO_2.

Yelling and Metcalfe (1980) – temperature is the only parameters used in this correlation. They also suggested the MMP of CO_2 should be higher than bubble point pressure of reservoir.

Eakin and Mitch (1988) – it is the generalized correlation for CO_2, N_2 and LPG.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In the early stage of the project which is in FYP 1, in order to further understand the project and the problem statement, researching, data gathering and literature reviews have been done. The objective of the research work mainly is to fully understand and increase the knowledge in enhanced oil recovery, minimum miscibility pressure and also the methodology that can be used to determine the MMP with the best gas injection to determine it.

In order to precede with the IFT experiments and measurement, first and foremost the density of the gas injections and the crude oil need to be obtained. The density of the gas injection which is nitrogen and carbon dioxide are obtained from the standard property table at different temperatures and pressures. Meanwhile, the densities of the crude oil (Angsi and Dulang) are determined through Anton Paar Density Meter. In this part, the crude oil density is taken at different temperatures and later it is extrapolated to the reservoir temperature in graph of temperature against density.

Last but not least, by using Interfacial Tensometer, the IFT between the crude oil and gas injections are measured at reservoir temperature and varying pressure. In order to determine the MMP of the crude oil, the IFT is then plotted as a function of pressure and extrapolated to zero IFT.

3.1.1 Density Measurement

In this experiment, there will be two densities that will be needed before proceeding to the next stage which are density of Angsi and Dulang light oil samples. The density of the crude oil is needed in the VIT experiment since the value is necessarily in obtaining the IFT.

Procedure:

1. Crude oil sample is prepared by heating and stirring before drawing some into a 3ml syringe.
2. The density meter is turned on and crude oil is injected into the density meter until the U-tube in the density meter is filled all the way.
3. Ensure that there is no air bubble in the U-tube of the density meter.
4. From the GUI, the temperature is set to start from 40°C to 89°C. The density is recorded for every increment of 10°C and the density of the oil experimented will be obtained through extrapolation to the reservoir temperature of the oil.

Fig. 8 Anton Paar Density Meter 4500M

3.1.2 Interfacial Tension Measurement

In this experiment, Interfacial Tensometer IFT700 is used to measure interfacial tension between the oil and gas injected. Pendant drop technique has been used in order to determine the interfacial tension value.

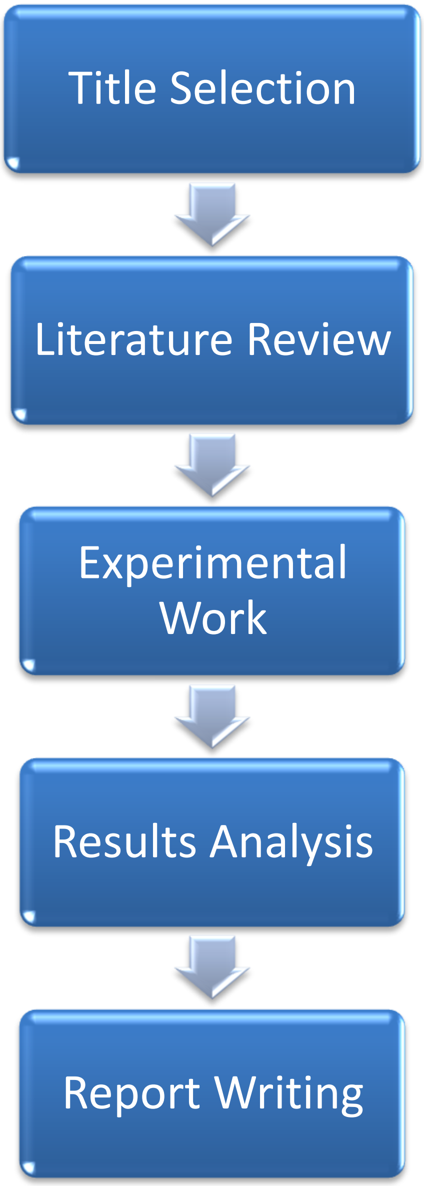
Fig 9 Interfacial Tensometer IFT 700

Procedure

1. The equipment is setup for a pendant drop, where the capillary injector is plugged at the top of the cell.
2. Temperature of the accumulator and cell are set to reservoir temperature. Alarm is set 5°C above the reservoir temperature.
3. Gas to be injected is placed on the right inlet valve, while the crude oil sample is injected into the left side.
4. After reaching the desired temperature, the pressure is increased slowly to the desired test pressure by injecting the gas.
5. By using hand pumps, a drop of crude oil is then produced.

6. Video settings are carried out from the Workshop menu.
7. Density of oil and gas are keyed in the software measurement setup. Frontier setup and one image analysis are also attuned.
8. Measurements for IFT are then run for 30 seconds. For every second, there will be an IFT computed. .
9. Step 4 is repeated for different test pressures, while Step 5 is repeated for every new drop produced.
10. Experiment is repeated using different type of gas and crude oil.

3.2 Project Activities



3.3 Gantt Chart

FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								Mid-semester break							
2	Preliminary Research Work															
3	Submission of Extended Proposal															
4	Proposal Defence															
5	Project work continues															
6	Submission of Interim Draft Report															
7	Submission of Interim Report															

FYP2

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues								Mid-Semester Break								
2	Submission of Progress Report																
3	Project Work Continues																
4	Pre-SEDEX																
5	Submission of Draft Report																
6	Submission of Dissertation (soft bound)																
7	Submission of Technical Paper																
8	Oral Presentation																
9	Submission of Project Dissertation (Hard Bound)																

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Oil Density Measurement

4.1.1 Dulang Oil Density

Table 1: Dulang Oil Density

Temp (^{o}C)	**Density (g/cm^3)**
40	0.8294
60	0.8191
70	0.8126
80	0.8061
85	0.8031
89	0.8005

Dulang reservoir temperature is 102^{o}C, therefore extrapolation from the graph of density versus temperature is needed.

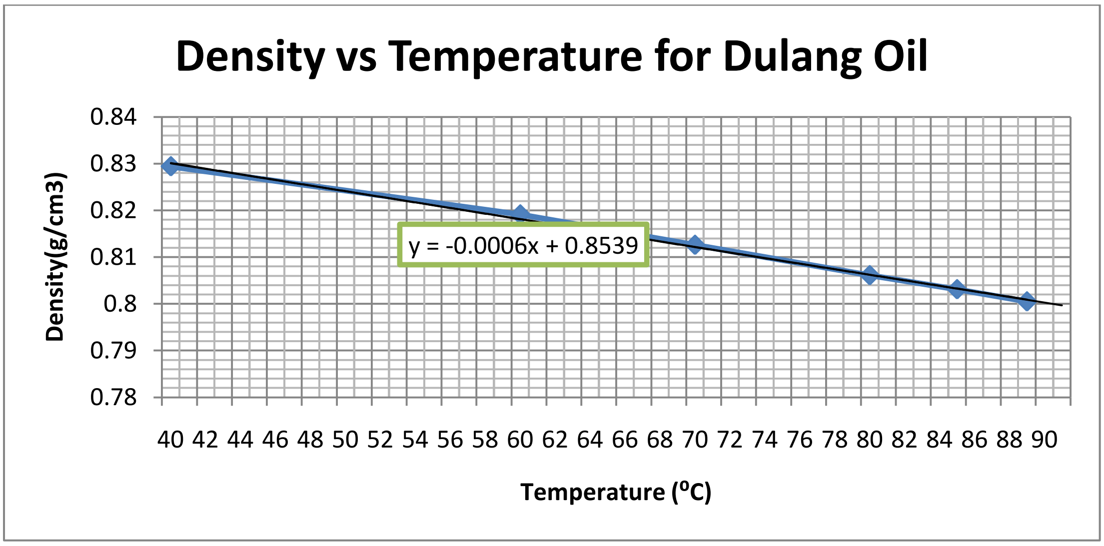


Fig. 10 Density vs Temperature for Dulang oil

Density of Dulang crude oil at 102^{o}C is **0.793g/cm^3**.

4.1.2 Angsi Oil Density

Table 2: Angsi oil density

Temp (°C)	**Density (g/cm^3)**
60	0.7898
70	0.7832
80	0.7765
85	0.7731

Angsi reservoir temperature is 119°C, therefore the extrapolation of graph density versus temperature is needed to determine the density of the crude oil.

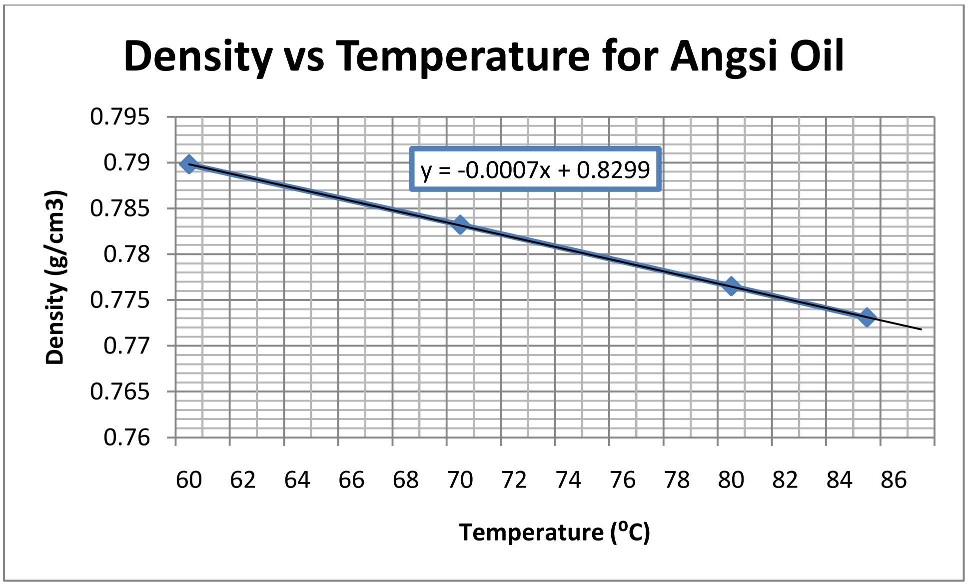


Fig 11 Density vs Temperature for Angsi oil

The Angsi crude oil density at 119°C is **0.7466g/cm^3.**

4.1.3 Oil Composition (Juan, 2012)

Table 3: Dulang Oil Composition

Dulang oil composition	
component	mol%
CO2	20.743
N2	0.109
C1	15.062
C2	3.007
C3	2.71
iC4	1.032
nC4	0.854
iC5	0.415
nC5	0.283
C6	2.917
C7	2.833
C8	1.285
C9	2.47
C10	2.357
C11+	43.923

Table 4: Angsi Oil Composition

Angsi oil composition	
component	mol%
CO2	1.91
N2	0.15
C1	35.83
C2	7.24
C3	6.26
Ic4	2.82
nC4	2.1
iC5	1.75
nC6	1.14
C6	2.96
C7	3.9
C8	5.69
C9	4.1
C10	3.7
C11	3.04
C12+	17.41

4.2 IFT measurement

4.2.1 Dulang IFT with carbon dioxide (CO_2) gas injection

Table 5: Dulang IFT using CO2 injection

Dulang ift using CO2						
pressure	800psi		1200psi		1600psi	2000psi
attempt	1	2	1	2	1	1
Measured IFT over time	14.34	14.48	11.9	11.8	9	6.3
	14.37	14.58	11.93	11.88	9.04	6.64
	14.48	14.69	11.84	11.81	9.16	6.44
	14.49	14.38	11.83	11.78	9.05	6.21
	14.46	14.59	11.91	11.77	9.06	6.41
	14.42	14.52	11.94	11.77	8.97	6.42
	14.39	14.49	11.96	11.84	8.93	6.16
	14.51	14.81	11.93	11.75	9	7.29
	14.5	14.69	11.9	11.72	8.97	6.25
	14.42	14.43	11.92	11.73	9.02	6.72
	14.44	14.51	11.92	11.67	9.03	6.37
	14.47	14.57	11.91	11.75	9.01	6.51
	14.55	14.12	11.89	11.77	8.65	6.45
	14.46	14.24	11.9	11.79	9.03	6.48
	14.42	14.62	11.83	11.79	8.98	6.7
	14.48	14.39	11.95	11.74	9.01	6.49
	14.39	14.41	11.82	11.8	8.96	6.55
	14.38	14.33	11.86	11.79	8.93	6.61
	14.45	14.54	11.93	11.74	9.01	6.42
	14.35	14.44	11.86	11.74	8.99	5.95
	14.52	14.37	11.89	11.83	8.92	6.35
	14.44	14.69	11.87	11.78	8.98	6.74
	14.48	14.54	11.86	11.85	8.98	6.51
	14.44	14.26	11.93	11.75	8.89	6.5
	14.45	14.62	11.9	11.76	8.97	6.56
	14.47	14.65	11.88	11.74	8.98	6.53
	14.59	14.46	11.9	11.78	9.01	6.28
	14.5	14.42	11.83	11.74	9	6.38
	14.58	14.31	11.86	11.81	9.01	7.21
average	14.45655	14.48793	11.89138	11.77483	8.984138	6.497586
average 2	14.47224138		11.83310345			

Table 6 Dulang IFT using CO2 at different pressures.

Pressure(psia)	800	1200	1600	2000
IFT(N/m)	14.4722414	11.8331	8.984138	6.497586

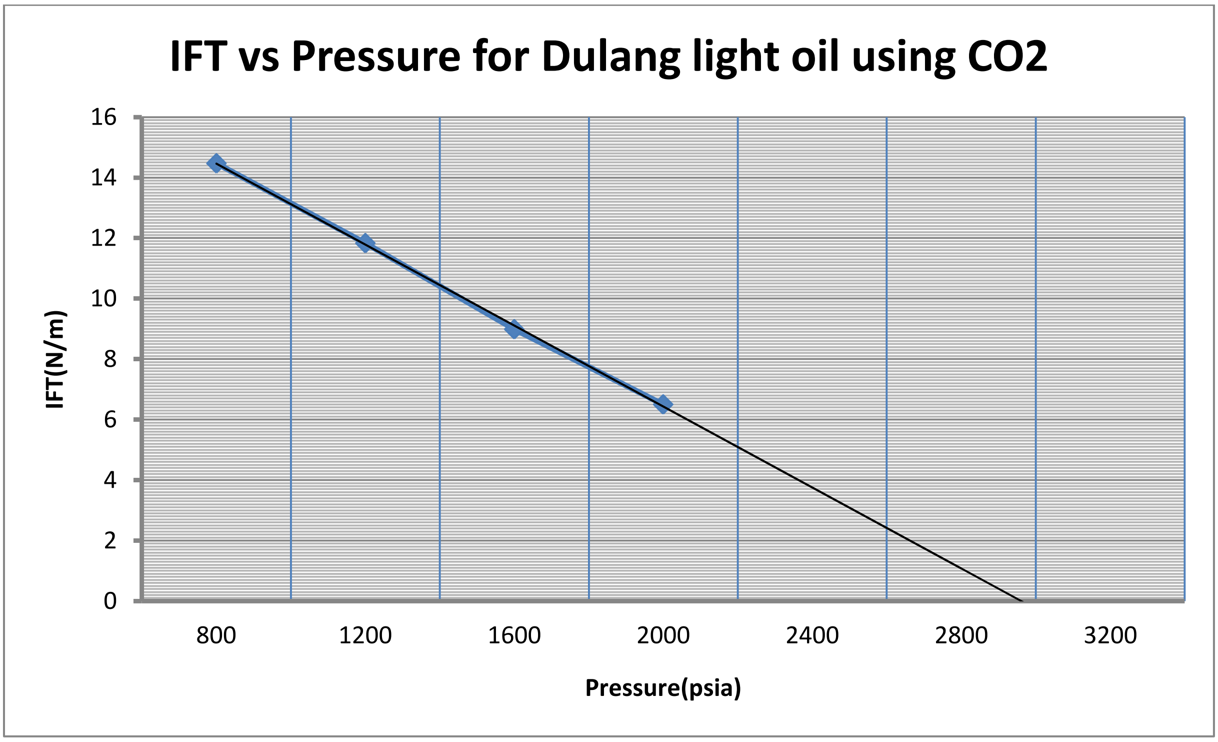


Fig 12 IFT versus pressure of Angsi oil using CO2

In order to find the value of MMP, extrapolation to zero IFT from the IFT vs Pressure graph is needed.

Therefore from the above graph and through the extrapolation MMP of Dulang crude oil using carbon dioxide as the gas injection is 2957psi.

4.2.2 Angsi IFT using carbon dioxide (CO_2) injection

Table 7: Angsi IFT using CO2

Angsi IFT using CO2									
Pressure	800		1600	2000			2400		
Attempt	1	2	1	1	2	3	1	2	3
Measured IFT over time	10.79	10.69	7.52	7.44	4.55	5.23	3.84	16.22	3.7
	10.85	10.7	9.92	5.56	4.62	5.46	3.68	3.49	3.67
	11.03	10.71	8.67	6.75	4.94	5.47	3.69	3.73	3.83
	10.73	10.86	8.81	6.6	4.84	4.91	3.73	3.6	3.83
	11.05	10.83	8.19	8.62	4.77	4.47	3.82	3.89	3.89
	11.12	11.19	8.2	4.38	5.1	4.75	3.64	3.59	3.7
	11.1	10.9	8.81	6.44	4.98	5.65	3.7	3.31	3.95
	11.14	11.12	10.32	8.21	4.92	4.93	3.47	3.51	3.43
	10.87	11.16	8	6.35	6.26	4.69	3.49	3.79	3.43
	11.27	10.97	8.84	6.2	5.65	4.63	3.8	3.6	3.61
	11.06	11.17	8.51	5.01	4.47	5.21	3.71	3.55	3.75
	11.15	11.28	7.7	4.97	5.07	5.11	3.73	3.67	3.66
	11.29	11.65	8.06	4.2	5.2	4.95	3.84	3.67	3.95
	11.89	11.32	8.81	5.53	4.88	5.02	3.74	3.69	3.74
	11.21	11.16	8.32	3.44	4.66	5.2	3.63	3.61	4.12
	11.14	11.38	7.53	3.92	5.17	4.97	3.65	3.71	4.05
	11.19	11.19	8.08	3.83	4.97	4.79	3.67	3.66	3.9
	11.25	11.08	7.45	4.3	5.37	5.48	3.77	3.85	3.46
	11.24	11.38	7.86	3.35	5.3	5.65	3.81	3.77	4.16
	11.18	11.32	7.83	4.38	5.64	5.33	3.84	3.8	3.7
	11.46	11.29	8.05	3.79	5.45	6.29	3.51	3.9	3.71
	11.61	11.11	9.16	3.79	5.46	5.72	3.47	3.83	3.85
	11.41	11.38	7.83		5.48	5.85	3.72	3.69	3.76
	11.52	11.14	8.91	4.03	5.41	5.4	3.85	3.75	3.99
	11.18	11.48	7.97	4.46	5.66	6.02	3.71	3.71	3.62
	11.48	11.47	7.18	7.11	5.78	6.05	3.64	3.67	3.74
	11.54	11.39	7.5	2.08	4.9	5.65	3.85	3.56	3.61
	11.23	11.38	6.97	4.11	5.45	5.74	3.93	3.84	3.98
	11.65	11.18	7.47	3.19					
Average	11.22862	11.16828	8.223103	5.072857	5.176786	5.307857	3.711786	4.130714	3.778214
Average2	11.19844828		8.247348	5.185833333			3.873571429		

Table 8 Angsi IFT using CO_2 at different pressures.

Pressure(psia)	800	1600	2000	2400
IFT(N/m)	11.19845	8.247348	5.185833	3.873571

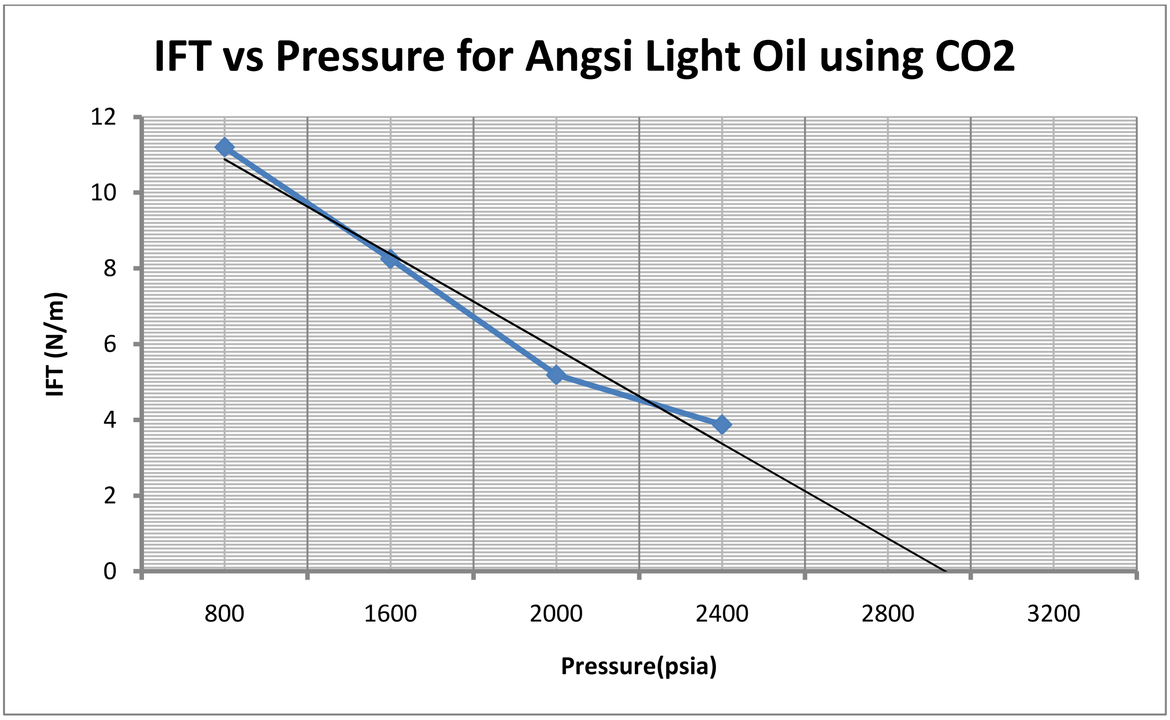


Fig 13 IFT versus Pressure for Angsi using CO_2

In order to determine the value of MMP of Angsi crude oil using carbon dioxide injection, extrapolated to zero IFT is needed from IFT versus pressure graph.

Based on the extrapolation, the value of MMP for Angsi using CO_2 is 3077psi.

4.2.3 Dulang IFT using Nitrogen (N2) gas injection

Table 9: Dulang IFT using nitrogen

Dulang ift using N2						
pressure	800psi			1200psi		
attempt	1	2	3	1	2	3
Measured IFT over time	17.43	17.24	17.37	15.86	15.84	15.96
	17.56	17.5	17.45	15.4	15.84	15.85
	17.5	17.19	17.44	15.15	15.58	15.78
	17.43	17.27	17.3	15.85	15.97	15.93
	17.41	17.36	17.42	15.42	15.13	15.04
	17.25	17.32	17.31	15.75	15.28	15.86
	17.43	17.28	17.31	15.32	15	15.82
	17.39	17.31	17.4	15.99	15.05	15.91
	17.49	17.44	17.32	15.04	15.04	15.02
	17.46	17.36	17.18	15.25	15.31	15.88
	17.36	17.5	17.47	15.54	15.15	15.15
	17.43	17.28	17.29	15.67	15.12	15.21
	17.39	17.56	17.45	15.75	15.83	15.18
	17.4	17.5	17.45	15.83	15.04	15.21
	17.34	17.39	17.36	15.41	15	15.26
	17.44	17.41	17.36	15.63	15.45	15.1
	17.45	17.37	17.41	15.77	15.95	15.91
	17.48	17.34	17.53	15.82	15.97	15.82
	17.53	17.38	17.33	15.68	15.96	15.81
	17.47	17.36	17.27	15.58	15.11	15.14
	17.49	17.41	17.53	15.78	15.32	15.87
	17.52	17.17	17.48	15.88	15.11	15.03
	17.46	17.44	17.59	15.51	15.93	15.92
	17.42	17.16	17.26	15.62	15.13	15.98
	17.48	17.34	17.46	15.57	15.94	15.89
	17.47	17.4	17.26	15.69	15.17	15.84
	17.43	17.32	17.44	15.44	15.93	15.71
	17.34	17.27	17.51	15.69	15.01	15.64
	17.42	17.34	17.45	15.94	15.84	15.8
average	17.4369	17.35207	17.3931	15.61483	15.44828	15.60414
average 2	17.194022299			15.5910313		

Table 10: Dulang IFT using Nitrogen

Dulang ift using N2							
1600psi				2000psi			
1	2	3	4	1	2	3	4
15.66	14.68	14.55	14.73	12.16	12.22	12.27	12.39
14.67	14.74	14.54	14.41	12.96	12.32	12.09	12.34
14.59	14.7	14.37	14.59	12.5	12.31	12.21	12.35
14.74	14.68	14.47	14.46	12.16	12.28	12.3	12.37
14.48	14.76	14.57	14.4	12.25	12.22	12.26	12.26
14.52	14.43	14.49	14.73	12.14	12.22	12.24	12.34
14.7	14.64	14.48	14.63	12.36	12.28	12.17	12.25
14.59	14.57	14.61	14.61	12.21	12.21	12.16	12.39
14.75	14.73	14.52	14.78	12.11	12.22	12.01	12.25
14.39	14.56	14.4	14.56	12.51	12.26	12.17	12.39
14.69	14.57	14.63	14.7	12.34	12.25	12.07	12.35
14.46	14.59	14.48	14.54	12.36	12.31	12.08	12.24
14.82	14.63	14.4	14.58	12.16	12.32	12.04	12.35
14.64	14.51	14.62	14.64	12.86	12.27	12.05	12.34
14.64	14.58	14.65	14.58	12.23	12.21	12.32	12.35
14.61	14.6	14.56	14.57	12.24	12.19	12.14	12.29
14.5	14.63	14.59	14.65	12.16	12.15	12.2	12.36
14.56	14.66	14.5	14.74	12.11	12.28	12.22	12.38
14.5	14.63	14.62	14.84	12.2	12.28	12.27	12.32
14.57	14.74	14.62	14.61	12.2	12.26	12.09	12.35
14.67	14.62	14.58	14.45	12.03	12.35	12.37	12.35
14.59	14.65	14.56	14.57	12.09	12.26	12.17	12.36
14.36	14.59	14.45	14.61	12.85	12.26	12.18	12.23
14.6	14.66	14.68	14.4	12.34	12.13	12.1	12.34
14.67	14.5	14.63	14.54	12.9	12.23	12.22	12.24
14.73	14.63	14.45	14.56	12.25	12.12	12.1	12.47
14.74	14.57	14.37	14.51	12.04	12.17	12.15	12.37
14.55	14.65	14.67	14.46	12.1	12.08	12.09	12.19
14.72	14.65	14.43	14.47	12.02	12.15	12.13	12.08
14.64517	14.62586	14.53414	14.58345	11.928	12.23483	12.16793	12.32034
14.20053517				12.09611586			

Table 11 Dulang IFT using N2 at different pressures.

Pressure(psia)	800	1200	1600	2000
IFT (N/m)	17.19402	15.59103	14.20053	12.09611

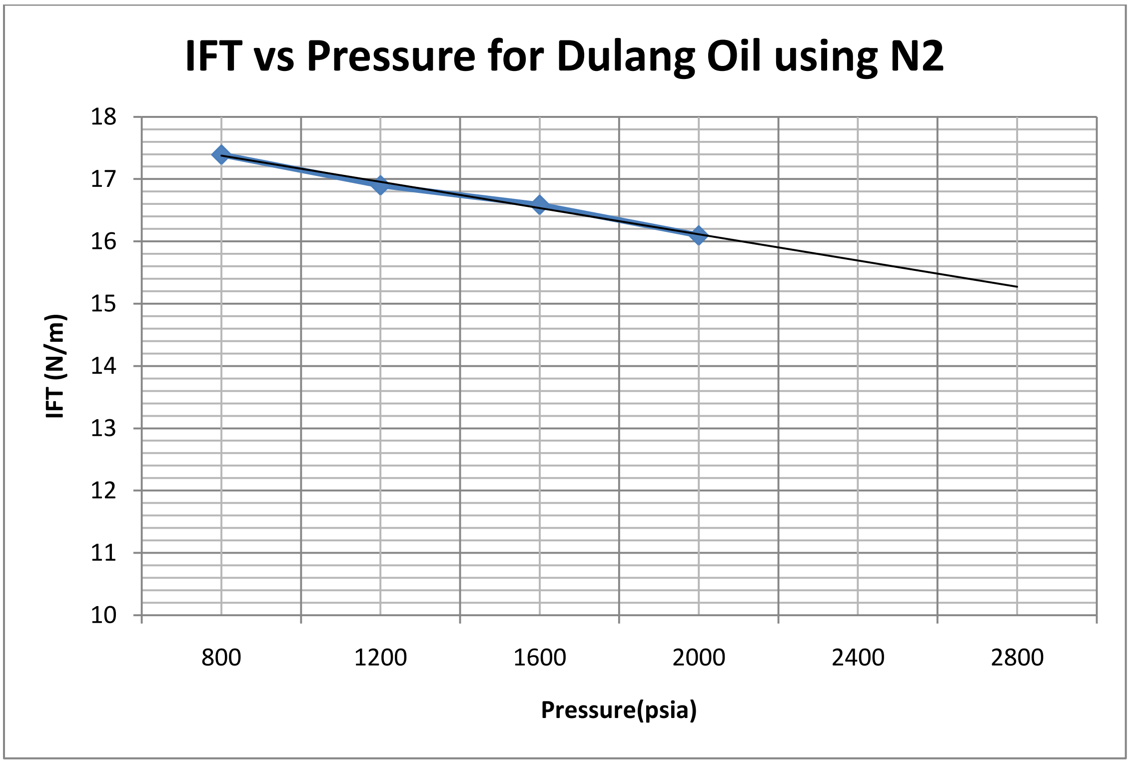


Fig 14 IFT vs Pressure for Dulang Oil using N2

4.2.4 Angsi IFT using Nitrogen (N2) gas injection

Table 12: Angsi IFT using Nitrogen

pressure	800psi				1200psi			
attempt	1	2	3	4	1	2	3	4
Measured IFT over time	16.11	16.01	16.04	16.13	13.62	13.5	13.81	13.48
	16.09	16.26	16.21	16.2	13.63	13.52	13.66	13.59
	16.12	16.2	16.13	16.18	13.54	13.49	13.85	13.72
	16.26	16.3	16.21	16.16	13.64	13.6	13.65	13.64
	16.42	16.28	16.24	16.06	13.6	13.61	13.43	13.64
	16.25	16.26	16.14	16.11	13.5	13.73	13.78	13.66
	16.28	16.15	16.22	16.09	13.56	13.46	13.61	13.66
	16.08	16.06	16.14	16.22	13.69	13.53	13.89	13.68
	16.25	16.1	16.1	16.07	13.68	13.54	13.8	13.72
	16.22	16.2	16.18	16.23	13.58	13.54	13.69	13.62
	16.14	16.2	16.03	16.08	13.58	13.61	13.71	13.7
	16.11	16.26	16.08	16.08	13.63	13.54	13.66	13.61
	15.99	16.16	16.1	16.03	13.65	13.5	13.72	13.63
	16.19	16.17	16.15	16.07	13.69	13.48	13.97	13.61
	15.99	16.04	16.25	16.01	13.63	13.51	13.54	13.7
	16.23	16.17	16.14	15.98	13.6	13.52	13.65	13.63
	15.97	16.22	16.21	15.99	13.71	13.51	13.81	13.54
	16.12	16.23	16.24	16.05	13.6	13.37	13.78	13.73
	16.11	15.97	16.1	16.17	13.64	13.57	13.56	13.68
	16.29	15.99	16.11	16.13	13.82	13.42	13.6	13.65
	15.85	15.88	16.2	16.1	13.5	13.58	13.85	13.65
	16.1	16.26	16.16	15.96	13.52	13.44	13.73	13.65
	16.02	16.04	16.32	16.1	13.52	13.46	13.61	13.64
	16.05	16.13	16.12	16.04	13.71	13.61	13.7	13.57
	16.03	16.09	16.26	16.14	13.55	13.5	13.77	13.54
	16.11	16.15	16.28	15.97	13.65	13.54	13.62	13.67
	16.07	16.1	16.22	16.23	13.63	13.52	13.73	13.56
	16.08	16.05	16.3	16.05	13.68	13.64	13.55	13.73
	16.34	16.12	16.25	15.93	13.66	13.6	13.87	13.66
average	16.13345	16.13966	16.1769	16.08828	13.62103	13.53241	13.71034	13.64
average 2	16.13457897				13.52595828			

Table 13: Angsi IFT using Nitrogen

pressure	1600				2000			
attempt	1	2	3	4	1	2	3	4
Measured IFT over time	12.26	12.26	12.32	12.32	11.77	11.07	11.08	11.13
	12.36	12.29	12.33	12.33	11.94	11.94	11.12	11.8
	12.32	12.34	12.15	12.15	11.91	11.65	10	11.02
	12.37	12.12	12.18	12.18	11.63	11.85	11.92	11.93
	12.32	12.4	12.28	12.28	11.97	10.88	11.89	11.79
	12.3	12.24	12.24	12.24	10.02	11.97	11.89	11.95
	12.31	12.28	12.33	12.33	11.2	11.05	11.93	11.1
	12.31	12.2	12.34	12.34	11.08	10.77	11.2	11.7
	12.31	12.3	12.3	12.3	11.29	11.63	11.16	11.06
	12.23	12.29	12.37	12.37	10.1	11.58	11.95	11.97
	12.27	12.24	12.29	12.29	11.08	11.87	11.97	10.8
	12.24	12.24	12.22	12.22	11.15	11.81	11.14	11.86
	12.37	12.24	12.23	12.23	10.16	10.6	11.38	11.76
	12.32	12.19	12.27	12.27	11.08	11.01	11.11	10.9
	12.32	12.12	12.18	12.18	11.03	11.82	10.15	12.27
	12.28	12.32	12.32	12.32	11.95	11.06	11.94	11.76
	12.42	12.39	12.24	12.24	11.19	11.85	11.26	12.03
	12.31	12.41	12.31	12.31	11.07	11.12	11.03	11.97
	12.36	12.18	12.24	12.24	11.81	10.69	11.11	11.89
	12.29	12.21	12.18	12.18	10.94	11.02	11.21	11.09
	12.28	12.2	12.35	12.35	11.06	11.89	10.07	11.83
	12.29	12.34	12.14	12.14	11.89	11.08	11.34	12.15
	12.27	12.38	12.2	12.2	11.95	11.84	11.98	11.95
	12.34	12.2	12.28	12.28	11.61	11.87	11.05	11.99
	12.31	12.29	12.34	12.34	11.92	10.7	11.78	11.79
	12.29	12.26	12.19	12.19	11.86	11.65	11.83	10.9
	12.38	12.18	12.38	12.38	11.06	10.7	11.76	11.86
	12.26	12.28	12.2	12.2	11.03	11.88	11.91	11.62
	12.32	12.27	12.39	12.39	11.92	11.84	11.89	12.33
average	12.31069	12.26414	12.26862	12.26862	11.33345	11.4031	11.38103	11.66207
average 2	12.37802724				11.0535379			

Table 14 Angsi IFT using N2 at different pressures.

Pressure(psia)	800	1200	1600	2000
IFT (N/m)	16.13457	13.52595	12.37802	11.05353

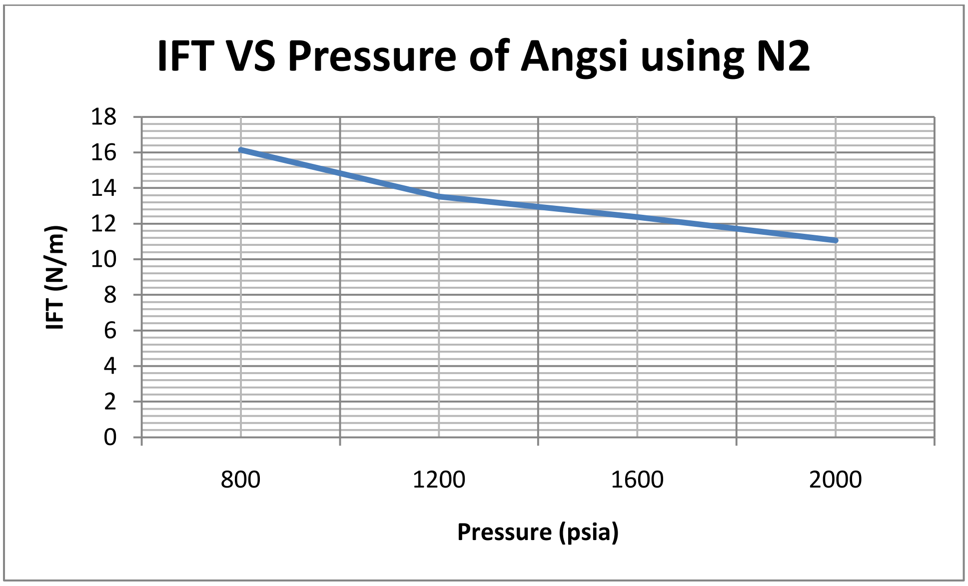


Fig 15 IFT vs Pressure for Dulang Oil using N2

4.3 Data Analysis

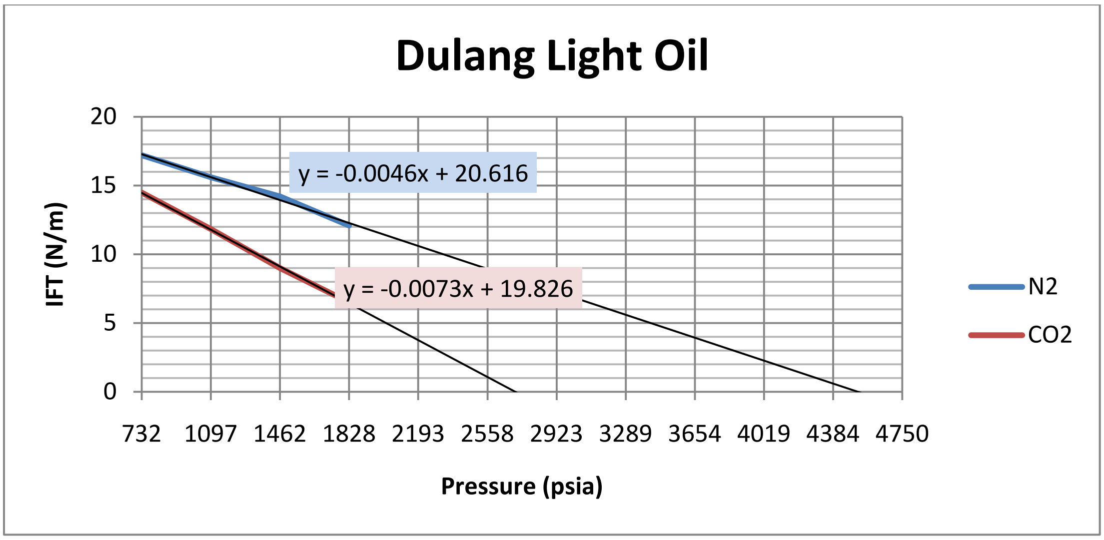


Fig 16 comparison of result for Dulang oil with different gases

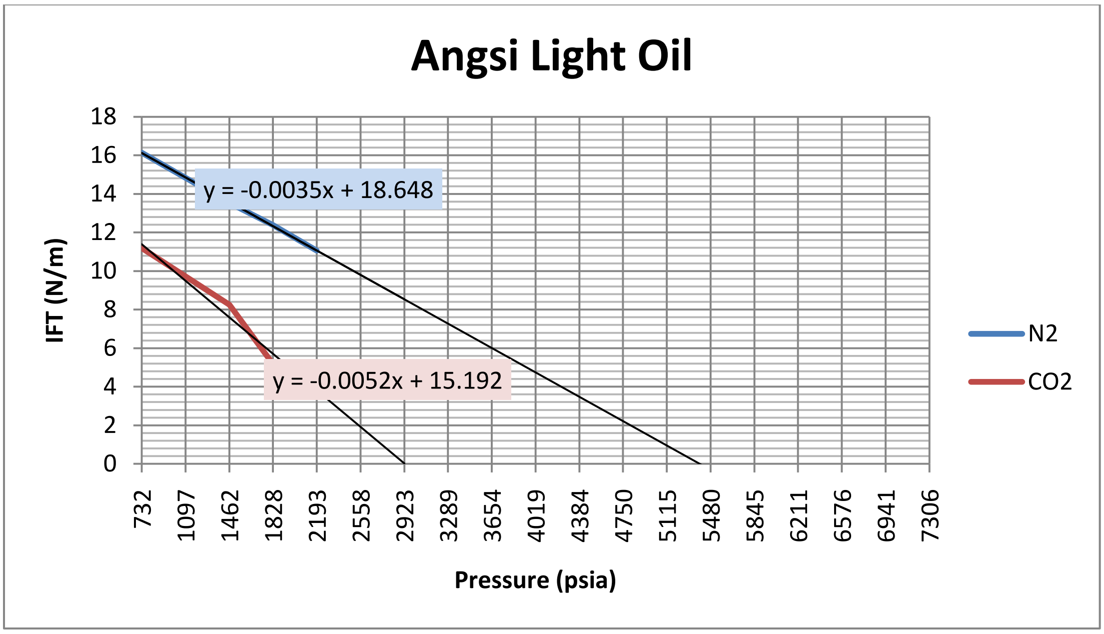


Fig 17 comparison of result for Angsi oil with different gases

Table 15 MMP of Dulang and Angsi for N2 and CO2

Gas injection	MMP(Dulang)	MMP (Angsi)
Carbon dioxide	2957	3077
Nitrogen	16881.83	17193.66

Carbon dioxide vs Nitrogen

Results show MMP for light oil when injected with carbon dioxide is much lower compare to using nitrogen as gas injection. The difference between both gases is approximately 10000 psia difference.

Dulang vs Angsi

Based on the Table 12, difference of result between Dulang and Angsi for carbon dioxide gas injection is ~120psia and for nitrogen gas injection ~300psia. Angsi has higher MMP compare to Dulang. Increment in MMP of using nitrogen gas injection on Angsi crude oil is higher than Dulang.

4.4 Discussion

Effect of oil composition

Based on gas chromatograph analysis in Table 3 and Table 4, it shows that Angsi has higher value of methane compare to Dulang. The MMP value for Angsi is higher compare to Dulang. According to Rathmaell, et al., (1971), the existence of volatile components such as methane in the crude oil leads to increase in MMP between oil and gas injected while the presence of intermediate components can reduce MMP. In addition, Alston et al, stated molecular weight of C_5^+ will affect MMP as well as C_1 and N_2 in miscibility process. Based on oil composition, Dulang has slightly higher composition of C_5^+ than Angsi which result in reduce in MMP value. Based on Holm and Josendal, (1982), the greater the concentration of extractable hydrocarbons in the oil, the lower the MMP.

Effect of reservoir temperature

Yellig and Metcalfe (1980) found that, the reservoir temperature has considerable effect on gas-oil MMP. MMP will increase steadily as temperature increase. VIT experiment is carried out at specific reservoir temperature for each crude oil. Experiment of Angsi is carried out at 119^{o}C and Dulang at 102^{o}C. As stated in Table 1 and Table 2, MMP of Angsi has greater value of MMP compare to Dulang.

Effect of gas used

CO_2 can achieve miscibility with the reservoir oil when it subjected to the favorable conditions of pressure and temperature. It helps in mobilized and produce residual oil trapped due to the capillary force. Generally, carbon dioxide will cause lower value of MMP compare to nitrogen. Carbon dioxide's density is high enough for it to be a good solvent for oil which contains significant amount of light hydrocarbon. On the other hand, nitrogen becomes an efficient miscible displacement in high pressure where the density is high enough to extract light hydrocarbon from the oil.

Correlation

Table 16 Published correlation results (Juan, 2012)

Correlation	Dulang (psia)	Error (%)	Angsi (psia)	Error (%)
VIT	2957.00		3077.00	
Cronquist	2741.69	7.28	3313.63	7.69
Glaso C2-C6>18%	2654.26	10.24	3191.35	3.72
Glaso C2-C6<18%	4778.57	61.60	5299.83	72.24
Alston LO	3361.29	13.67	4216.19	37.02
Alston STO	3059.86	3.48	3849.39	25.10
Yuan	3596.91	21.64	3993.40	29.78
Yellig and Metcalfe	2666.73	9.82	3054.80	0.72

Table 13 shows the correlation results for Dulang and Angsi oil for carbon dioxide gas injection. Percentage of error for Angsi is higher for almost all the correlations. Based on the results, the best correlation in represent Dulang crude oil is the correlation by Cronquist. The correlation is depending on reservoir temperature, molecular weight of C_{5+} and mole percentage of C_1. Meanwhile, for Angsi the best correlation is by Yellig and Metcalfe, percentage of error is only 0.72% but in this correlation the only parameter used is the reservoir temperature.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

MMP determination using VIT experimental method has been conducted on two Malaysian light oil samples which are Angsi and Dulang crude oil. The experiment has been carried out at 4 different test pressures (800, 1200, 1600, 2000 psia) with two different type of gases which are nitrogen and carbon dioxide. This study is carried out purposely to determine the gas injection that suits with light oil at reservoir temperature. Based on the results, it clearly shows carbon dioxide gives a lower MMP compare to nitrogen for both Angsi and Dulang light oil. Reservoir temperature, type of gases to be injected and composition of crude oil are three main factors that will determine MMP of the oil. Angsi has higher temperature compare to Dulang and results in higher value of MMP compare to Dulang. In term of oil composition, C_{5+} component in Dulang oil is higher than Angsi and result in lower MMP for Dulang in comparing with Angsi. On the other hand, Angsi has higher MMP due to presence of methane in Angsi is higher.

It is recommended to use different type of gases including LPG with different compositions in order to obtain lowest possible value of MMP for Dulang and Angsi light crude oil. Another recommendation is to use different methods in determine the MMP such as RBA and slimtube in order to reduce the percentage of error.

REFERENCES

1. Adel Elsharkawy, Adel Malallah, Osamah Alomair, 2011. An Accurate Prediction of CO2 MMP Using Alternating Conditional Expectation Algorithm (ACE). SPE 149086.
2. Ayirala, S. and Rao, D., 2006. Comparative Evaluation of a New MMP Determination Technique. In *Proceedings of SPE/DOE Symposium on Improved Oil Recovery*. SPE/DOE Symposium on Improved Oil Recovery. doi: 10.2118/99606-MS.
3. Christiansen, R.L and Haines, K.H. 1987. Rapid Measurement for Minimum Miscibility Pressure with the Rising Bubble Apparatus. SPE Reservoir Engineering 2 (4): 523-527. SPE 13114-PA.
4. Dadina N Rao.1997. Anew technique of Vanishing Interfacial Tension for Miscibility Determination. Fluid Phase Equilibria, 139,311-324 Elsevier Science.
5. Eakin, B.E and Mitch, F.J. 1988. Measurement and Correlation of Miscibility Pressures of Reservoir Oils. Paper SPE 18065 presented at the SPE Annual Technical Conference and Exhibition, Houston, 2-5 October
6. E Isharkawy. A. M.. Poettmann. F. 11. and Christiansen. R. L. (1992). Measuring minimum miscibility pressure : slim tube or rising bubbles method?. Proceeding of SPE/DOE Enhanced Oil Recovery Symposium, Soviety of Petroleum Engineers.
7. Emera K. M.and Sarma H. K. 2006. A Reliable Correlation to predict minimum miscibility pressure when C02 is diluted with other gases. SPE Reservoir Evaluation and Engineering, 366-377.
8. Emera K. M.and Sarma H. K. 2005. Use of genetic algorithm to estimate CO2-oil minimum miscibility pressure-a key parameter in design of C02, miscible flood. Journal of petroleum science and engineering 46, 37-56.
9. Glaso,O. (1985) Generalized Minimum Miscibility Pressure Correlation. SPE 12893
10. Holm, L.W., Josendal,V.A., “Mechanism of Oil Displacement by Carbon Dioxide”, Journal of Petroleum Technology p1427-1436.

11. Huang Y. F. ,Huang G. F,Dong, M.Z., and Feng G.M. 2003. Development of an artificial Neural Network for predicting minimum miscibility pressure in CO2 flooding. Journal of Petroleum Science and Engineering 37, 83-95.
12. Jessen. Kristian and Stenby, Erling, 2007. Fluid characterization for miscible EOR projects and CO2 Seqestration. SPE Reservoir evaluation and engineering 10(5).
13. Johnson, J.P.and Pollin, J.S. (1981). Measurement and Correlation of CO2 Miscibility Pressure SPE/DOE 9790.
14. Metcalfe, R.S. Fussel, D.D and Shelton,J.L., 1973. A multi-cell equilibrium separation model for the study of multiple contact miscibility in rich gas drive. Paper SPE 3995 presented at SPE-AIME 47th annual fall meeting, held in Sant Antonio.
15. Metcalfe, R.S and Yarborough, Lyman. 1979. The effect of pahse equilibriaon the CO2 displacement mechanism. SPE of petroleum engineers journal, 19(4).
16. Neau, E., Avaullee, L. and Jaubert J.N. 1996. A new algorithm for enhanced oil recovery calculations. Fluid Phase Equilibria 117, 265-272.Elsevier Science.
17. Rao, D.N., 1997. A New Technique of Vanishing Interfacial Tension for MiscibilityDetermination. *Fluid Phase Equilibria*, 139(1-2), pp.311-324. doi: 10.1016/S0378-3812(97)00180-5.
18. Rao, D.N. and Lee, J.I., 2002. Application of the New Vanishing Interfacial Tension Technique to Evaluate Miscibility Conditions for the Terra Nova Offshore project. *Journal of Petroleum Science and Engineering*, 35(3-4), pp.247-262. doi: 10.1016/S0920-4105(02)00246-2.
19. Stalkup, F.I. Displacement Behavior of the Condensing / Vaporizing Gas Drive Process. SPE1987,16715, 171-182.
20. Wang, Y. 1998. Analytical calculation if minimum miscibility pressure. PhD dissertation, Stanford University, Stanford, California.
21. Wei Yan, Michael L. Michlesen and Erling H. Stenby. 2012. Calculation of Minimum Miscibility Pressure usinf Fast Slimtube Simulation. SPE153758-MS
22. Wu, R.S. and Batycky, J.P 1990. Evaluation of Miscibility from Slim Tube Tests. Journal of Canadian Petroleum Technology 29, (6): 63-70.

23. Yelling W. F. and Metcalfe R.S. 1980. Determination and prediction of CO2 minimum miscibility pressure. Journal of Petroleum Technology,160-168.
24. Zick, A.A., 1986. A Combined Condensing/Vaporizing Mechanism in the Displacement of Oil by Enriched Gases. In *Proceedings of SPE Annual Technical Conference and Exhibition*. SPE Annual Technical Conference and Exhibition. doi: 10.2118/15493-MS.