CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Crude oil development and production may include up to three distinct phases: primary, secondary, and tertiary (or enhanced) recovery. During primary recovery, the natural pressure of the reservoir or gravity drive oil into the wellbore, combined with artificial lift techniques (such as pumps) which bring the oil to the surface. But only about 10 percent of a reservoir's original oil in place is typically produced during primary recovery [7]. Secondary recovery techniques to the field's productive life generally by injecting water or gas to displace oil and drive it to a production wellbore, resulting in the recovery of 20 to 40 percent of the original oil in place [7].

However, with much of the easy-to-produce oil already available, producers have attempted several tertiary, or enhanced oil recovery (EOR), techniques that offer prospects for ultimately producing 30 to 60 percent, or more, of the reservoir's original oil in place. Three major categories of EOR have been found to be commercially successful to varying degrees:

- **Thermal recovery**, which involves the introduction of heat such as the injection of steam to lower the viscosity, or thin, the heavy viscous oil, and improve its ability to flow through the reservoir.
- **Gas injection**, which uses gases such as natural gas, nitrogen, or carbon dioxide, CO_2 (which will be studied in this project), that expand in a reservoir to push additional oil to a production wellbore, or other gases that dissolve in the oil to lower its viscosity and improves its flow rate.

- **Chemical injection**, which can involve the use of long-chained molecules called polymers to increase the effectiveness of waterfloods, or the use of detergent-like surfactants to help lower the surface tension that often prevents oil droplets from moving through a reservoir. Alkaline also can be used in this injection in order to lower the surface tension and produce more oil.

When a field has already been waterflooded, a tertiary CO_2 flood will normally provide incremental recovery of 8% to 16% of the original oil in place [10]. When CO_2 is used instead of waterflood for secondary recovery, the field can produce up to 40% of the original oil in place.

The first CO_2 flood took place in 1972 in Scurry County, Texas [10]. Since then, floods have been used successfully throughout the Permian Basin, as well as in Louisiana, Mississippi, Wyoming, Oklahoma, Colorado, New Mexico, Utah, Montana, Alaska and Pennsylvania. Outside the U.S., CO_2 floods have been implemented in Canada, Hungary, Turkey and Trinidad.

Today half of the CO_2 floods around the world are located in the Permian Basin. These 40 or so floods use more than 1 BCF of CO_2 per day and produce more than 20% of the area's total oil production – more than 140,000 barrels of oil each day. Recent studies report that more than 50 potentially economical CO_2-floodable reservoirs still remain in the Permian Basin, representing incremental oil reserves of 500 million to 1 billion barrels [10].

1.2 PROBLEM STATEMENT

Miscible CO_2 gas injection has been identified to be the most amenable enhanced oil recovery (EOR) process for Malaysian oil fields. In order to predict the performance of these fields undergoing miscible flooding using a reservoir simulation model, there is a need to identify parameters that have significant effect on the predictions. For a reservoir that has been producing under miscible flooding, its model must be history-matched by modifying various parameters to minimize discrepancy between the actual reservoir performance and the model simulated performance. Sensitivity study is usually conducted to evaluate the effect of varying parameters on the reservoir performance.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objective of this project is to determine the fluid properties that have major impact on the oil recovery of Tinggi field from continuous miscible CO_2 injection. An additional objective in this project is to quantify sensitivity of each fluid property in the reservoir.

The scopes of study for this project are:

1. Study the reservoir fluid properties
2. Understand the concept of miscible gas flooding.
3. Conduct simulation on waterflooding and miscible flooding for conceptual design as to familiarize the procedures in analyzing the miscible CO_2 injection on the real field with various fluid properties
4. Simulation and analysis on Tinggi Field

CHAPTER 2

LITERATURE REVIEW

2.1 MISCIBLE GAS FLOODING

Miscible gas flooding is another common approach to enhanced oil recovery in today's field. Miscible gas, which is usually either a hydrocarbon mixture (natural gas) or carbon dioxide (CO_2), is injected into a well. The gas will act as solvent, forming a single oil-like liquid that can flow through a reservoir to other wells more easily than the original crude. CO_2 is injected under such high pressure that it becomes like a liquid which is miscible with oil. The cost of CO_2 flooding is more efficient. From some studies been made, the cost of CO_2 flooding ranges from about $10 to $23 per barrel [10].

2.1.1 How CO_2 works

Carbon dioxide is used in selectively, primarily in wells which will benefit not only from re-pressurization, but also from a reduction in viscosity of the oil in the reservoir caused by a portion of the CO_2 dissolving in the oil. Carbon dioxide is used in oil wells for oil extraction and maintains pressure within a formation. When CO_2 is pumped into an oil well, it is partially dissolved into the oil, rendering it less viscous, allowing the oil to be extracted more easily from the bedrock. Considerably more oil can be extracted from through this process.

2.1.2 Injecting miscible CO_2

In general it is acknowledged that using CO_2 for tertiary EOR may add an additional 5 - 12% of OOIP to the anticipated total production [10]. The mechanism by which this occurs is perhaps best illustrated in the figure below showing the classic configuration of an injector-well working in combination with a producer.

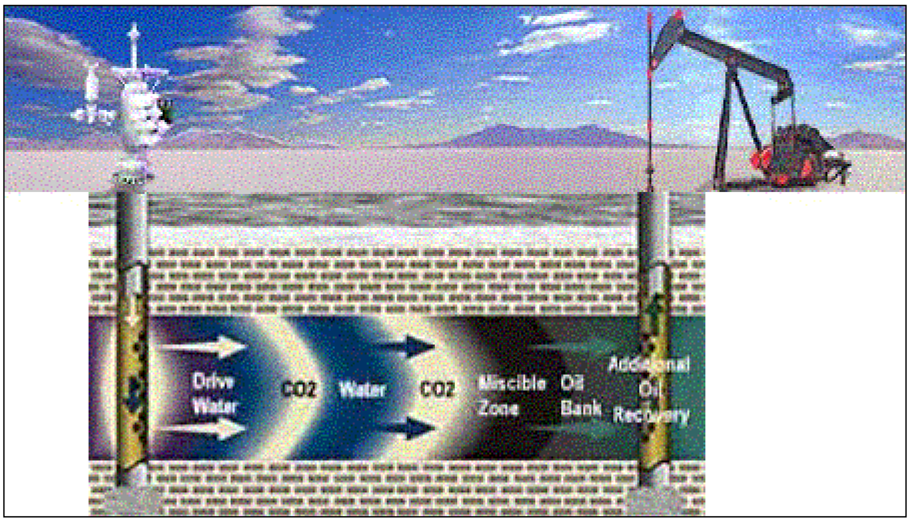


Figure 2.1: Mechanism of miscible CO_2 injection

The CO_2 is typically injected in an alternating water and gas (WAG) process. But in this study, continuous injection will be assumed. As illustrated above, the water is being injected behind a "slug" of CO_2 that creates a miscible zone which helps release oil that had previously been trapped when using only water.

2.2 RESERVOIRS-FLUID PROPERTIES

In order to understand and predict the volumetric behavior of oil and gas reservoirs as a function of pressure, knowledge of the physical properties of reservoir fluids must be gained. These fluid properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties, it is necessary for the petroleum engineers to determine the properties from empirically derived correlations.

2.2.1 Properties of Natural Gases

A gas is defined as a homogeneous fluid of low viscosity and density that has no definite volume but expands to completely fill the vessel in which it is placed. Generally, the natural gas is a mixture of hydrocarbon and non-hydrocarbon gases. The hydrocarbon gases that are normally found in a natural gas are methane, ethane, propane, butane, pentane, and small amounts of hexane and heavier. The non-hydrocarbon gases include carbon dioxide, hydrogen sulfide, and nitrogen. Knowledge of pressure-volume-temperature (PVT) relationships and other physical and chemical properties of gases are essential for solving problems in natural gas reservoir engineering. These properties include apparent molecular weight, M_a, specific gravity, γ_g, compressibility factor, z, density, ρ_g, specific volume, v, isothermal gas compressibility coefficient, c_g, gas formation volume factor, B_g, gas expansion factor, E_g, and viscosity, μ_g. These gas properties may be obtained from direct laboratory measurements or by prediction from generalized mathematical expressions.

2.2.2 Properties of Crude Oil system

Petroleum (an equivalent term is crude oil) is a complex mixture consisting predominantly of hydrocarbons and containing sulfur, nitrogen, oxygen, and helium as minor constituents. The physical and chemical properties of crude oils vary considerably and are dependent on the concentration of the various types of hydrocarbons and minor constituents present. An accurate description of physical properties of crude oils is of a considerable importance in the fields of both applied and theoretical science and especially in the solution of petroleum reservoir engineering problems. Physical properties of primary interest in petroleum engineering studies include fluid gravity, specific gravity of the solution gas, gas solubility, bubble-point pressure, oil formation volume factor, isothermal compressibility coefficient of under saturated crude oils, oil density, total formation volume factor, crude oil viscosity, and surface tension. Data of most of these fluids properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties of crude oils, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations.

2.2.3 Properties of Reservoir Water

There are 4 properties of reservoir water have been identified. These properties are Water Formation Volume Factor, Water Viscosity, Gas Solubility in Water, and Water Isothermal Compressibility**.**

2.2.4 Variation of Fluid Properties With Depth and Area

In low-closure fields, fluid properties usually are uniform throughout the reservoir. In high-closure reservoirs, however, fluid properties can vary significantly with depth and sometimes with area location. In these reservoirs, solution GOR and API gravity normally decrease with depth, while oil viscosity increases with depth. Reservoir temperature also varies enough areally to require adjustment of PVT properties.

In general, if closure exceeds a few hundred feet or if a field is large, enough fluid samples should be taken to ensure that any significant trends in reservoir fluid properties are defined.

2.3 MISCIBLE CO_2 PROCESS

CO_2 is not miscible on first contact with reservoir oils. However, at sufficiently high pressure CO_2 achieves dynamic miscibility with many reservoir oils. According to this concept, CO_2 vaporizes or extracts hydrocarbons from the crude as heavy as the gasoline and gas/oil fractions. Vaporization occurs at temperature where the fluid at the displacement front is a CO_2 rich gas, and extraction occurs at temperatures where the fluid at the displacement front is a CO_2 rich liquid.

The pressure required for achieving dynamic miscibility with CO_2 is usually significantly lower than the pressure required for dynamic miscibility with either natural gas, flue gas, or nitrogen. This is a major advantage of the CO_2 miscible process because dynamic miscibility can be achieved at attainable pressure in a broad spectrum of reservoirs. A disadvantage of CO_2 flooding compared with waterflooding result from the low viscosity of CO_2 relative to that of oil.

The densities of oil and CO_2 are similar at many reservoir conditions, which tend to minimize, although not necessarily eliminated, segregation between these fluids in reservoirs that have not been waterflood. In reservoirs that have been waterflooded or have had water injected with CO_2 to counteract the effects of viscosity ratio and permeability stratification, the density contrast between water and CO_2 may cause segregation.

2.4 TINGGI FIELD

The Tinggi field is the fifth field put on production by ESSO Production Malaysia Inc (EPMI), off the East Coast of Peninsula Malaysia. It was discovered in July 1980 by well Tinggi-1 and field development commenced in August 1982 with the installation of a single 32-conductor platform (Tinggi-A). Total of 31 wells have been drilled. The major oil-bearing formation is located within the J19/20 & J21 reservoirs with additional production from the J15, J15.5, J16, J18, K10 and K20/25 reservoirs. These are stacked reservoirs with depth ranging from 1,250 mSS to 1,650 mSS. First oil commenced in November 1982 with cumulative oil and gas productions (as of 1st. January 2005) at 125.04 MMSTB and 127.72 BSCF respectively.

The Tinggi Full Field Review (FFR) project started on August 15, 2003 with an 18-month planned project period. The technical work in this project has been successfully completed and approved. The primary objectives of the Tinggi FFR project were to re-assess Tinggi hydrocarbon in-place volumes and remaining reserves, identify by-passed oil in major producing reservoirs, estimate recompletion/infill drilling potential and investigate the hydrocarbon potential in the deeper horizons. In the Tinggi Field some producing reservoirs experienced high recovery efficiency (>70%). One of the focus areas of the Tinggi FFR study was to investigate and resolve this anomaly and identify potential recovery improvement areas. Being a multi-discipline integrated study, the Tinggi FFR Study estimated and refined the ultimate recoverable volumes and ultimate recovery efficiencies.

2.5 ASSESSMENT OF PROCESS

2.5.1 CO_2 Breakthrough and Production

Most projects, both secondary and tertiary recovery floods, have experienced early CO_2 breakthrough, usually after injection of 0.05 to 0.2 HCPV of total fluid (CO_2 or CO_2 plus water). This also is typical of behavior observed in field tests of miscible flooding with hydrocarbon solvents [5], but in most cases subsequent CO_2 production has not been excessive, and corrective measures such as alternate water injection, zonal isolation, and reducing the injection pressure have been partially successful in moderating CO_2 production.

2.5.2 Oil Recovery

Incremental recovery is affected by volumetric sweepout of the CO_2, by swept-zone residual oil saturations left both to waterflood and CO_2 flooding, and by cross-flow and resaturation, which reduce the fraction of displaced oil actually produced. It also affected by the CO_2 slug size, effective mobility ratio of the flood, fluid used to drive the slug (gas or water), degree of heterogeneity, and well pattern, all of which affect sweepout and oil capture efficiency. Hydrocarbon liquid recovery of course relates directly to the FVF.

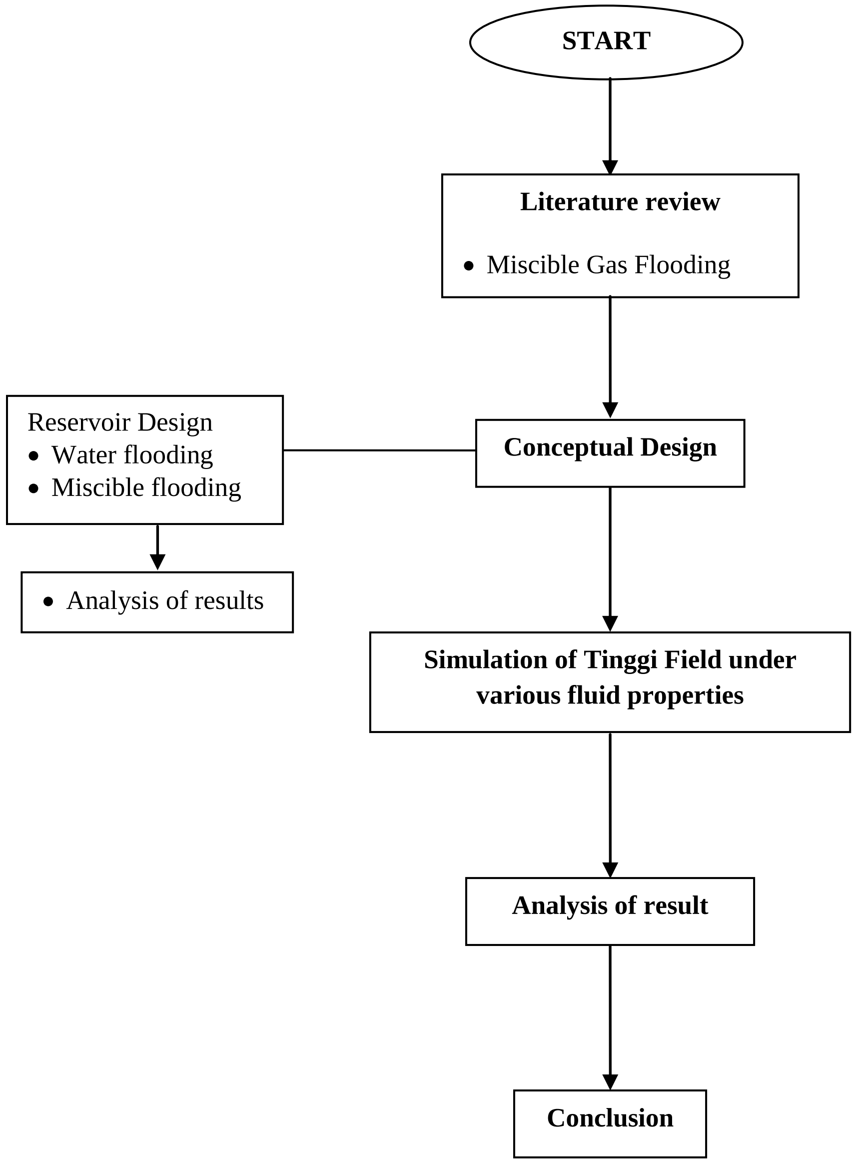
The bulk incremental oil production in the CO_2 flooding tests occurred after CO_2 breakthrough, the incremental oil was produced concurrently with CO_2. In the tertiary recovery floods, CO_2 breakthrough occurred shortly after or practically coincident with the first production of the tertiary oil bank. This behavior undoubtedly is caused by a combination of viscous fingering, gravity segregation/override, channeling caused by stratification, and crossflow of the oil bank. The relative importance of these phenomena varied from project to project but the general flood character of relatively early CO_2 breakthrough followed by a prolonged period of production of incremental oil along with CO_2 should be anticipated for the typical project.

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW CHART

The methodology of this project is summarized in the following flow chart:



3.2 SELECTION OF FLUID PROPERTIES DATA

CO_2 flooding has been proven to be a viable enhanced oil recovery process in many geographic locations. To evaluate the effect of reservoir and fluid properties on CO_2 flooding performance, a sensitivity study of reservoir modeling will be performed on a five-spot injection-production pattern. A variety of reservoir configurations will be simulated based on the large range of API gravities of the oils produced as well as its spatial variation and anisotropy of relative permeability. CO_2 flooding is generally not sensitive to lithology but is sensitive to reservoir characteristics

Fluid properties data either describe the properties of reservoir fluids or relate reservoir volumes to surface volumes. Both kinds of data are discussed briefly in the following subtopic. Terms that are specific to the petroleum in industry will be defined.

Volumetric and Physical Properties of Reservoir Fluids

Oil, gas, and water viscosities, μ_o, μ_g, and μ_w. Viscosity is a property that controls and influences the flow of a fluid through porous media and pipes. The less viscous a fluid is, the easier the fluid to flow. It is obtained from PVT laboratory measurements. In this case study, viscosity of gas and water will be neglected and only viscosity of oil will be taken into account.

Oil, gas, and water densities, ρ_o, ρ_g, and ρ_w. Density is the mass of a unit volume. Lower density tends to be on top of the higher one. It can be calculated from PVT measurements or obtained from existing correlation. Only the densities of oil will be considered.

Oil, gas, and water formation volume factor (FVF), B_o, B_g, and B_w. FVF is the ratio of the specific volume of oil with its dissolved gas at reservoir conditions to the specific volume of oil at stock-tank conditions. The oil FVF is a function of the composition of the system, pressure, temperature, and the manner in which gas and oil are separated. It is obtained from PVT measurements. Same as densities and viscosities, only oil FVF will be taken into consideration.

All these properties will be examined in the simulation run in Eclipse 100. From the simulation, the sensitivity of each property will be determined.

3.3 CONCEPTUAL MODEL AND SIMULATION

3.3.1 Conceptual Design

A conceptual model has been developed in order to familiarize the procedures needed in the real case study. In this conceptual design, three dimensional reservoir of size 2500' x 2500' x 150', divided into nine layers of equal thickness was used. The depth of reservoir top is 8000 ft and the initial pressure at 8075 ft is 4500 psia. The porosity of the reservoir rock is 0.20. Permeability for x, y, and z is 200 mD, 150 mD, and 20 mD respectively. The number of cells in the x, y, and z direction are 15, 15, and 9 respectively. After the modification, the conceptual design data had been run in Eclipse 100. The simulation of conceptual reservoir can be observed in FloViz from Eclipse menu. The conceptual model was run in waterflooding and miscible CO_2 flooding before the real simulation on Tinggi Field was performed in order to familiarize the procedures in analyzing the simulation results.

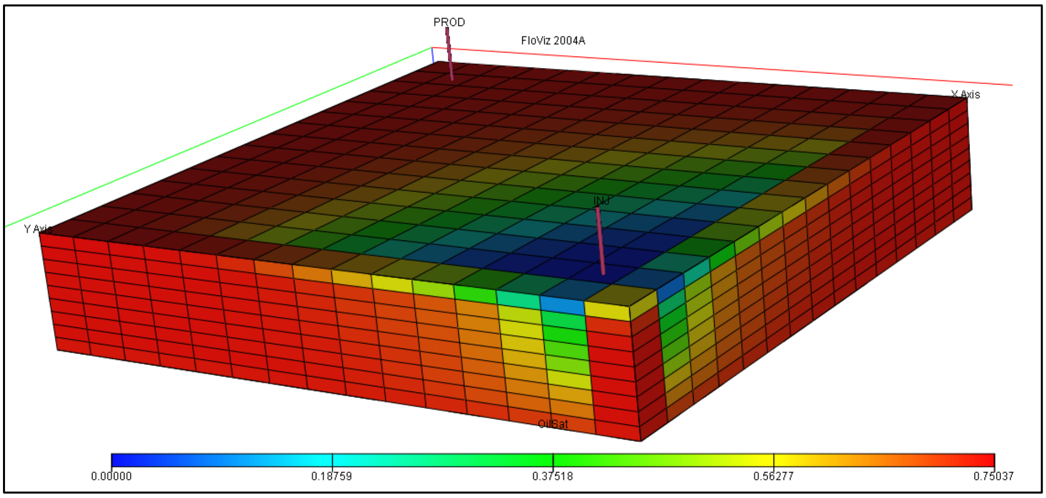


Figure 3.1 Conceptual Model

3.3.2 Waterflooding – Conceptual Design

The simulation of water injection (secondary recovery) for the conceptual model was run using Eclipse 100 from the programmed data file prepared earlier. There were several modifications been made in this data file in order to simulate the reservoir as being injected by water. This simulation was done in order to familiarize the procedures for analysis and also to observe the results that should be obtained in the real Tinggi Field. Water being injected continuously and the results obtain shows that decreasing density and viscosity will give a greater oil recovery and increasing oil formation volume factor gives greater oil recovery.

3.3.3 Miscible Flooding – Conceptual Design

The simulation of miscible flooding (tertiary/enhanced oil recovery) for the conceptual model was run using Eclipse 100 from the programmed data file prepared earlier. There were several modifications been made in this data file in order to simulate the reservoir as being injected by miscible CO_2. This simulation was also done in order to familiarize the procedures for analysis and also to observe the results that should be obtained in the real Tinggi Field. Miscible CO_2 being injected continuously and the results obtain shows that decreasing density and viscosity will give a greater oil recovery and increasing oil formation volume factor gives greater oil recovery. So, the same results were expected from the real Tinggi Field.

After running the simulation, the summary data, from the .RSM file been studied and several graphs were plotted in order to show the differences or sensitivities of each property to the recovery factor. The graphs are

1. FOPR vs HCPV - observe the field oil production rate
2. FOE vs HCPV - observe the recovery factor of the reservoir
3. WWCT vs HCPV - observe the water that will be pumped out together with oil in the oil production,
4. Spider Plot, final FOE vs percentage difference - compare the sensitivity of recovery factor for all cases in each property.

Notes

HCPV is the acronym of Hydro Carbon Pore Volume. To obtain HCPV, a formula is used and the formula is,

$$HCPV = \frac{FVIT}{PV}$$

Where FVIT = Res Volume Injection Total

PV = Pore Volume

In these conceptual models, the value of pore volume is 33403191 rb

3.4 MISCIBLE CO_2 FLOODING – TINGGI FIELD – ACTUAL STRUCTURE

This model represents the reservoir is having a 124 x 1 x 116 gridblocks in x, y, z directions. That means this model is a section model which is 2D reservoir simulation. The simulation was done for 20 years starting from 1 November 1982. It consists of 3 wells which are 2 gas injection wells and a production well.

In order to study the sensitivity of each property that has been selected (density, oil formation volume factor, and viscosity) to the recovery factor, these properties were manipulated into six cases for each property, similar to the simulation of waterflooding and miscible CO_2 flooding for the conceptual design. The details are as follow:

Cases	Property manipulation
A	minus (-) 10%
B	plus (+) 10%
C	minus (-) 2%
D	plus (+) 2%
E	minus (-) 30%
F	plus (+) 30%

Table 3.1 Manipulations of each property

For Tinggi field analysis, the results will be represented in graphs plotted that are:

1. FOPR vs HCPV - observe the field oil production rate
2. FOE vs HCPV - observe the recovery factor of the reservoir
3. FGOR vs HCPV - observe the gas-oil ratio from the production.

The gas-oil ratio (gas solubility) is defined as the number of cubic feet of gas measured at standard conditions which will dissolve in one barrel of stock tank oil when subjected to reservoir temperature and pressure

$$HCPV = \frac{FVIT}{PV}$$

Where, FVIT = Res Volume Injection Total

PV = Pore Volume

In Tinggi field model, the value of pore volume is 37247938 rb

3.5 MISCIBLE CO_2 FLOODING – TINGGI FIELD - MODIFIED STRUCTURE

There were several inconsistencies in the results of the Miscible CO_2 Flooding by using the actual structure. Because of that, there is a need to modify the actual structure. The results and probable causes will be discussed in the next chapter.

In order to obtain the expected results, the original reservoir structure that is anti-cline has been rearranged to represent a horizontal rectangular shaped model to eliminate the effect of dipping reservoir and the grid blocks are as follow;

1. Dimension of x-direction, DX = 14384*150
2. Dimension of y-direction, DY = 14384*150
3. Dimension of z-direction, DZ = 14384*3

Other than that, no other properties been modified. The analysis procedures will be the same as the actual structure model. The details are the same as the actual structure model of Tinggi Field. In this modified Tinggi field model, the value of pore volume is 36031070 rb

The difference between the actual model and the modified model are summarized in the following table:

Original	Modified
Anti-cline reservoir shape	Horinzontal reservoir shape
Oil-water contact (OWC) = 4393	Oil-water contact (OWC) = 4660
Injection: Reservoir fluid volume rate target or upper limit = 20000	Injection: Reservoir fluid volume rate target or upper limit = 5000
Injection: BHP target or upper limit = 5000	Injection: BHP target or upper limit = 3500
Production: Reservoir fluid volume rate target or upper limit = 10000	Production: Reservoir fluid volume rate target or upper limit = 15000

Table 3.2 Differences between the actual model and modified model

CHAPTER 4

RESULTS AND DISCUSSION

CO_2 flooding has proven to be a viable enhanced oil recovery process in many geographic locations. To evaluate the effect of reservoir and fluid properties on CO_2 flooding performance, a sensitivity study of reservoir modeling has been performed on a five-spot injection-production pattern. In this project simulation, we only consider a quarter of the five-spot pattern.

Analysis of waterflooding and miscible CO_2 flooding for the conceptual model has been discussed in the last progress reports. Basically, what is expected from the analysis of miscible CO_2 flooding for Tinggi Field is similar to the results of those conceptual models.

4.1 ANALYSIS OF MISCIBLE CO_2 FLOODING – ACTUAL STRUCTURE

A sensitivity study of fluid properties to miscible CO_2 performance for the actual structure of Tinggi Field was done as mentioned in the methodology and the result will be discussed in this chapter. The result was divided into 3 as there were 3 properties that were studied in this project, that are Oil Density, Oil Formation Volume Factor (Oil FVF), and Oil Viscosity.

After running the simulation of the six manipulated Oil Densities, Oil FVF, and Oil Viscosity from case A to case F, differences in sensitivity of the property from the graphs plotted can be observed.

There are 3 graphs being plotted and that are FOPR vs HCPV, FOE vs HCPV, and FGOR vs HCPV.

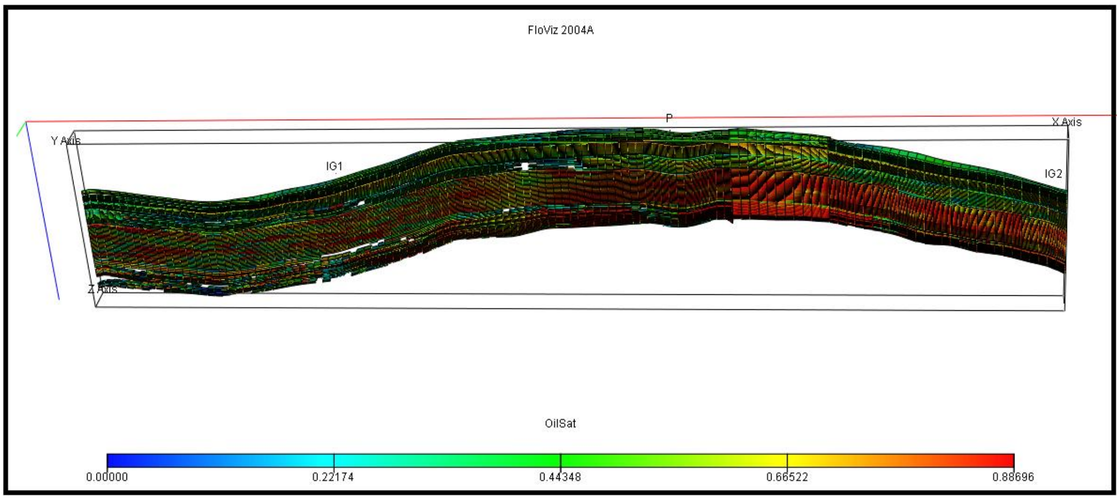


Figure 4.1 Actual Structure Reservoir

Density

These are the graphs for oil density:

FOPR vs HCPV

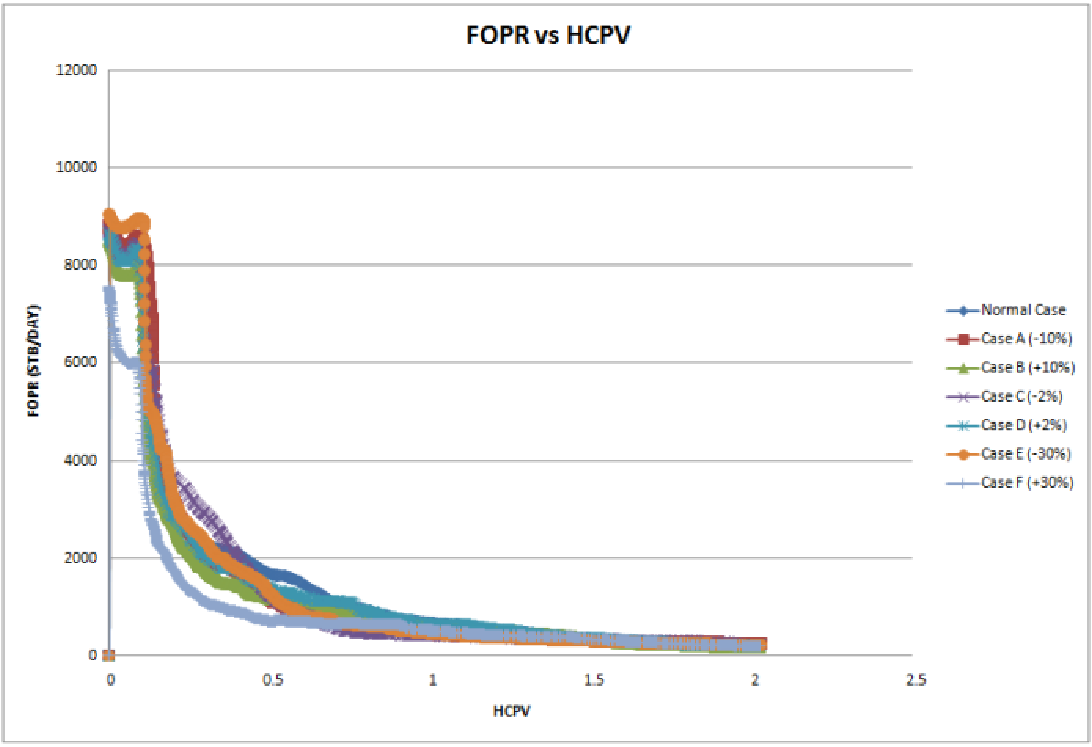


Figure 4.2 FOPR vs HCPV

From this graph, the oil production rates vary with the changes in the value of density clearly. At the early phase, it can be observed that the highest production rate is the orange line which represents case E which the density was reduced by 30% from original value. Followed by case A (-10%), case C (-2%), and the normal case. The lowest production rate is case F which the density was increased 30%. This is because the lower the density, the easier the oil being removed by miscible CO_2 injection. As a conclusion, increasing oil density will decrease the oil production rate and decreasing oil density will result in higher production rate.

FOE vs HCPV

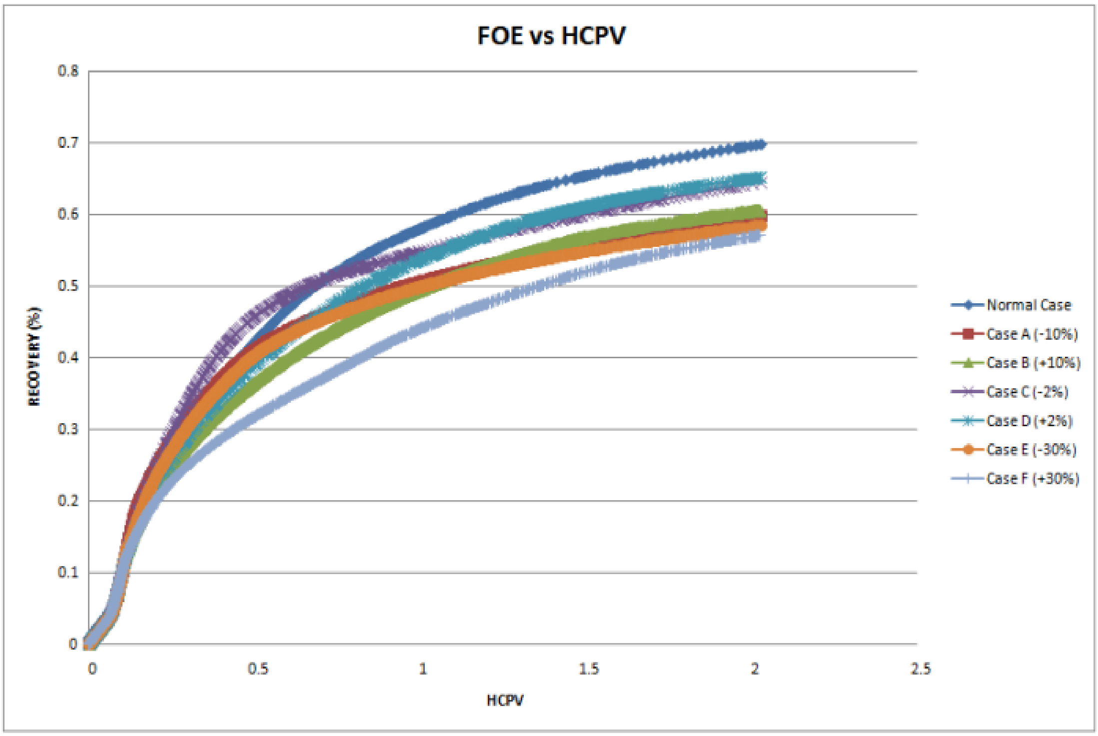


Figure 4.3 FOE vs HCPV

From this graph, the normal case which is the darkest blue has the highest oil recovery. The results obtained are not as expected. Supposedly, the lowest density will give the highest recovery factor, but in this graph, it shows that the highest recovery is the normal case. A further study on this problem will be conducted in order to identify what was the cause of this error.

FGOR vs HCPV

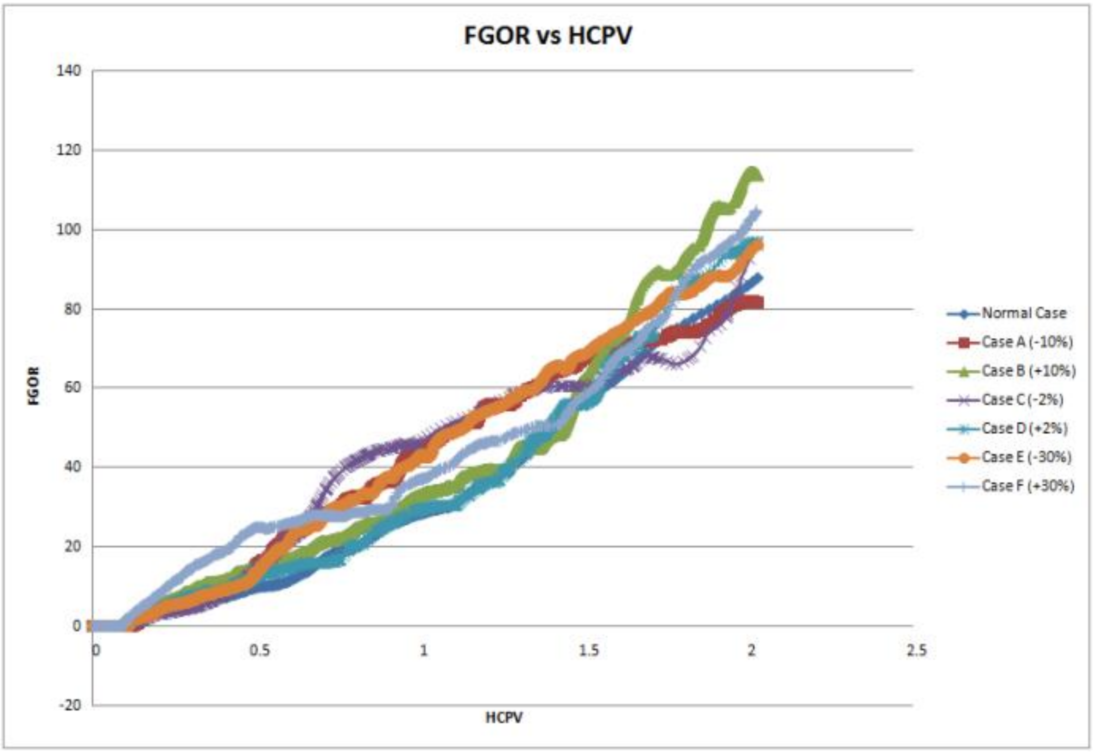


Figure 4.4 FGOR vs HCPV

A high value of Gas-Oil ratio (GOR) is not desirable in oil production. It is always better to have a small GOR. From this graph, no clear pattern of the line can be observed. But it can observed that at HCPV = 1, the lowest GOR is case D which the density was increased 2% and the highest GOR is case C which the density was decreased 2%. The results obtained were not as expected; case C and D should be in the middle of other cases because the changes are smaller than ±10% and ±30%. So, further studies on this matter need to be performed.

Oil Formation Volume Factor

In manipulating the value of oil FVF into these six cases, case A which is reduced by 10% gave a value of 0.9585 and case E which was reduced by 30% gave a value of 0.7455. As we know, oil FVF is impossible to be less than 1. The value should be higher than 1. So, case A and E was eliminated and didn't put into consideration in this study.

FOPR vs HCPV

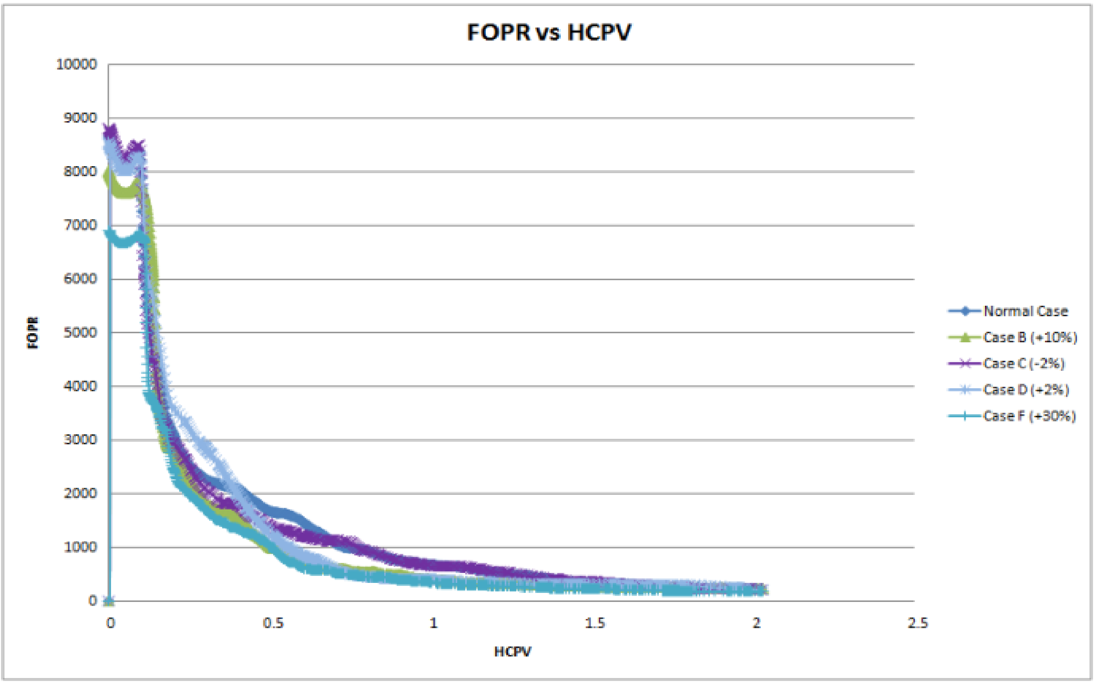


Figure 4.5 FOPR vs HCPV

As shown in this graph, the lowest production rate is the darker blue that represents case F which the value of FVF was increased 30% and the highest oil production is case C which was decreased by 2%. This phenomenon should not occurred because increasing oil FVF should give a greater production rate as proven by previous study on the miscible CO_2 for the conceptual model. A further study on this matter should take place in order to determine what was the cause of these results. Before that, we have to consider the other graphs or results from viscosity.

FOE vs HCPV

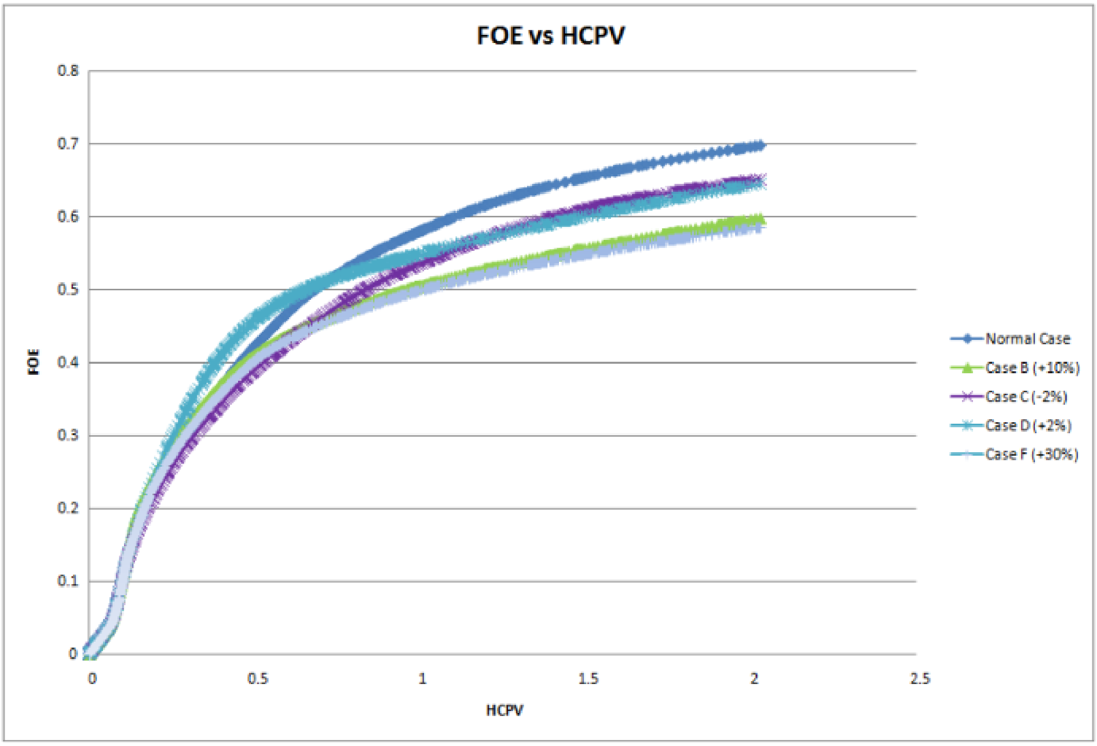


Figure 4.6 FOE vs HCPV

By referring to the graph, it was found that the normal case has the highest oil recovery while case F which the value of oil FVF was increased by 30% has the lowest oil recovery. This also should not happen as increasing oil FVF will give a better oil production and oil recovery.

FGOR vs HCPV

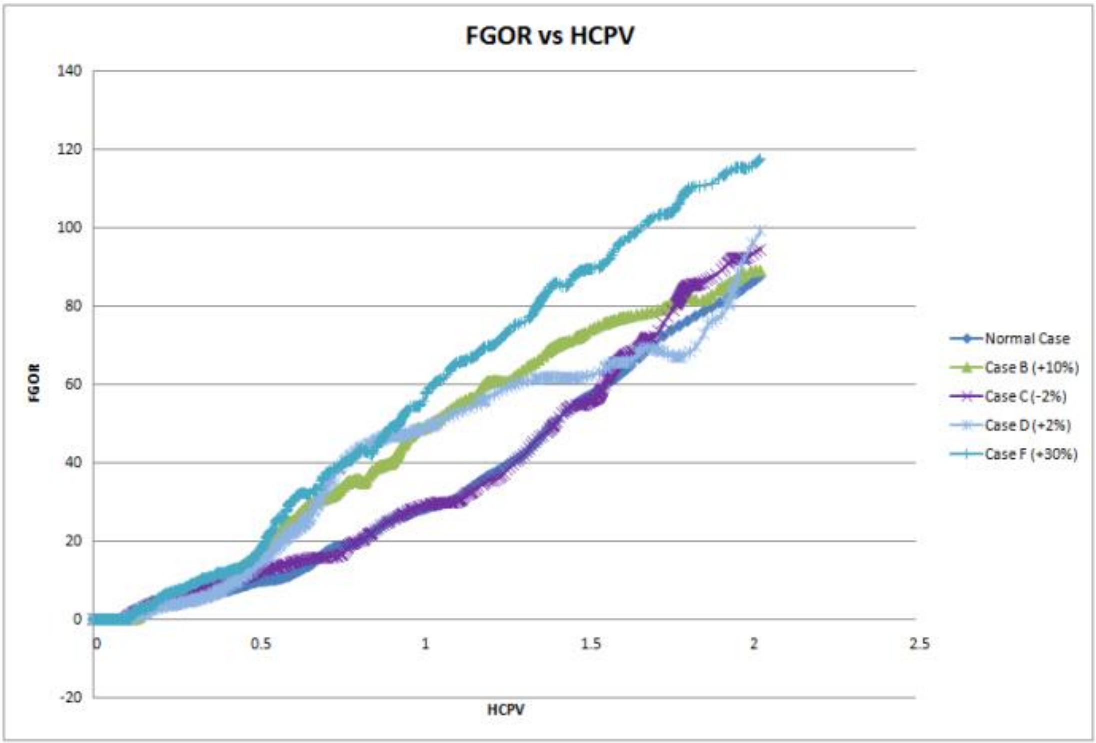


Figure 4.7 FGOR vs HCPV

This graph shows that the average highest GOR is case F which the FVF was increased 30% and the lowest GOR is case C which the FVF was decreased 2%. Supposedly, increasing FVF will give lower GOR because increasing GOR will results in better production. So these results have some errors and need some modifications.

Oil Viscosity

FOPR vs HCPV

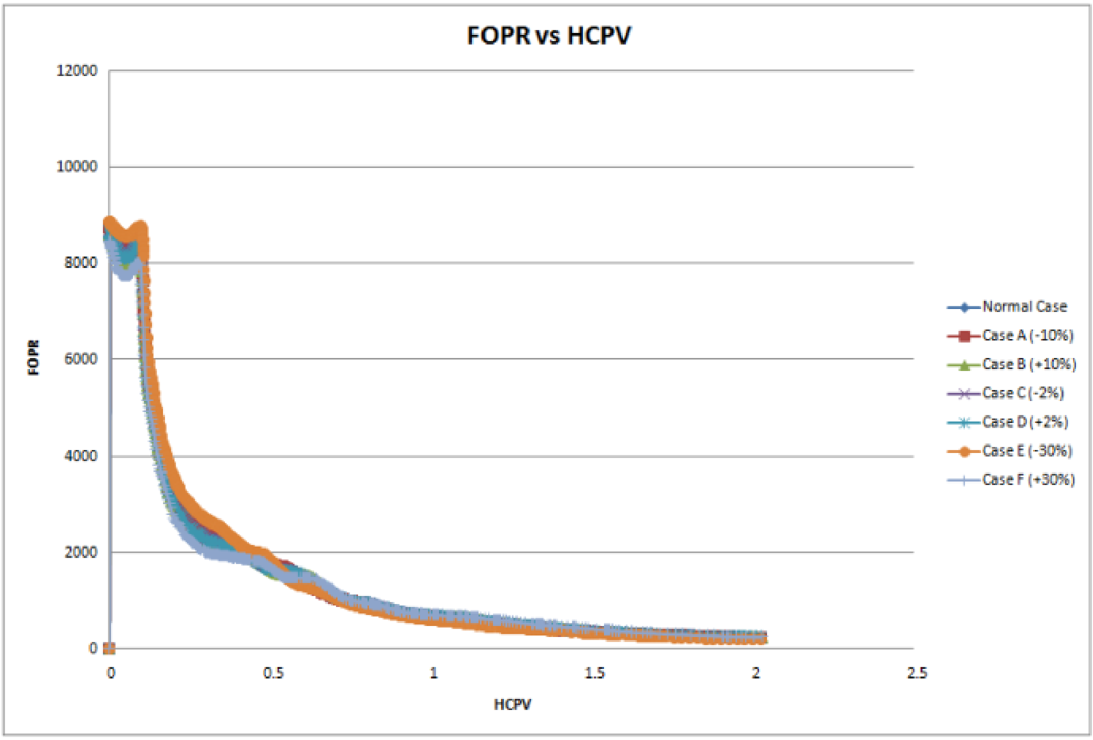


Figure 4.8 FOPR vs HCPV

By referring to this graph, it was observed that, decreasing the oil viscosity as much as 30%, the oil production rate will be higher than the normal case as proven by case E (-30%) and case A (-10%). However, increasing the value of oil viscosity, the production rate will be lower than the normal case as proven by case B (+10%) and case F (+30%). So, from the graph, it can be conclude that decreasing oil viscosity will increase the oil production rate and increasing the oil viscosity will decrease the oil production rate. This is because viscosity is the property that controls the movements of fluids. The higher the value, the harder the fluid to move.

FOE vs HCPV

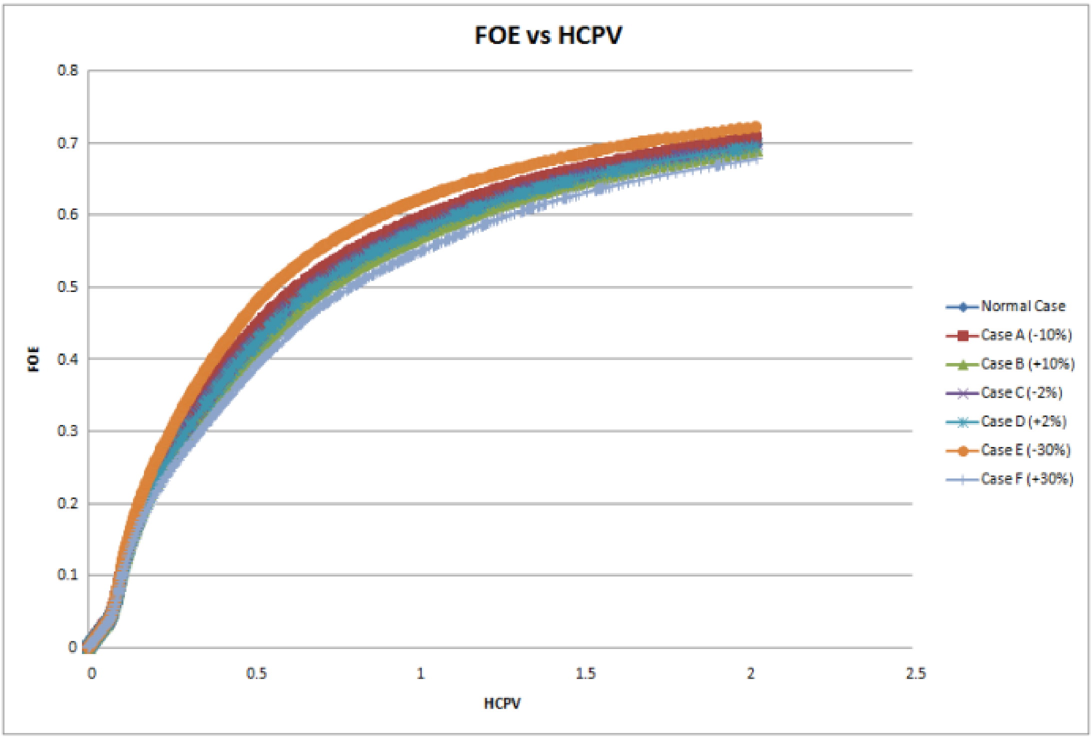


Figure 4.9 FOE vs HCPV

From the graph, decreasing oil viscosity will cause oil recovery to increase. The highest oil recovery is case E which was decreased by 30% of its initial value and the lowest oil recovery is case F which was increased by 30%. This is because lowering the viscosity, gives the oil easy to move and be recovered as viscosity is the property which controls the movements of fluids. By referring to this graph, it can be conclude that lowering the oil viscosity will give better oil recovery.

FGOR vs HCPV

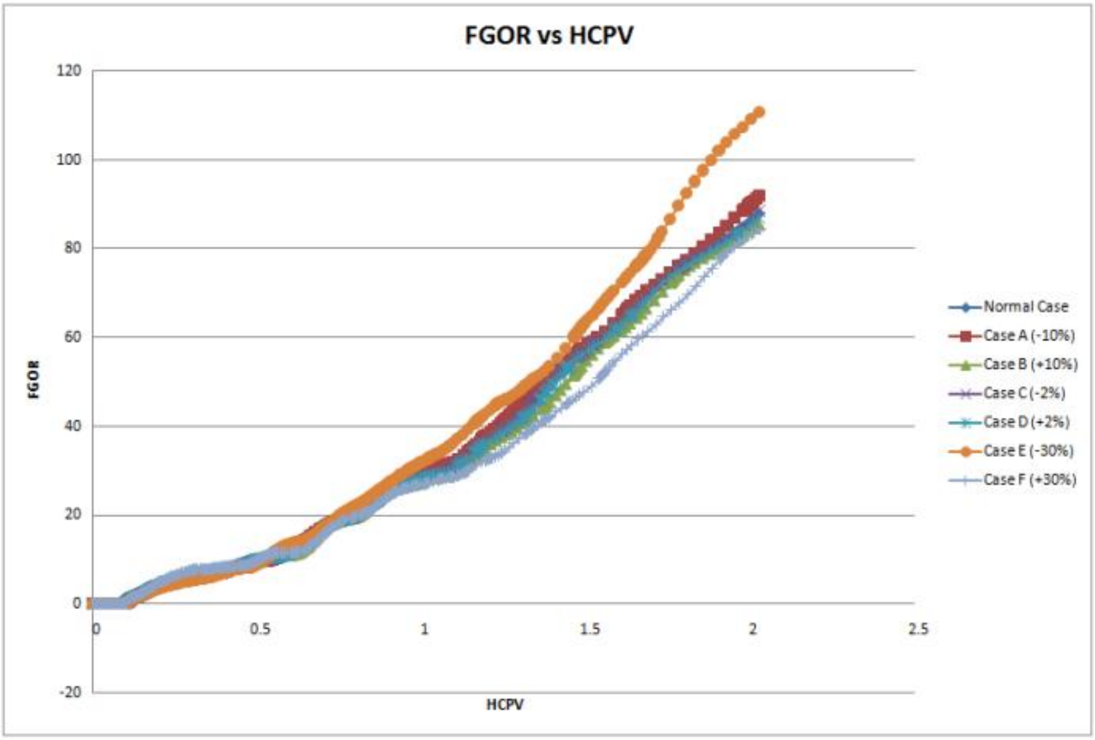


Figure 4.10 FGOR vs HCPV

GOR for case E which the viscosity was decreased by 30% is the highest in this graph and the lowest GOR is case F which the viscosity was increased 30%. This result is not as expected because by lowering viscosity, a better production is expected. But if the GOR is high, the production is not a good production. There must be some error in this result. So, further studies and modifications are needed in order to obtain expected results.

SPIDER PLOT

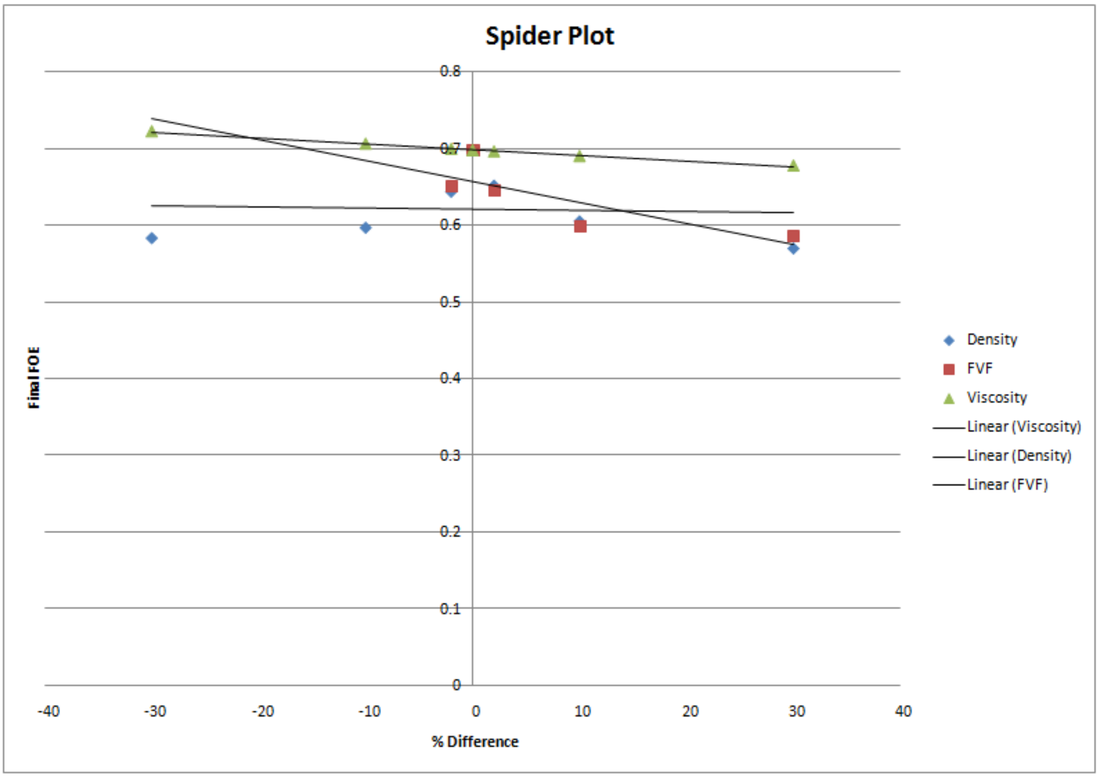


Figure 4.11 Spider Plot

From this spider plot, it can be observed that:

- For density, the normal case has the highest final FOE (oil recovery). The trend doesn't follow the expected profile. Thus, it is not accepted as the result of these studies.
- For formation volume factor cases, the normal case also has the highest FOE. This result is also cannot be accepted as the final results of these studies.
- Only viscosity gives an acceptable result and trend line.

Because most of the results obtained from this analysis are unacceptable, the simulation on this field will be modified to obtain a better result that is acceptable. This will be discussed in next subtopic.

4.2 ANALYSIS OF MISCIBLE CO_2 FLOODING – MODIFIED STRUCTURE

In the previous sensitivity study of fluid properties to miscible CO_2 performance for the actual structure of Tinggi Field, it can be observed that many errors occurred in the results although the procedures were done as mentioned in the methodology. After further studies, a conclusion was made, that the errors caused by the anti-cline shape of the reservoir. Because of the anti-cline, the density and oil formation volume factor was affected by gravity segregation where gases bypass the oils making the oil unrecoverable.

Similar to the previous analysis, the result was divided into 3 as there were 3 properties that were studied in this project, that are Oil Density, Oil Formation Volume Factor (Oil FVF), and Oil Viscosity.

After running the simulation of the six manipulated Oil Densities, Oil FVF, and Oil Viscosity from case A to case F, differences in sensitivity of the properties can be observed from the graphs plotted. There are 3 graphs being plotted and that are FOPR vs HCPV, FOE vs HCPV, and FGOR vs HCPV.

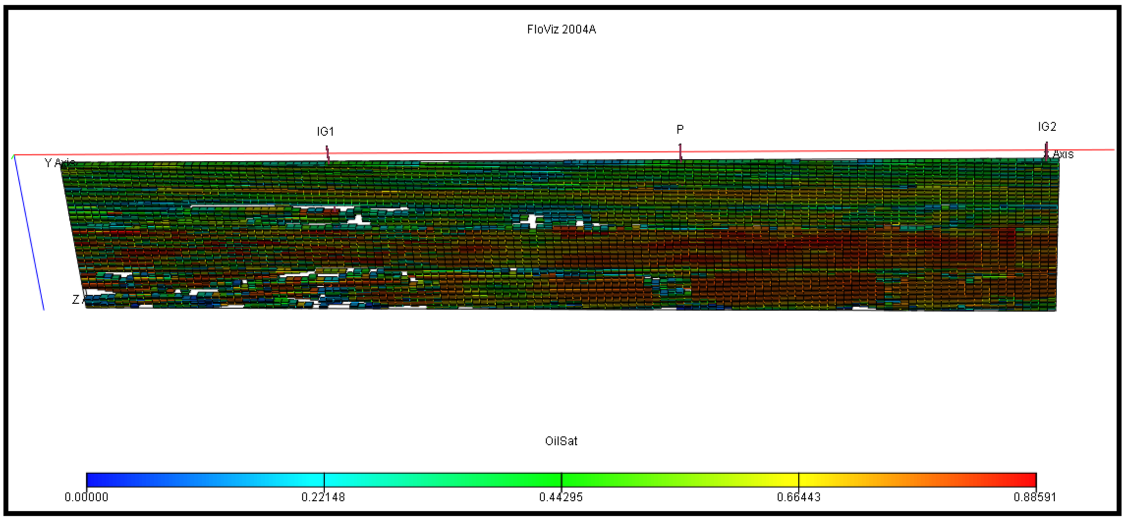


Figure 4.12 Modified Structure Reservoir

Density

These are the graphs for oil density:

<u>FOPR vs HCPV</u>

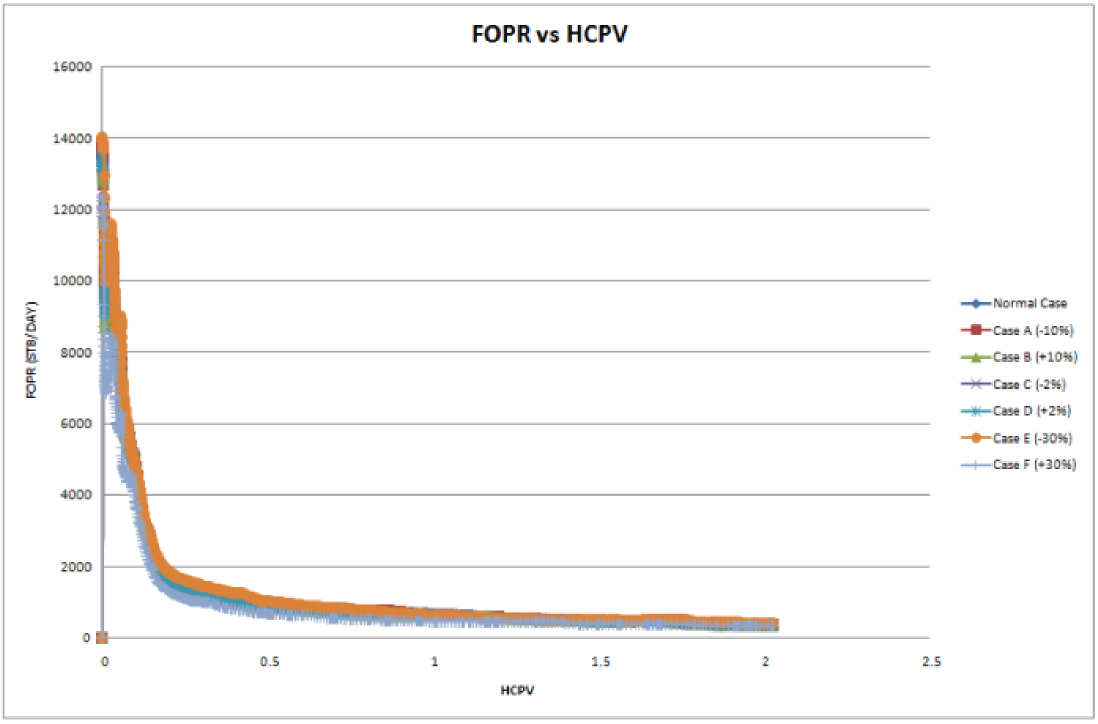


Figure 4.13 FOPR vs HCPV

As shown in this graph, the highest production rate is case E which the oil density decreased by 30%. The lowest production rate is case F which the oil density was increased 30%. This is because the lower the density, the easier the oil being removed by miscible CO_2 injection. As a conclusion, increasing oil density will decrease the oil production rate and decreasing oil density will result in higher production rate.

FOE vs HCPV

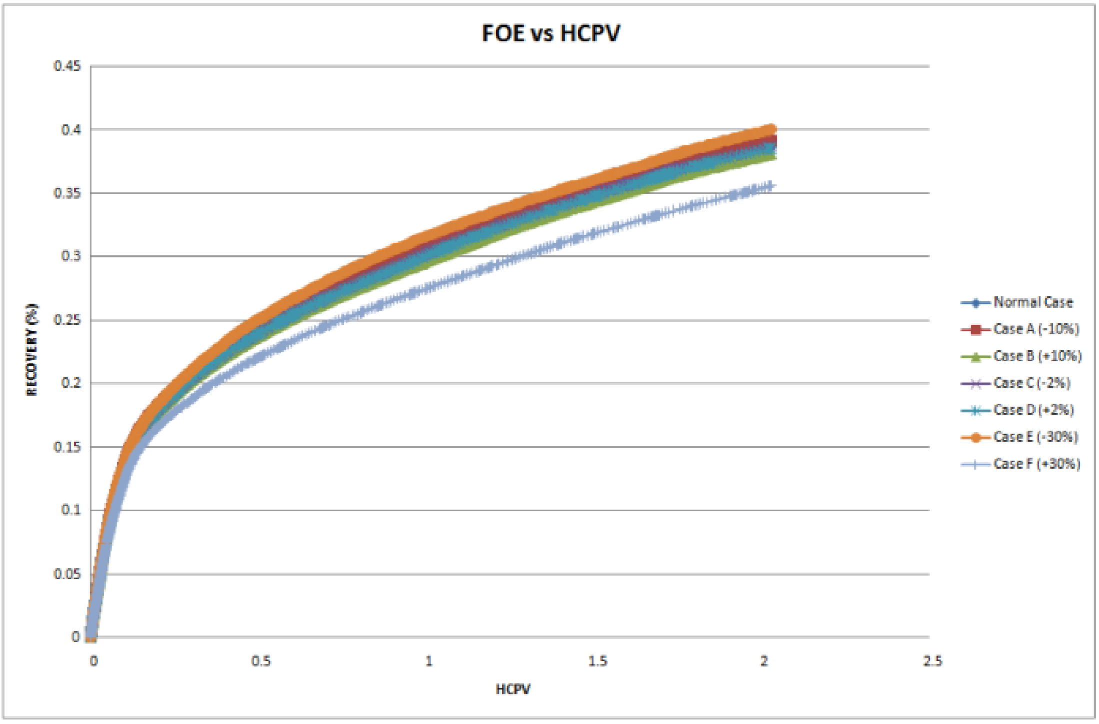


Figure 4.14 FOE vs HCPV

From this graph, it is observed that case E which the oil density was decreased by 30% gives the highest oil recovery followed by case A which the oil density was decreased by 10%. A lower oil recovery is case B which the oil density was increased by 10% and the lowest recovery factor is case F which the density was increased by 30%. So, from this graph, it can be concluded that increasing oil density will give less oil recovery and by decreasing it, a greater recovery can be obtained. This result supports the statement from FOPR vs HCPV graph

FGOR vs HCPV

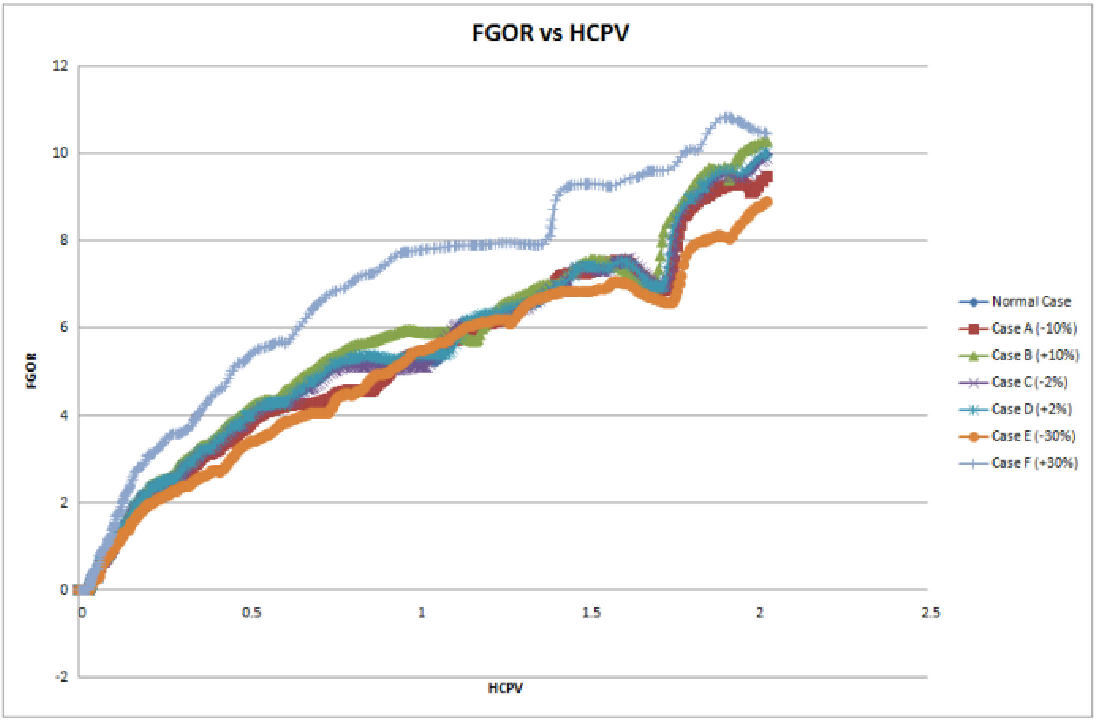


Figure 4.15 FGOR vs HCPV

A good production should have a low GOR ratio. As shown in this graph, the lowest GOR is case E, the orange coloured line which the density was decreased as much as 30%, followed by case A which was decreased 10%. The highest GOR is case F, the light blue coloured line which the density was increased 30%. So, these 3 graphs support the statement that decreasing oil density will give a better production.

Oil Formation Volume Factor

As stated in the previous subtopic, in manipulating the value of oil FVF into these six cases, case A which was reduced by 10% gave a value of 0.9585 and case E which was reduced by 30% gave a value of 0.7455. As we know, oil FVF is impossible to be less than 1. The value should be higher than 1. Case A and E was eliminated

FOPR vs HCPV

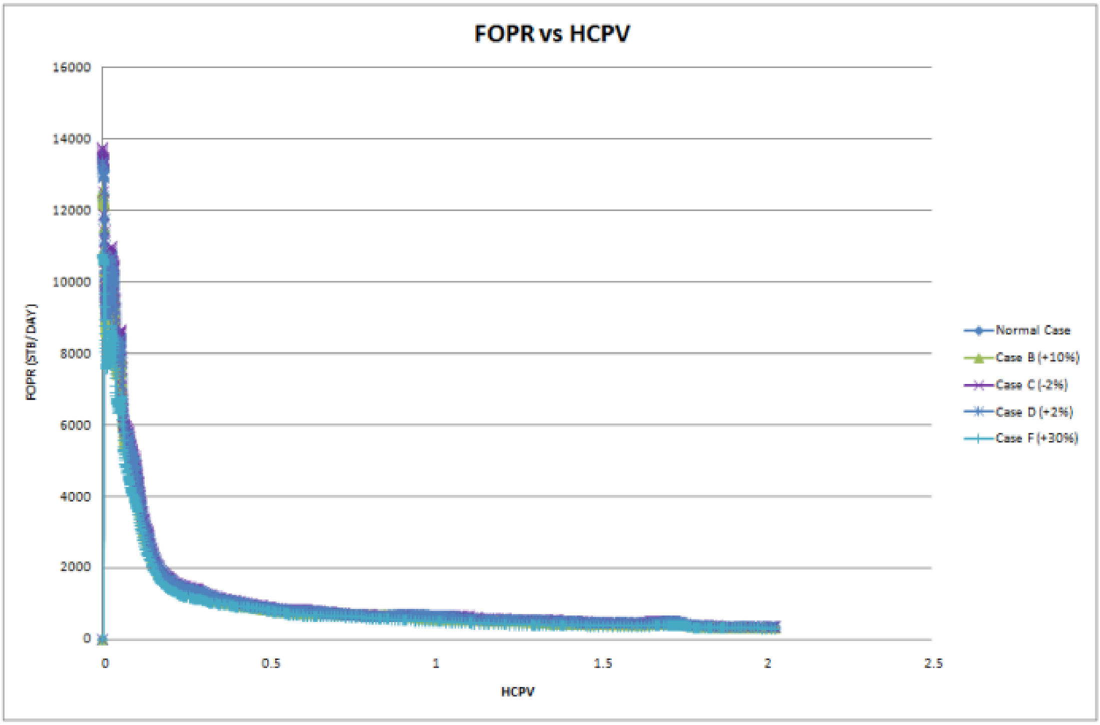


Figure 4.16 FOPR vs HCPV

In this graph, it can be observed that no obvious differences between all cases. All cases have a quite similar production rate. So, let's see the next graph which represents the oil recovery factors.

FOE vs HCPV

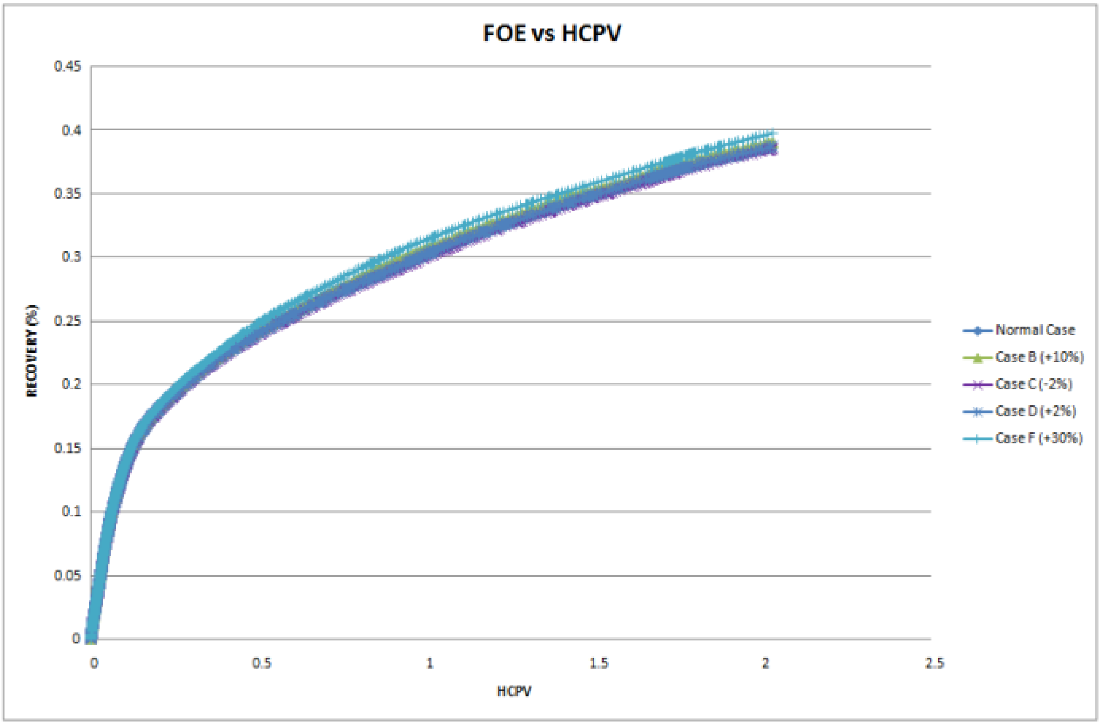


Figure 4.17 FOE vs HCPV

By referring to the graph, it is observed that increasing the value of Oil FVF, the oil recovery will increase, proven by case B, case D, and case F which is increased by 10%, 2%, and 30% respectively. The highest oil recovery is case F which the FVF was increased by 30% and the lowest oil recovery is case C which the FVF was decreased by 2%. As a conclusion, increasing the value of Oil FVF will increase the oil recovery factor.

FGOR vs HCPV

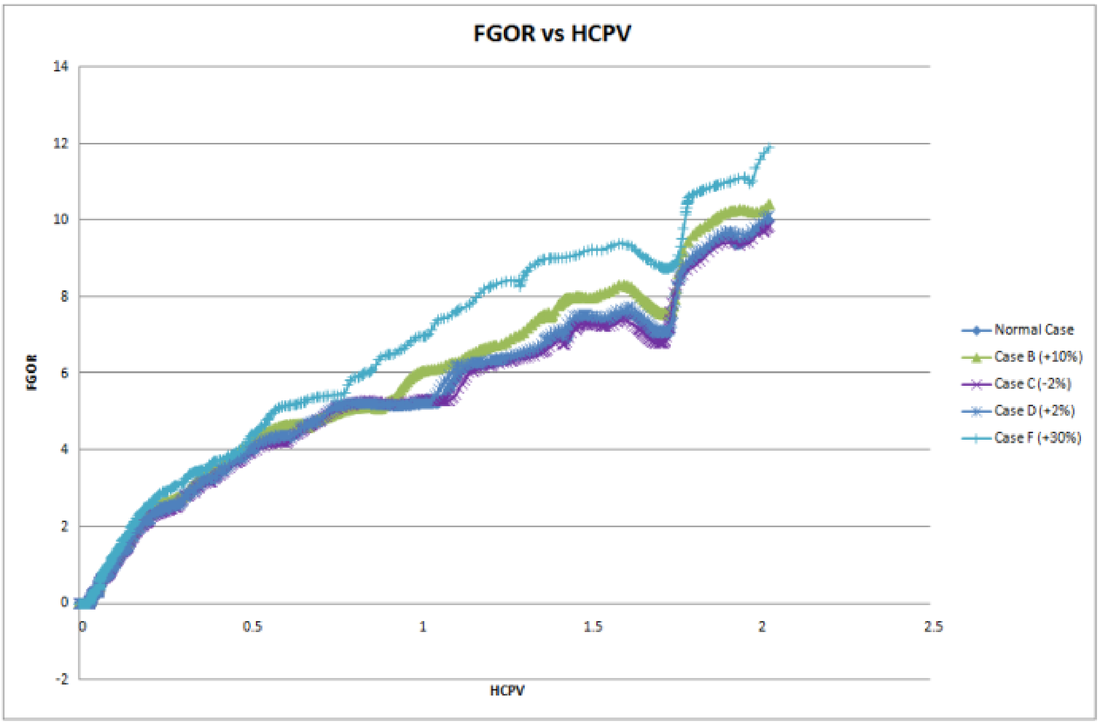


Figure 4.18 FGOR vs HCPV

From this graph, the highest GOR is case F which was increased by 30% and the lowest GOR is case C which the FVF was decreased by 2%. GOR should be low in order to obtain a good production. But in this case, the result doesn't support the previous graph that is FOE vs HCPV.

Oil Viscosity

<u>FOPR vs HCPV</u>

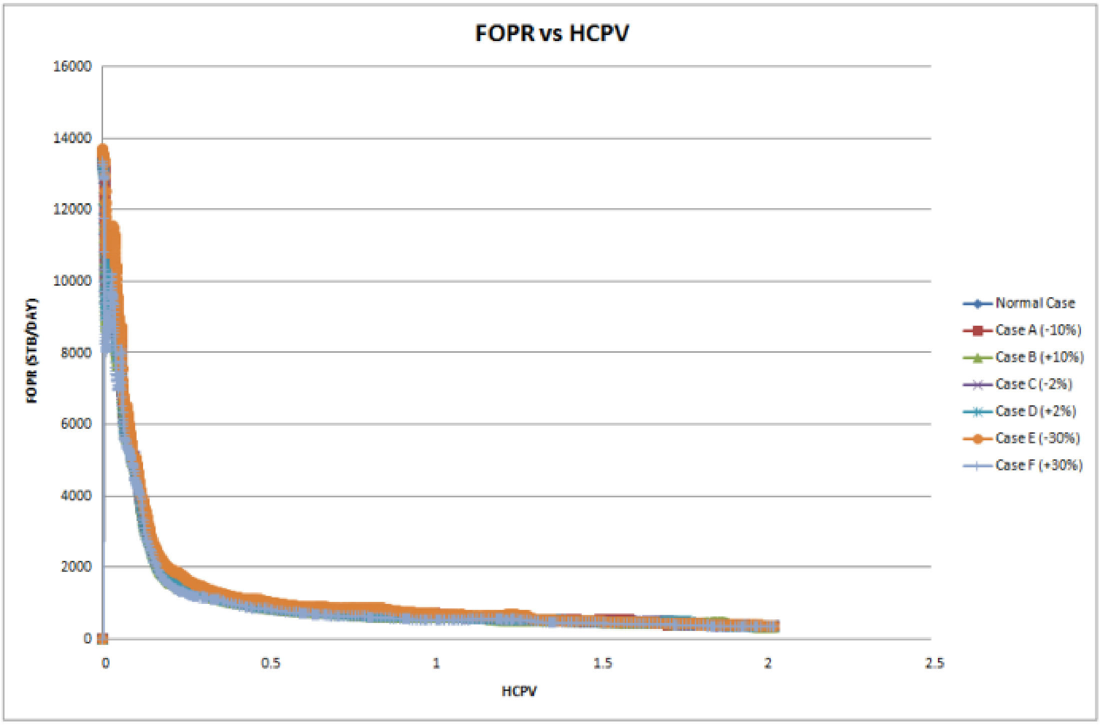


Figure 4.19 FOPR vs HCPV

By referring to this graph, it was found that if we decrease the oil viscosity as much as 30%, the oil production rate will be higher than the normal case as proven by case E (-30%) and case A (-10%). However, if we increase the value of oil viscosity, the production rate will be lower than the normal case as proven by case B (+10%) and case F (+30%). As a conclusion, oil viscosity will result in increasing oil production rate and increasing the oil viscosity will decrease the oil production rate. This is because viscosity is the property that controls the movements of fluids. The higher the viscosity, the harder the fluid to move.

FOE vs HCPV

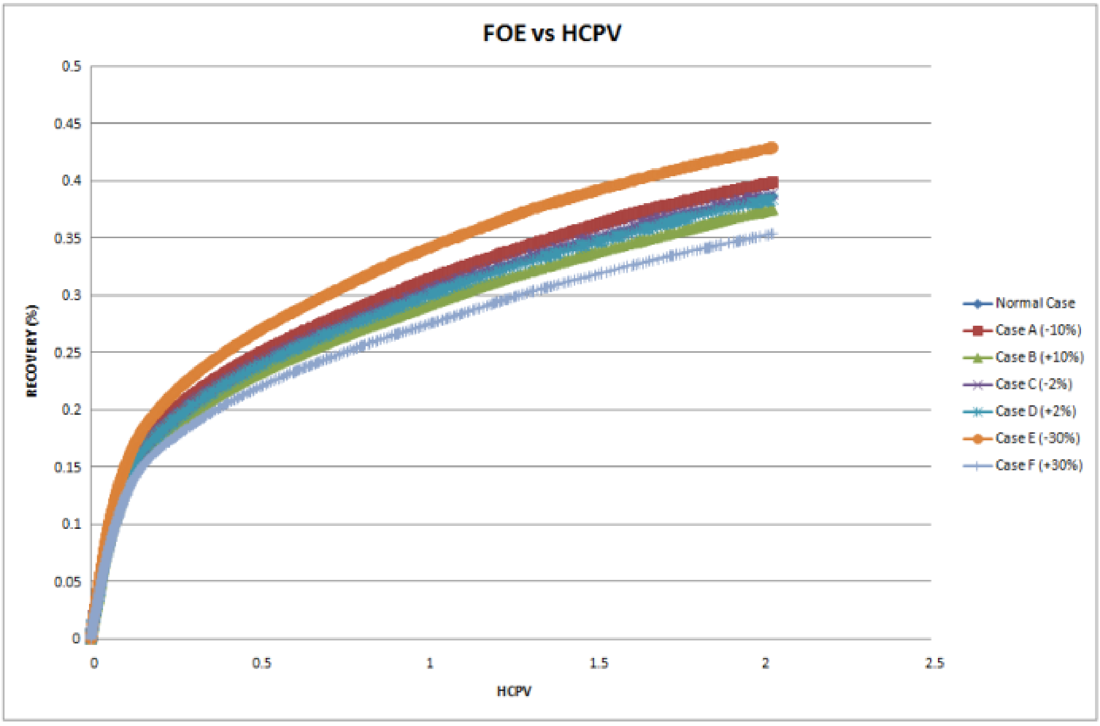


Figure 4.20 FOE vs HCPV

From the graph, decreasing oil viscosity will cause oil recovery to increase. The highest oil recovery is case E which was decreased by 30% of its initial value and the lowest oil recovery is case F which was increased by 30%. This is because lowering the viscosity, gives the oil easy to move and be recovered as viscosity is the property which controls the movements of fluids. By referring to this graph, it can be concluded that lowering the oil viscosity will give better oil recovery.

FGOR vs HCPV

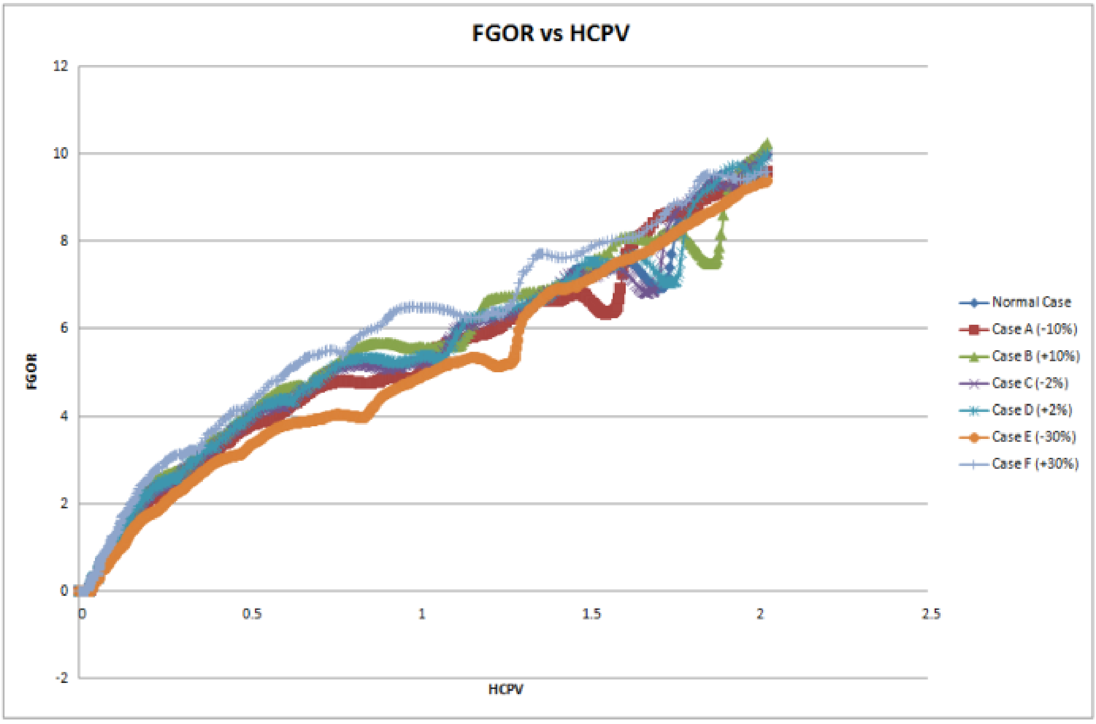


Figure 4.21 FGOR vs HCPV

This graph shows that case E, represented by orange coloured line which the viscosity was decreased by 30% has the lowest GOR and the highest GOR is case F which the viscosity was increased 30%. This proved that decreasing oil viscosity will give a better production. This graph supports the other 2 previous graphs that decreasing oil viscosity will give a better production as lower viscosity will make the fluid easier to move and be recovered.

SPIDER PLOT

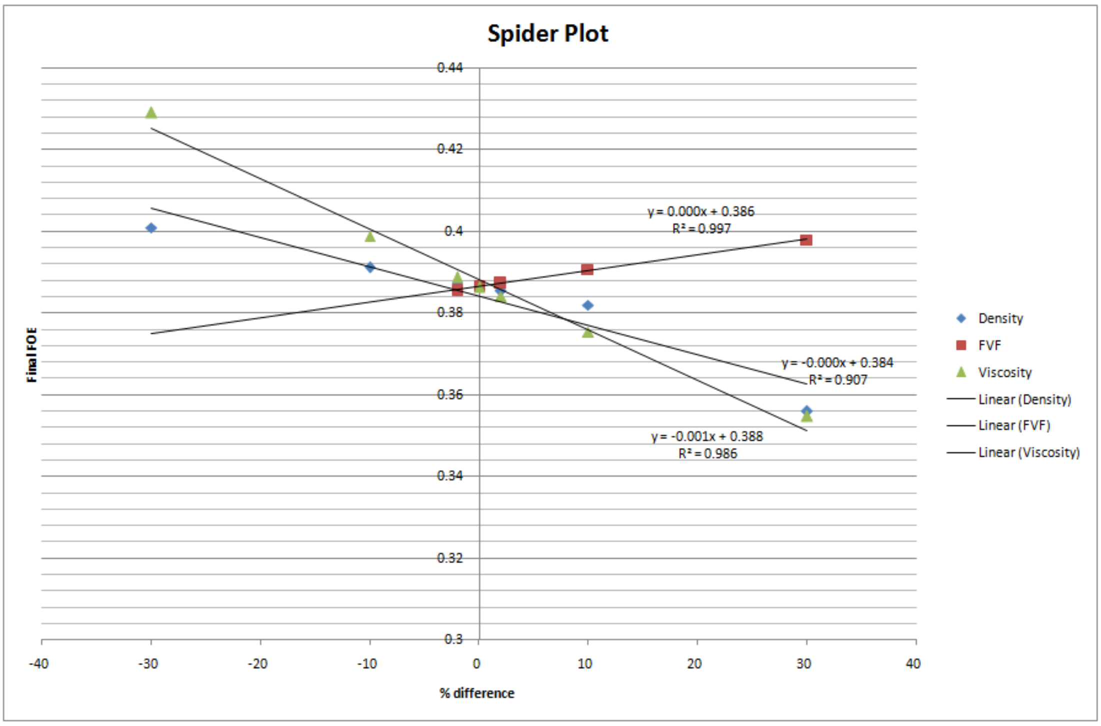


Figure 4.22 Spider Plot

From this spider plot, we can make these justifications:

- Increasing oil density will result in decreasing final FOE (oil recovery) as increasing the oil density means increasing the mass per volume of oil making it become heavier thus, harder to be recovered by water injection.
- Unlike oil density, increasing oil FVF will result in increasing final FOE (oil recovery).
- Similar to density, increasing oil viscosity will result in decreasing final FOE (oil recovery) as an increase in viscosity causes the fluids to be harder to move thus making it harder to be pumped out from the reservoir rock. Viscosity is the most sensitive properties in this study. As we can see, viscosity trend line has the steepest slope. Although it has the steepest slope, the value of the slope is only 0.001. It means that 1% change in the value of viscosity will give only 0.1% difference in the recovery factor. This means that the change in recovery factor due to viscosity is very small and not sensitive enough.

CHAPTER 5

SUMMARY AND CONCLUSION

In order to simulate the real field, Tinggi, practices of simulations have been done in the conceptual models. The miscible CO_2 flooding for Tinggi Field was performed and the analysis procedures have been done. The results have been discussed in the previous chapter. The most important thing in doing this simulation is to programme the data as accurate as possible in order to get a very precise result. After that, the analysis can be done perfectly. The procedures of the analysis for the real field were the same as the procedures done in this miscible CO_2 flooding simulation for a conceptual design.

From the first analysis that is the original field, there were factors that made the results unacceptable and need modifications. One of the factors is the condition or shape of the reservoir. The original field has an anti-cline reservoir shape. In this case, the gravity segregation influences the results and caused the result to be not as expected. Because of this, a modified data on this simulation were done in order to obtain acceptable results. In the modified field, only the reservoir field was changed into a horizontal shaped reservoir and other properties were the same. So, as a conclusion from the results, it was found that:

- Decreasing oil density and oil viscosity will give greater oil recovery factor and production and increasing them will decrease the oil recovery and also production
- Unlike oil density and oil viscosity, increasing oil formation volume factor will result in greater production and the recovery factor.

- From the sensitivity studies, viscosity is the most sensitive properties to the recovery factor. Although viscosity is the most sensitive properties, the sensitivity is very low. From the studies, 1% change in the value of viscosity will give only 0.1% difference in the recovery factor.

It is very important to study the sensitivity of fluid properties to the oil recovery factor in order to simulate a real oil reservoir field before the development of real oil field. This is because if we insert a false or incorrect data, the production forecast will vary from the real production and this can cause losses in profit for the company that runs the operations. A small difference in data keyed can give a change in the oil recovery and oil production. So, we must be careful in simulating an oil field.

As a recommendation, this simulation can give a better result if we use a 3D field simulation.

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APPENDICES

DATA ON PROPERTIES VALUE

	Case A	Case B	Case C	Case D	Case E	Case F
% difference	-10%	10%	-2%	2%	-30%	30%
Viscosity	0.63	0.77	0.686	0.714	0.49	0.91
Oil FVF	0.9585	1.1715	1.0437	1.0863	0.7455	1.3845
Density	40.5	49.5	44.1	45.9	31.5	58.5
		eliminated				

		Initial	
Pressure	Viscosity	Oil FVF	Density
1900	0.7	1.065	45