INJECTION STRATEGY TO DETERMINE HIGHEST OIL RECOVERY

By

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FINAL REPORT

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CERTIFICATION OF APPROVAL

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Muhammad Shukri b Ahmad Tajuddin

A final year project dissertation submitted to the
Petroleum Engineering Programme
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Approved:

Ms. Mazuin Jasamai
Project Supervisor

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TRONOH, PERAK

April 2011

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.

MUHAMMAD SHUKRI B AHMAD TAJUDDIN

ABSTRACT

The main objective of this project is to analyze different type of injection strategies by comparing the reservoir performance after applying different type of injection pattern and injection fluid techniques. The main parameter that crucially observed in this project is the percentage of oil recovery after applying recovery method, field reservoir pressure depletion, watercut and gas oil ratio from particular field.Injection is important for secondary oil recovery and highly affecting the performance of particular reservoir. In order to get the best or most efficient injection, there are several factors that need to be considered such as injection patterns and also injection fluid techniques. During FYP1, the author has implemented different type of injection pattern through out several cases in the conceptual model where injection at one corner of the reservoir from the bottom has proved the most effective pattern to be applied in the model. However, the author cannot continue the project to the real field like Angsi field that the author planned to do since the reservoir is homogenous and the injection pattern do not effect much in the production of oil from the field. So, for FYP2 the author focused mainly on the different types of injection fluid techniques including water injection, gas injection and also water alternating gas injection as the next injection strategy to be implemented in the particular real field in Malaysia which is Angsi field. The main methadology to be used in this project is simulation of Angsi field by using Eclipse 100 as the main software and Petrel as the add-on software.

ACKNOWLEDGEMENT

First of all, the author would like to take this opportunity to express a lot of thank you to everyone who has involve directly and indirectly until the completion of this final year project. The author really appreciates their effort on making this final year project as successful from the beginning until the end of the project period.

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Last but not least, the author would like to express special thanks to his family members and his friends for their encouragement, continues support, and helpful advices that really help to finish theproject with courage and spirit.

Thank You.

With Utmost Gratitude,

(MUHAMMAD SHUKRI B AHMAD TAJUDDIN)

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CHAPTER 1
INTRODUCTION

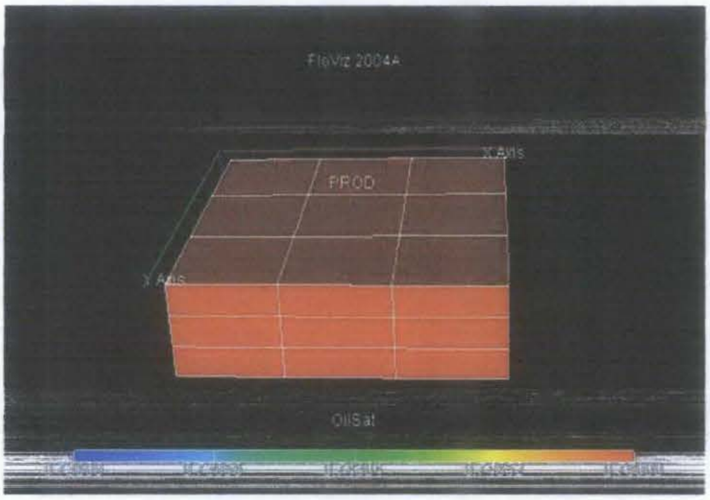
1.1 BACKGROUND

Injection strategy in this project is focused mainly on different types of injection patternand injection fluids techniques that will result in highest oil recovery. There are three injection patternsand injection fluidstechniques that being introduced in this project and based on these three injection pattern that being operated at the same condition of reservoir, a simulation study has been run in order to get the reservoir performance for each cases of fluids injection.

By using Eclipse DATA file, the basecase of reservoir model has been generated to be tested again these three injection strategies. For injection pattern strategy that has been implemented during FYP1, the injection patterns were tested based on conceptual model. For different injection fluids techniques which being implemented during FYP2, the strategy was conducted in the real Angsi field model where the reservoir model consists of 12 producing wells and set as active producer from 2001 until 2026. The reservoir is almost homogenous reservoir and produced naturally without any drive mechanism throughout the field life.

By using Eclipse DATA file, the conceptual reservoir model was generated to be tested again these three injection pattern. The reservoir model is in three dimensional where it is 3 cells in x, y and z directions. The reservoir is a homogenous reservoir where the porosity and permeability is the same throughout the reservoir.

The permeability for this reservoir is 200 mD and the porosity is 20%. The initial oil saturation is 75%. Picture below shows the conceptual reservoir model where there is production well at the middle of the reservoir and is producing for 5 years timeline.



[illegible]

[illegible] pattern which are:

1. [illegible] changing location of producer.
2. [illegible] location of the producer to another corner of the reservoir.
3. [illegible] wells surrounding the producer.

The efficiency for each of the injection patterns are analyzed by comparing the cumulative oil produced at the end of 5 years timeline of production.

For second strategy which is injection fluid technique, the Angsi field consists ofaverage permeability in x and y direction about551.8mD and in z direction about 55.181mD. The average porosity is 23% andthe initial oil saturation is 0.85 with initial water saturation is 0.15. The current stock tank oil initially in place, STOOIP is 231.143 MMbbl. Picture below shows the reservoir model overview where there are 105336 cells number for the whole grid and only 29248 is active cells.

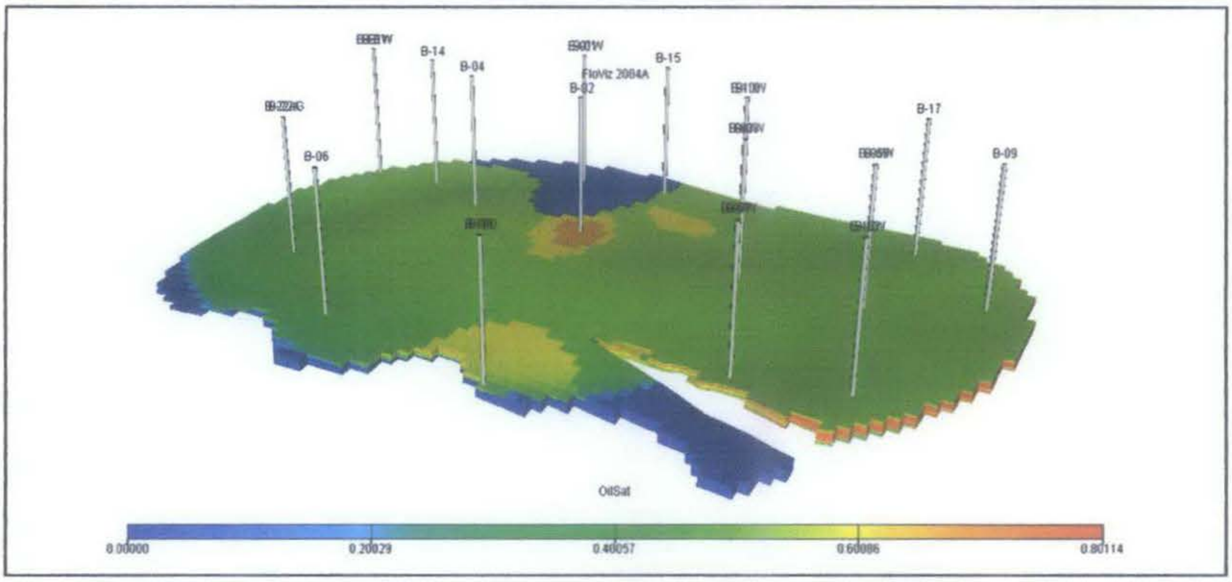


Figure 1.2: Basecase of Angsi reservoir model

Based on this basecase model, the author has implemented three different cases of injection fluids which are:

1) Case 1 –Water injection where there are 4 permanent water injection wells, 7 converted producer to water injector wells (after the well not producing economically) and 5 permanent producing wells.

2) Case 2 – Gas Injection where there are 4 permanent gas injection wells, 7 converted producer to gas injector wells (after the well not producing economically) and 5 permanent producing wells.
3) Case 3 –Water Alternating Gas (WAG) where there are 4 permanent WAG injection wells, 7 converted producers to water injector wells (after the well not producing economically) and 5 permanent producing wells.

The efficiency for each of the injection fluid typesis analyzed by comparing thereservoir performance for each of the cases in terms of Oil Recovery, Watercut and Gas Oil Ratio.

1.2 PROBLEM STATEMENT

1.2.1 PROBLEM IDENTIFICATION

Nowadays, injection becomes one of the important technology in secondary oil recovery in order to increase oil recovery. Theoritically, there are many methods of injection fluids that can be done for particular reservoir in order to increase oil recovery. However, it is crucial to compare different types of injection fluids in order to get the best method to increase oil recovery.

Eventhough the pattern introduced based on the theory; peripheral injection pattern, line-drive injection pattern, and regular injection pattern (4, 5 spot and etc.) can significantly improve the oil recovery, but certain pattern only suitable for particular reservoir characteristic. This project will try to determine which injection pattern will result in highest oil recovery based on the same reservoir condition generated from conceptual model.

The implementation of secondary oil recovery namely water or gas injection and water alternating gas injection in Malaysia are getting more and more crucial since the oil reserve left these days more towards residual oil. This project will study the best methodology to be implemented particularly in injection fluids strategy to get the best oil recovery.

So, the study regarding this project is important to know what is the best injection fluids in order to be implemented in particular reservoir.

1.2.2 SIGNIFICANT OF THE PROJECT

Actually, the study regarding different injection patterns and injection fluids typesare important in order to determine which injection fluids will result in highest oil recovery. Due to many injection pattern existed in the industry nowadays, the study regarding which pattern will result inhighest oil recovery is important in order to maximize oil recovery. In terms of injection fluids techniques, there are three different injection fluids methods being analyzed which are water injection, gas injection and water alternating gas injection.It is important to study the effeciency for each of the injection fluids method in order to determine the best method which will result in highest oil recovery.

In the economic side, the secondary and tertiary recovery will cost a lot of money in order to be implemented. For example the cost to inject gas specifically nitrogen injection in 20 years time will surely cost a lot of money and the expection from the oil recovery should be high. Since the poor selection of injection strategy, the field produce less than expected. As for the injection pattern, it should be optimized because for example in the particular field, 4 spot injection can produce higher oil recovery compared to 5 spot injection. So, base on this project once can save money to be spent instead of applying 5 spot injection pattern, 4 spot injection is more efficient and not too costly.This will surely give loss to the company. So this project is also crucial to give the best method to increase oil recovery.

Besides that, the study regarding injection fluid types also can solve a few problem on certain reservoir that is having production problem even after applied injection. This is because, for particular reservoir characteristic, there are certain injection fluids type can be applied. It is important to study the injection fluids to solve the issue.

1.3 OBJECTIVE

The main objective of this project is to get the best injection fluids methods in order to be applied in particular field, so that the highest recovery can be achieved. Other than that are to:

- Determine the best injection pattern to be applied in the reservoir based on the conceptual model.
- Determine the best injection fluid techniques to be applied in the reservoir based on different injection cases.
- Compare the impact of different oil recovery mechanism towards total oil production.
- Analyze the effect of tertiary recovery specifically water alternating gas injection towards oil recovery.

1.4 SCOPE OF STUDY

The scope of this project is focused more towards on:

- Secondary oil recovery methadology which includes water injection and gas injection
- Tertiary oil recovery methadology specifically water alternating gas injection.
- Reservoir performance which includes reservoir pressure, gas oil ratio and water cut besides percentage of oil recovery.
- Different types of injection pattern being applied in the industry.

1.5THE RELEVANCY OF THE PROJECT

This project is still relevant since the secondary and tertiary recovery is a famous and well-known technology used by many oil companies in order to stimulate the production. The main things being discussed in this project is more towards the suitable injectionpatterns and injection fluids techniques which will surely affect the reservoir in terms of the recovery factor and pressure support.

If the injection patterns and injection fluids techniques are not suitable or not optimized for oil production, the project will be potentially facing lose in profit. In order to prevent this, it is important to consider the efficiency for each of the applied methods so that the production can be optimized.

So, this injection strategy project is a relevance topic to be considered since this secondary and tertiary oil recovery technique being used regularly in oil and gas company.

1.6FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

The project is suitable to be implemented within the scope and time frame where it involves the study on how different injection patterns and injection fluids techniques will affect the oil recovery. Besides that, this project also involves simulation of these injection strategy using ECLIPSE and Petrel softwares which does not takes long time for the project to be simulated. So it is feasible to be implemented within the scope and time frame.

CHAPTER 2
LITERATURE REVIEW

In this part, the theoritical analysis regarding the injection strategy throughout FYP 1 and FYP 2 is thoroughly discussed to get the better understanding on each strategy being applied either in conceptual model or even in the real model.

Based on this project, the injection strategy project during FYP 1 is more towards injection pattern and being applied in conceptual model.For FYP 2, the injection strategy will focus more on the current oil recovery techniques being applied nowadays such as water injection, gas injection and also water alternating gas injection where the simulation of these injection strategies being done in Angsi field located at Malaysia.

2.1 PRIMARY, SECONDARY AND TERTIARY RECOVERY

Primary oil recovery describes the production of hydrocarbons underthe natural driving mechanisms present in the reservoir without supplementaryhelp from injected fluids such as gas or water. In most cases, thenatural driving mechanism is a relatively inefficient process and resultsin a low overall oil recovery. The lack of sufficient natural drive in mostreservoirs has led to the practice of supplementing the natural reservoirenergy by introducing some form of artificial drive, the most basicmethod being appliedare injection of gas or water.

Secondary oil recovery refers to the additional recovery that resultsfrom the conventional methods of water injection and immiscible gasinjection. Usually, the selected secondary recovery process follows theprimary recovery but it can also be conducted concurrently withthe primary recovery. Water injection is the most common methodof secondary recovery. However, before implementing a secondary recoveryproject, it should be clearly proven that the natural recovery processes are proved insufficient or otherwise there is a risk that the investmentfor a secondary recovery project may be wasted.

Tertiary (enhanced) oil recovery is that additional recovery over andabove what could be recovered by primary and secondary recovery methods.Various methods of enhanced oil recovery (EOR) are essentiallydesigned to recover oil, commonly described as residual oil, left in thereservoir after both primary and secondary recovery methods have beenapplied. Figure 2shows the effect of the three oil recovery categories to the field flow rate and overall recovery. (Ref 3)

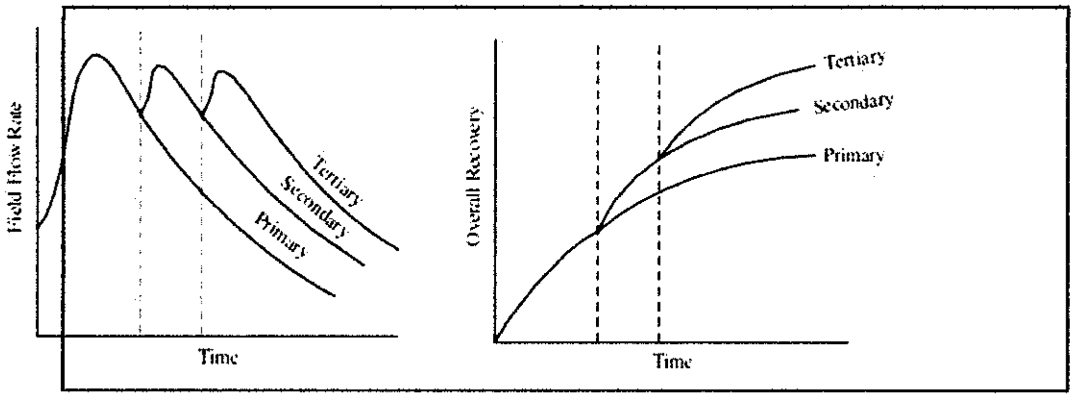


Figure 2.1: Effect of oil recovery categories to field flow rate and overall recovery

2.2WATER INJECTION, GAS INJECTION AND WATER ALTERNATING GAS

2.2.1 Water Injection

Water injection is a process whereby a large amount of water is pumped through injection well and displace the oil to the producer. Water can be injected into the aquifer and increase the water drive mechanism to support the oil production hence increase oil recovery. This process is also called water flooding. (Ref 5)

2.2.2 Gas Injection

Gas injection is a process of injection to oil reservoir by using gas supplement into the gas cap of the reservoir. This will inrease the gas cap drive mechanism of the reservoir which will push the oil to the producer. The source of gas usually takes from reservoir hydrocarbon gas or Carbon Dioxide (CO_2). There are two cases involved gas injection which are Immiscible displacement or miscible displacement. The tendency of gas to fingering during oil displacement usually cause the gas to mix with oil; and is called miscible displacement. However, there are certain point below minimum miscibility pressure where the gas will not mix with the oil. This is called immiscible displacement of oil. (Ref 5)

2.2.3 Water Alternating Gas Injection

Water alternating gas injection is usually done as supplementary to secondary oil recovery to further increase oil production by displacing attic oil inside the reservoir. The process is by injecting water at certain rate and volume for certain period of time, then the injected water is switched gas injection for certain period of time. Depending on the WAG ratio and WAG cycle, the process is repeated until the WAG plan for oil recovery is achieved. (Ref 5)

2.3FACTORS TO BE CONSIDERED IN WATER INJECTION

Based on Thomas, Mahoney, and Winter (1989), in determining the suitibility of a candidate reservoir for water injection, the following reservoir characteristics must be considered:

- Reservoir Geometry
- Fluid Properties
- Reservoir Depth
- Lithology and Rock Properties
- Fluid Saturations
- Reservoir uniformity and pay continuity
- Primary reservoir driving mechanisms

2.3.1 Reservoir Geometry

The areal geometry of the reservoir will influence the location of wellsand, if offshore, will influence the location and number of platformsrequired. The reservoir's geometry will essentially dictate the methods bywhich a reservoir can be produced through water-injection practices.An analysis of reservoir geometry and past reservoir performance isoften important when defining the presence and strength of a naturalwater drive and, thus, when defining the need to supplement the naturalinjection. If a water-drive reservoir is classified as an active water drive,injection may be unnecessary. (Ref 3)

2.3.2 Fluid Properties

The physical properties of the reservoir fluids have pronounced effectson the suitability of a given reservoir for further development by waterflooding.The viscosity of the crude oil is considered the most importantfluid property that affects the degree of success of a waterflooding project.The oil viscosity has the important effect of determining the mobilityratio that, in turn, controls the sweep efficiency. (Ref 6)

2.3.3 Reservoir Depth

Reservoir depth has an important influence on both the technical andeconomic aspects of a secondary or tertiary recovery project. Maximuminjection pressure will increase with depth. The costs of lifting oil fromvery deep wells will limit the maximum economic water–oil ratios thatcan be tolerated, thereby reducing the ultimate recovery factor andincreasing the total project operating costs.

On the other hand, a shallowreservoir imposes a restraint on the injection pressure that can be used,because this must be less than fracture pressure. In waterflood operations,there is a critical pressure (approximately 1 psi/ft of depth) that, if exceeded,permits the injecting water to expand openings along fractures or tocreate fractures.

This results in the channeling of the injected water or thebypassing of large portions of the reservoir matrix. Consequently, an operationalpressure gradient of 0.75 psi/ft of depth normally is allowed toprovide a sufficient margin of safety to prevent pressure parting. (Ref 6)

2.3.4 Lithology and Rock Properties

Thomas et al. (1989) pointed out that lithology has a profound influence on the efficiency of water injection in a particular reservoir. Reservoirlithology and rock properties that affect flood ability and successare:

- Porosity
- Permeability
- Clay content
- Net thickness

In some complex reservoir systems, only a small portion of the totalporosity, such as fracture porosity, will have sufficient permeability to beeffective in water-injection operations. In these cases, a water-injectionprogram will have only a minor impact on the matrix porosity, whichmight be crystalline, granular, or vugular in nature.Although evidence suggests that the clay minerals present in somesands may clog the pores by swelling and deflocculating when waterfloodingis used, no exact data are available as to the extent to which thismay occur.(Ref 6)

Tight (low-permeability) reservoirs or reservoirs with thin net thicknesspossess water-injection problems in terms of the desired waterinjectionrate or pressure. Note that the water-injection rate and pressureare roughly related by the following expression:

$P_{inj} \propto i_w / hk$ 2.1

where p_{inj} = water-injection pressure

i_w = water-injection rate

h = net thickness

k = absolute permeability

The above relationship suggests that to deliver a desired daily injectionrate of iw in a tight or thin reservoir, the required injection pressure mightexceed the formation fracture pressure.

2.3.5 Fluid Saturation

In determining the suitability of a reservoir for waterflooding, a highoil saturation that provides a sufficient supply of recoverable oil is theprimary criterion for successful flooding operations. Note that higher oilsaturation at the beginning of flood operations increases the oil mobilitythat, in turn, gives higher recovery efficiency. (Ref 3)

2.4FACTORS TO BE CONSIDERED IN INJECTION PATTERN

The areal geometry of the reservoir will influence the location of well, which will influence the location and number of platformsrequired. The reservoir's geometry will essentially determine the methods bywhich a reservoir can be produced through injection practices.

An analysis of reservoir geometry and past reservoir performance isimportant when defining the presence and strength of a naturalwater drive and also determine the need to supplement the naturalinjection. If a water-drive reservoir is classified as an active water drive,injection may be unnecessary. (Ref 4)

The physical properties of the reservoir fluids have effectson the suitability of a given reservoir for further development of injection.The viscosity of the crude oil is considered the most importantfluid property that affects the degree of success of a injection project.The oil viscosity has the important effect of determining the mobilityratio that which will control the sweep efficiency.

In terms of oil saturation, a highoil saturation that provides a sufficient supply of recoverable oil is theprimary criterion for successful injection operations. This is because higher oilsaturation at the beginning of injection operations will increase the oil mobilitythat which will give higher recovery efficiency.

2.5INJECTION PATTERN SELECTION

The regular injection patterns yield areal sweep efficiencies in the high permeability layers where the proposed injection pattern usually:

- Provide desired oil production rate.
- Provide sufficient injection rate to support oil production rate.
- Maximize oil recovery with minimize water production to lift,handle and dispose.
- Utilize existing wells and thus minimize drilling of new wells.
- Be compatible with flooding patterns.

Basically, two different choices of injection patterns are available which are:

- Treatment of the reservoir as a whole using a peripheral injection.

  This technique utilizes wells along the flanks of a reservoir for injection. For example, one of the world largest offshore waterfloods is the Umm Shaif field of Abu Dhabi which has 25 peripheral injection wells. In such a flood, production well can be shut-in at or shortly after water breakthrough, and the oil recoverable at these well will be recovered at the next row of producers.

The peripheral flood generally yields a maximum oil recovery with aminimum of produced water.Because of the unusually small number of injectors compared with thenumber of producers, it takes a long time for the injected water to fill upthe reservoir gas space. The result is a delay in the field response to theflood.

For a successful peripheral flood, the formation permeability must belarge enough to permit the movement of the injected water at thedesired rate over the distance of several well spacings from injectionwells to the last line of producers.

- Treatment using repeating pattern such as five spot, nine spot, etc.

If a pattern injection is indicated, the engineer must decide the type of pattern. In the industry, five spots and nine spots are common flooding pattern. Labaratory studies have shown that both of these pattern yield the same oil recovery.

2.6TYPICAL INJECTION PATTERNS

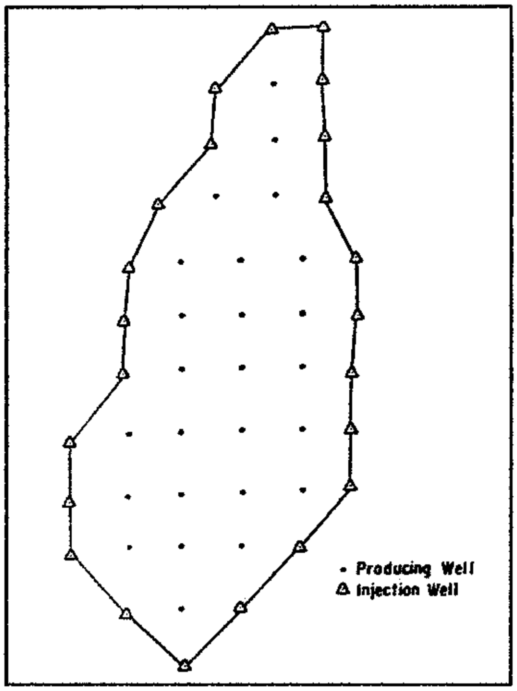


Figure 2.2: Typical Peripheral Injection

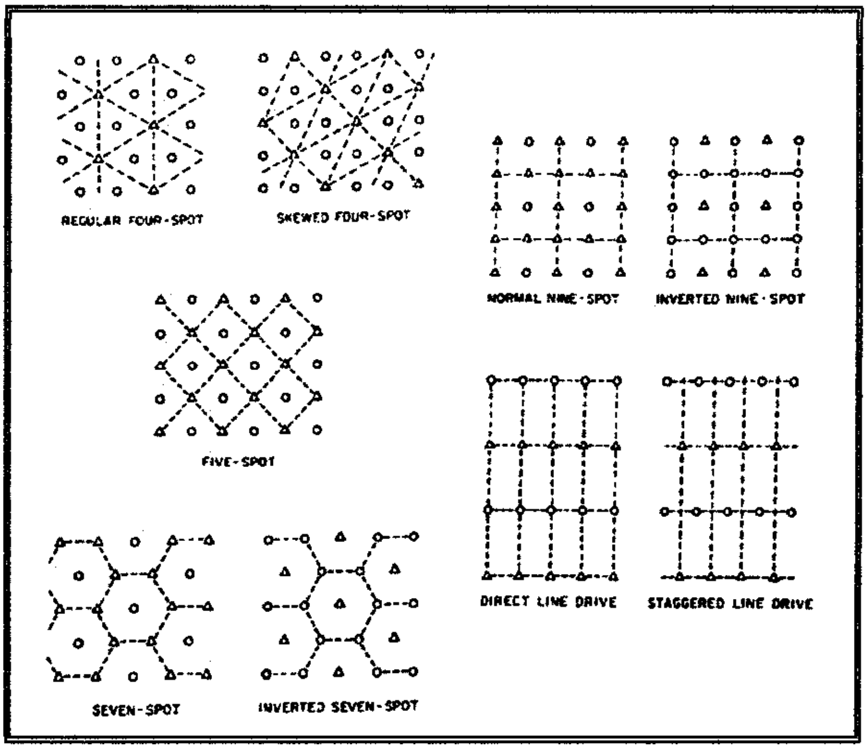


Figure 2.3: Injection Pattern

2.7BUCKLEY-LEVERETT THEORY

Other main concern in designing the conceptual model for this project is when to start injection and the suitable rate of injection. In order to determine these things, Buckley-Leverett theory is applied. Below is a standard reservoir pressure curve where the water injection is applied toincrease reservoir pressure.

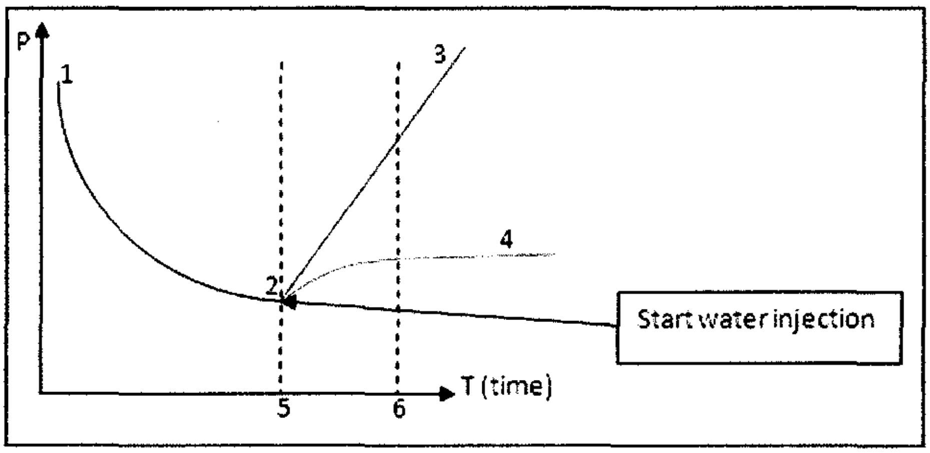


Figure 2.4: Standard Reservoir Pressure Decline.

Based on the graph shown above, the reservoir pressure starts to decline from point 1 to point 2. In order to maintain the reservoir pressure, water injection start to be implemented at point 2 where to increase back the reservoir pressure. There are two possibilitiesof injection result:

Result 1 (Point 3) – Injecting water at high rate. This will make reservoir pressure to increaseextremely high without any caution. Possibility of pressure to be above fracture pressure is high.

Result 2 (Point 4) – Injecting water at stabilised rate. This will make reservoir pressure toincrease gradually where there are filled up time between point 5 and 6. The pressure has been stabilised at point 4 where below fracture pressure and at pressure at bubble point pressure (Lowest viscosity and easy for oil to flow).

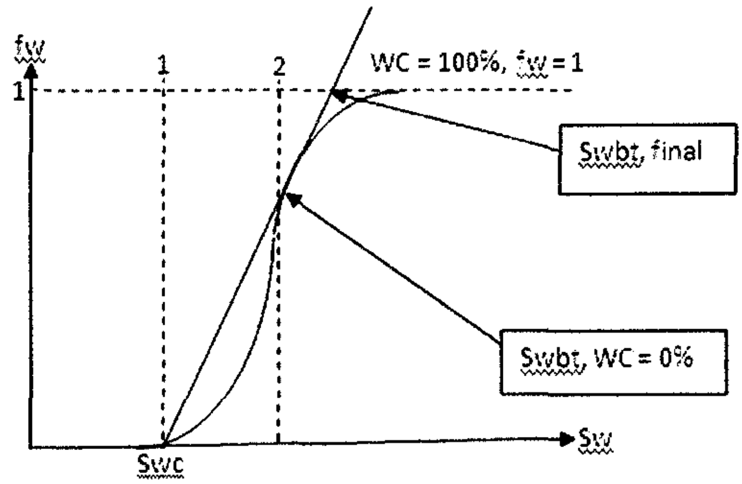


Figure 2.5: Buckley-Leverett frictional flow curve

Graph show how water injection react based on Buckley-Leverett theory:

i) Swc: Start to inject water at initial water connate saturation. Point between Swc and Swbt is called filled up time.

ii) Swbt: Water break through saturation where water phase start to touch oil phase in the field. At this point water starts to produce.

iii) Swbt, final: Final water break through saturation where watercut, WC = 100% and fractional flow = 1.

CHAPTER 3
METHADOLOGY

3.1 RESEARCH METHADOLOGY

The research methodology involve in this project consist of three main phases. First one is research study, then conducts simulation and lastly evaluates result.

In the research study, things regarding theory and application of different injection pattern are studied. Besides that, all the data are gathered throughout this phases which includes the reservoir data, injection data and production data.

After that is conducting simulation where in this phases, the author start to generate the reservoir model in the simulation software and start to play around with the different injection pattern andinjection fluid techniquesincluding water injection, gas injection and water alternating gas injectionin the simulation.

The last phase is evaluating result. In this phase, all results from the simulation will be compiled and evaluated. It is important to compare the results from different injection pattern and different injection fluid techniques in order to get the most efficient one which will result in highest oil recovery.

3.2 PROJECT ACTIVITIES

Table 3.1: FYP1 & FYP2 Project Activities

No	Activities	FYP 1	FYP 2
1	Selection of FYP Topic	/	
2	Research Studies on FYP 1	/	
5	Data Gathering	/	
6	Simulation of Conceptual Model	/	
7	Completing Simulation and & Data Analysis	/	
8	Submission of Interim Report	/	
10	Research Studies on FYP 2		/
11	Simulation on Angsi Model		/
13	Data Analysis on Simulation Result		/
14	Pre-EDX, Poster Exhibition and Final Report		/
16	Final Oral Presentation		/
17	Final Report delivery to External Examiner		/

3.3 KEY MILESTONE

Table 3.2: FYP 1 Key Milestone

No	Activities	Date(Week)
1	*Selection of FYP topic*	W2
2	Research Study	W3-W4
3	Conducting Simulation	W5-W8
4	Results Evaluation from data	W8-W12
5	Interim Report & Oral Presentation	W13-W14

Table 3.3: FYP 2 Key Milestone

No	Activities	Date(Week)
1	Research Study	W1-W3
2	Conducting Simulation	W3-W7
3	Results Evaluation from data	W7-W9
4	Pre-EDX, Poster Exhibition &Final Report Submission	W9-W12
5	Final Oral Presentation	W13-W14

3.4 GANTT CHART

Table 3.4: FYP1 Gantt Chart

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	Research Work				■	■	■				■	■	■	■	■	■
3	Submission of Preliminary Report						●									
4	Submission of Progress Report										●					
5	Data Gathering											■	■	■		
5	Simulation of Reservoir Model													■	■	
6	Seminar 1															
7	Completing Simulation & Data analysis												■	■	■	■
8	Submission of Interim Report Final Draft															●
9	Oral Presentation															●

Table 3.5: FYP2 Gantt Chart

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Research Work	■	■	■	■	■	■	■	Mid-semester break							
2	Simulation of Reservoir Model				■	■	■				■	■	■			
3	Submission of Progress Report									●						
4	Completing Simulation & Data analysis											■	■			
5	Result Analysis between Different Cases												■			
6	Pre-EDX, Poster Exhibition and Submission of Final Report													■		
7	Engineering Design Exhibition (EDX)													■		
8	Final Oral Presentation														■	
9	Final Report delivery to Ext. Examiner															●

■ Progress
● Key milestone

3.5RESERVOIRSIMULATION MODELS

The main tool that been used in order to conduct this project is ECLIPSE software where many of the cases involve the simulation of conceptual model and real field model throughout different injection fluid methods.

Other software that also involve in this project is Petrel RE where this software act as viewing toolof reservoir model and also display the result of the project based on the ECLIPSE data file.

In designing the basecase model and injection model, there are several steps to be included in order to compare different types of injection patterns and injectionfluid techniques, which are:

FYP 1 Simulation Modelling

- Basecase model

  The basecase model is designed for the initial or original conditions of the reservoir before apply the injection. Based on this model, all the reservoir parameter like the permeability, porosity, oil saturation is coded in the ECLIPSE data file. After run the ECLIPSE, the model is further analyzed in the PETREL software for the detailed simulation result.

- Case 1, Case 2 and Case 3 Model

  The process is the same as the basecase model, but there are slightly different in the coding of the DATA file where for each different injection pattern, there are certain modification have been made in the SCHEDULE>INJECTION CONTROL section. Under this section, the location and the number of injection wells involve for each of the cases is changed for different injection patterns.

FYP 2 Simulation Modelling

- Basecase model

  The basecase model is designed for the initial or original conditions of the reservoir before apply the injection where the reservoir produced naturally without any drive mechanism. Based on this model, all the reservoir parameters like the permeability, porosity, oil saturation arecodedin the ECLIPSE data file. After run the ECLIPSE software, all the important parameters such as oil initially in place, cumulative oil, field reservoir pressure, field gas oil ratio and field watercut are analyzed.

- Case 1, Case 2 and Case 3

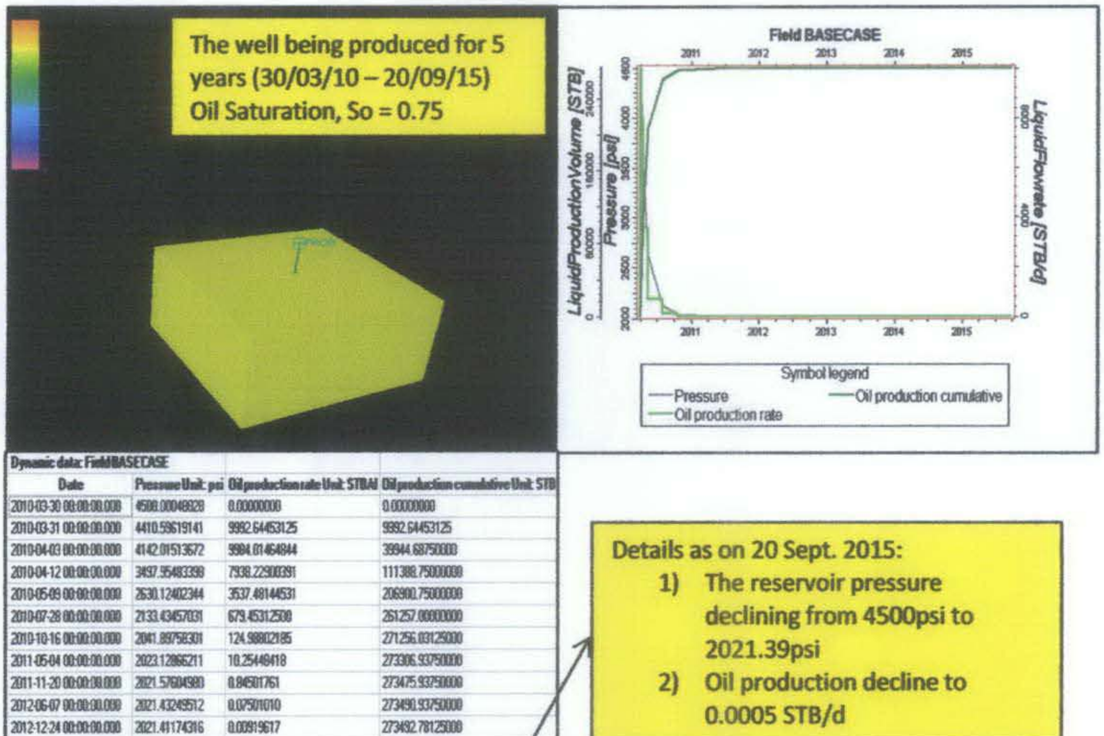
  The process is the same as the basecase model, but there are slightly different in the coding of the DATA file where for each different injection fluid types, there are certain modification have been made in the SCHEDULE>WCONINJE section. Under this section, the injection fluids for different cases are modified to water or gas depends on the cases. For case 3 model, there are certain keywords have been added in the data file like WCYCLE and WELOPEN in order to allow certain well to apply Water Alternating Gas (WAG) injection for certain period of time with specific WAG ratio and WAG Cycle.

CHAPTER 4

RESULTS & DISCUSSION

FYP 1 RESULTS AND DISCUSSIONS

4.1 BASECASE OF CONCEPTUAL MODEL



Dynamic data: Field BASECASE

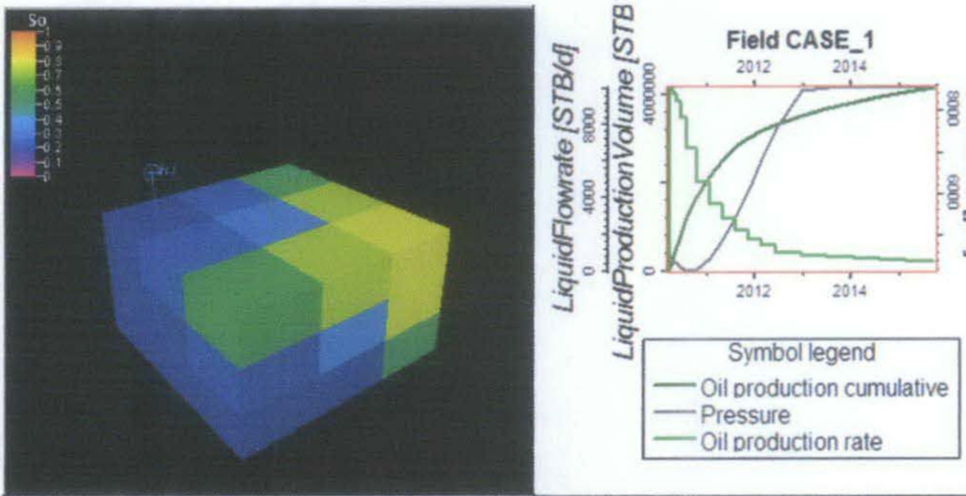
Date	Pressure Unit: psi	Oil production rate Unit: STB/d	Oil production cumulative Unit: STB
2010-03-30 00:00:00.000	4500.00048828	0.00000000	0.00000000
2010-03-31 00:00:00.000	4410.59619141	9992.64453125	9992.64453125
2010-04-03 00:00:00.000	4142.01513672	9984.01464844	39944.68750000
2010-04-12 00:00:00.000	3497.95483398	7938.22900391	111388.75000000
2010-05-09 00:00:00.000	2630.12402344	3537.48144531	206900.75000000
2010-07-28 00:00:00.000	2133.43457031	679.45312500	261257.00000000
2010-10-16 00:00:00.000	2041.89758301	124.98802185	271256.03125000
2011-05-04 00:00:00.000	2023.12866211	10.25449418	273306.93750000
2011-11-20 00:00:00.000	2021.57604980	0.84501761	273475.93750000
2012-06-07 00:00:00.000	2021.43249512	0.07501010	273490.93750000
2012-12-24 00:00:00.000	2021.41174316	0.00919617	273492.78125000
2013-07-12 00:00:00.000	2021.40319824	0.00316973	273493.40625000
2014-01-28 00:00:00.000	2021.39807129	0.00184874	273493.78125000
2014-08-16 00:00:00.000	2021.39453125	0.00122159	273494.03125000
2015-03-04 00:00:00.000	2021.39221191	[illegible]	273494.18750000
2015-09-20 00:00:00.000	2021.39062500	0.00053968	273494.31250000

Figure 4.1: Basecase of Conceptual Model

Based on the result shown, the reservoir pressure is declined from 4500 psi to 2021.39 psi. The oil production at the end of 5 years timeline is nearly no production with the rate of 0.0005 STB/d and the cumulative oil is 0.27 MMbbl. There are still much oil not being swept from the reservoir and this can be optimized by using different injection pattern from Case 1, Case 2, and Case 3.

4.2CASE 1 INJECTION

In this case, water injection well is placed at one corner of the reservoir where the injection is at the top layer. Figure below shows how the model looks like based on the PETREL simulation.



Date	Oil production cumulative Unit: STB	Pressure Unit: psi	Oil production rate Unit: STB/d
2010-03-30 00:00:00.000	0.00000000	4500.00048828	0.00000000
2010-03-31 00:00:00.000	9994.73339844	4496.57666016	9994.73339844
2010-04-02 01:41:16.421	30684.35156250	4489.25488281	9993.39648438
2010-04-08 06:45:05.685	92693.70312500	4467.43164063	9983.81640625
2010-04-18 07:02:46.882	192250.75000000	4432.70312500	9943.49121094
2010-05-01 08:25:08.093	320907.50000000	4388.90722656	9853.32714844
2010-05-21 13:30:09.558	515957.03125000	4325.62792969	9650.26855469
2010-06-21 21:19:58.707	805344.31250000	4241.99023438	9237.84472656
2010-08-06 21:41:52.793	1190355.87500000	4164.86376953	8367.05273438
2010-10-16 00:00:00.000	1656606.62500000	4190.82031250	6651.61035156
2011-01-23 02:51:57.480	2132624.50000000	4458.77050781	4802.46972656
2011-05-04 00:00:00.000	2495180.25000000	4896.93847656	3593.90820313
2011-08-12 00:00:00.000	2772577.50000000	5448.09228516	2773.97460938
2011-11-20 00:00:00.000	2988164.50000000	6089.16503906	2155.86840820
2012-02-28 00:00:00.000	3157398.00000000	6798.62695313	1692.33666992
2012-06-07 00:00:00.000	3290626.75000000	7560.97265625	1332.28723145
2012-12-24 00:00:00.000	3481398.75000000	8468.78906250	953.85968018
2013-07-12 00:00:00.000	3645718.75000000	8541.87695313	821.60040283
2014-01-28 00:00:00.000	3788553.25000000	8550.26171875	714.17138672
2014-08-16 00:00:00.000	3914560.00000000	8553.09960938	630.03442383
2015-03-04 00:00:00.000	4026819.00000000	[illegible]	561.2[illegible]
2015-09-20 00:00:00.000	4127025.00000000	8556.78808594	501.02999878

Details as on 20 Sept. 2015:

1) **Shows significance increase in reservoir pressure from 4500psi to 8556.78psi**
2) **Oil production decline to 501.03STB/d**
3) **Cumulative Oil is 4.12 MMbbl**

Figure 4.2: Case 1 Injection

Based on the result shown above, the reservoir pressure has increased from 4500psi to 8556psi. the oil production rate at the end of 5 years timeline is 501.03STB/d and the cumulative oil is 4.12MMbbl. From case 1 injection, it shows that there is more oil recovery produced compared to the basecase model.

4.3CASE 2 INJECTION

In this case, the injection is also at the corner of the reservoir and the production well is at the other corner of the reservoir. This can allow the water to sweep the oil to the other corner of the reservoir and produced through the production well. The injection well is penetrated at the bottom layer of the reservoir and the producer at the top layer. Figure below shows the process of water injection.

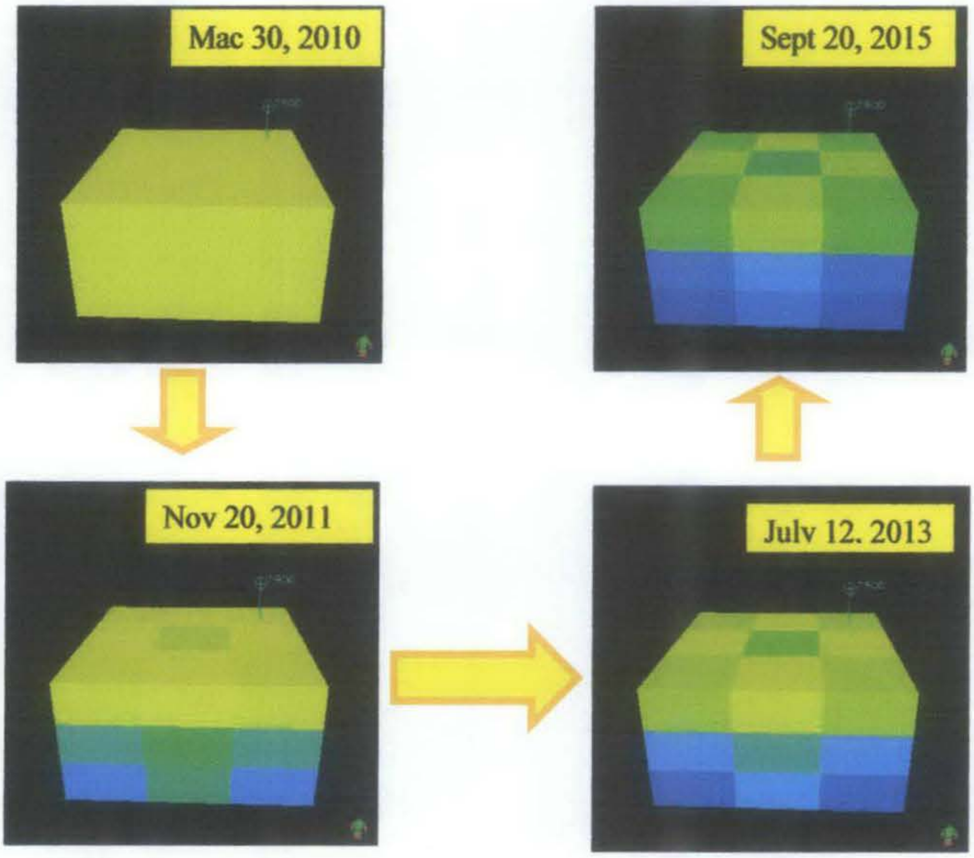


Figure 4.3: Case 2 Injection

The result of the injection is as shown below:

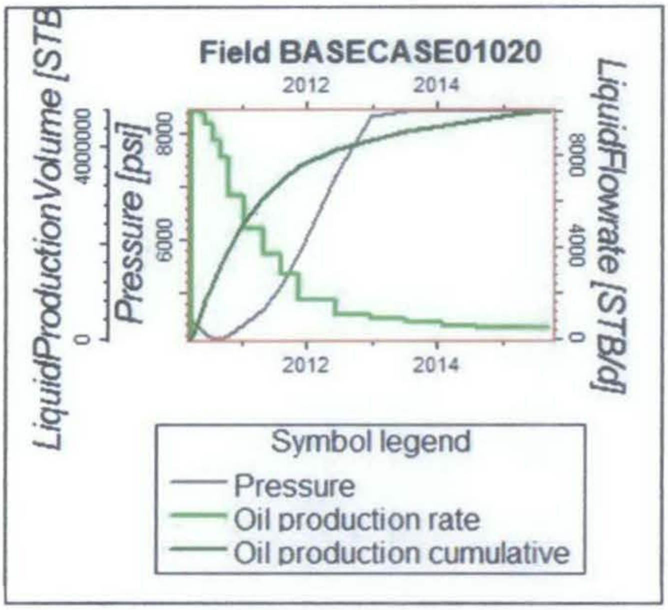


Figure 4.4: Case 2 graph

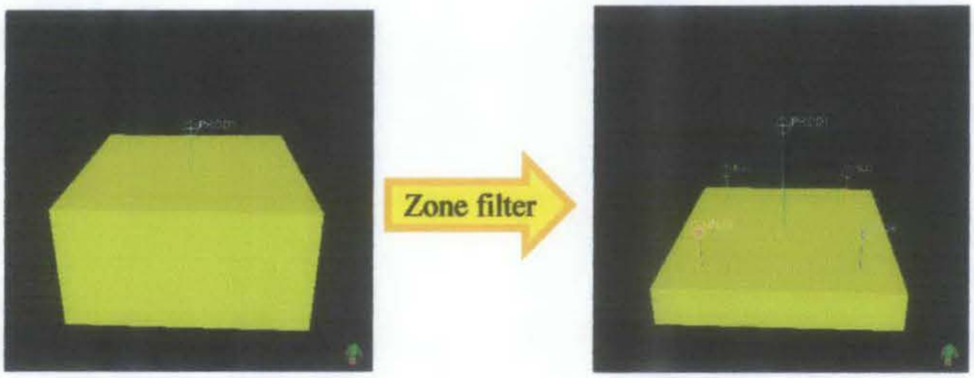
Table 4.1: Case 2 result

Pressure Unit: psi	Oil production rate Unit: STB/d	Oil production cumulative Unit: STB
4500.00048828	0.00000000	0.00000000
4496.56835938	9991.80468750	9991.80468750
4489.41503906	9990.11425781	30476.94335938
4468.07666016	9990.16992188	91932.70312500
4432.01562500	9990.01464844	196118.07812500
4388.34814453	9986.97460938	322630.53125000
4322.01464844	9964.28613281	515019.15625000
4229.80859375	9859.65820313	786317.43750000
4141.52392578	9426.14160156	1159959.25000000
4149.27929688	8685.32519531	1512750.37500000
4208.50390625	7924.45458984	1834635.50000000
4406.80712891	6286.13476563	2436648.00000000
4708.86962891	4800.03320313	2936963.50000000
5159.57470703	3657.86547852	3302750.25000000
5733.57128906	2819.66845703	3584717.00000000
7205.36425781	1691.59997559	3923037.00000000
8320.22656250	1071.66113281	4137369.25000000
8411.63671875	845.49481201	4306468.00000000
8423.35449219	700.32244873	4446532.50000000
8428.06250000	592.56597900	4565046.00000000
8431.51367188	508.62774658	4666771.50000000
8434.34277344	441.40652466	4755052.50000000

From the table above, the reservoir pressure has increased to 8434psi at the end of 5 year timeline. The oil rate produced at 441STB/d and the cumulative oil shows slightly increase which is 4.75MMbbl. It shows that the oil recovery is higher in this case compared to the Case 1 injection.

4.4 CASE 3 INJECTION

This case involved 4 water injection wells at each corner of the reservoir and one production well at the middle. This model is also called five-spot model and regularly used in common injection pattern. Below is the location of injection and production wells as after filtering zone 1 and 2.



The sequence of water injection process is as shown in the figure below.

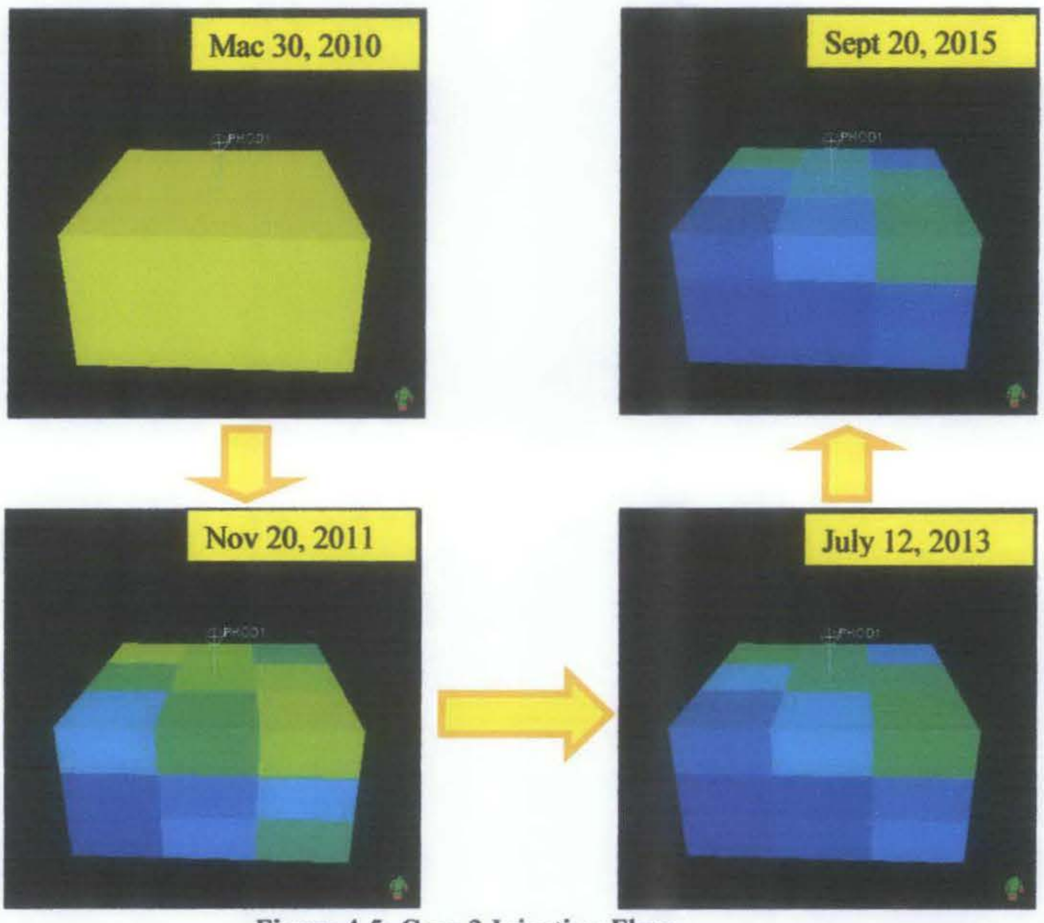


Figure 4.5: Case 3 Injection Flow

Below is graph and table of result from the case 3 injection.

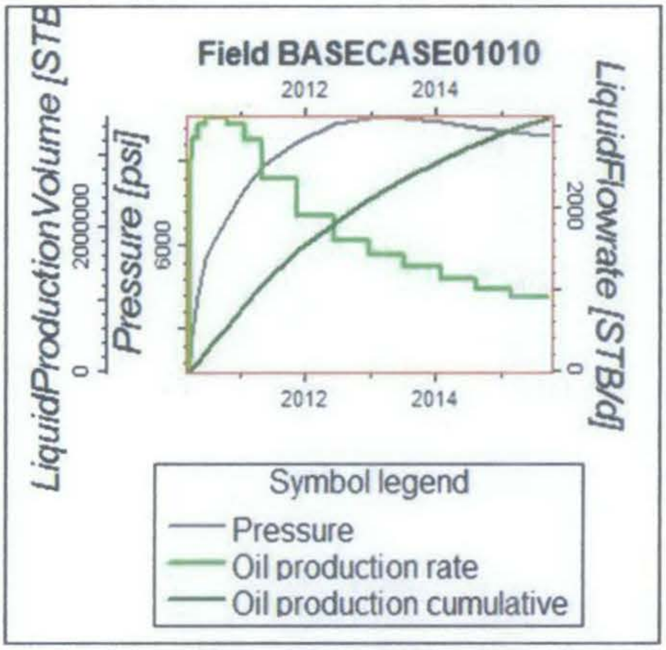


Figure 4.6: Case 3 graph

Table 4.2: Case 3 result

Pressure Unit: psi	Oil production rate Unit: STB/d	Oil production cumulative Unit: STB
4500.00048828	0.00000000	0.00000000
4540.07324219	2364.96264648	2364.96264648
4650.43896484	2435.54931641	9671.61035156
4915.10595703	2598.32568359	33056.53906250
5392.75097656	2852.87011719	110084.03906250
5836.65429688	3042.27880859	266137.28125000
6087.46044922	3101.05053711	434687.37500000
6326.84960938	3118.82519531	604203.56250000
6679.30664063	3026.88354492	906891.87500000
6943.05908203	2832.65161133	1190157.00000000
7237.80371094	2350.73168945	1660303.37500000
7444.51367188	1914.49890137	2043203.25000000
7529.21923828	1607.72949219	2364749.00000000
7517.55517578	1421.67773438	2649084.75000000
7467.23779297	1273.62780762	2903810.25000000
7409.36279297	1138.43444824	3131497.00000000
7352.73779297	1013.83404541	3334264.00000000
7300.55419922	900.40869141	3514345.75000000

Based on the result above, it shows that the oil recovery is only about 3.51MMbbl compared to case 2 and case 1 injection.

4.5 COMPARISON CASE 1, CASE 2, AND CASE 3

By analyzing the results from Case 1, Case 2, and Case 3, a table of comparison of each case can be generated based on oil recovery or cumulative oil at the end of 5 years time line.

Table 4.3: Oil recovery comparison

Date: 20 Sept 2015	Basecase	Case 1	Case 2	Case 3
Cum. Oil (MMbbl)	0.27	4.12	4.75	3.51

From the result shown in the table above, Case 2 injection is the most effective injection pattern since the oil recovery at the end of the field production is the highest compared to case 1 and case 3. By analyzing how the water sweep the oil in case 2, the location of injection well is considered the best because the water can sweep the oil from the bottom of the reservoir to the top thus allowing much more oil to be produced from the reservoir. Eventhough case 3 injection which is five spot injection consist of more injection well, but since the reservoir is not too suitable to be applied the current five spot injection, so it will result in lower oil recovery compared to case 1 and case 2 injection pattern.

4.6BASECASE OF ANGSI MODEL

This model is run for twenty six years timeline and producing naturally without any drive mechanism. Picture below shows the simulation of Angsi field after twenty six years of field production.

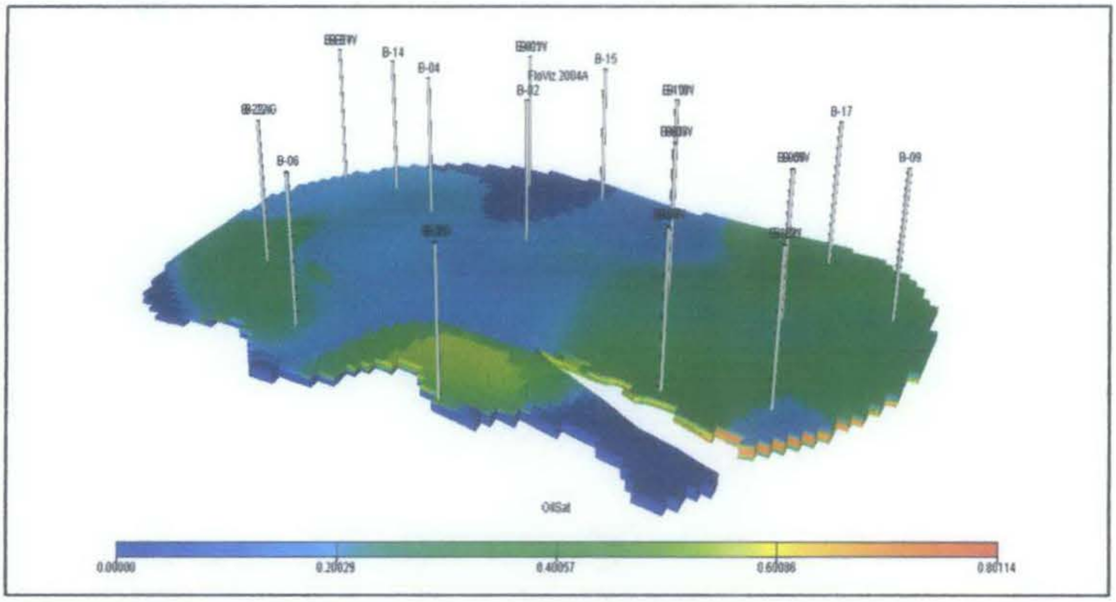


Figure 4.7: Reservoir simulation of basecase model after 26 years timeline

After twenty six year period of production, the result of reservoir production as well as reservoir performance is shown in graph below:

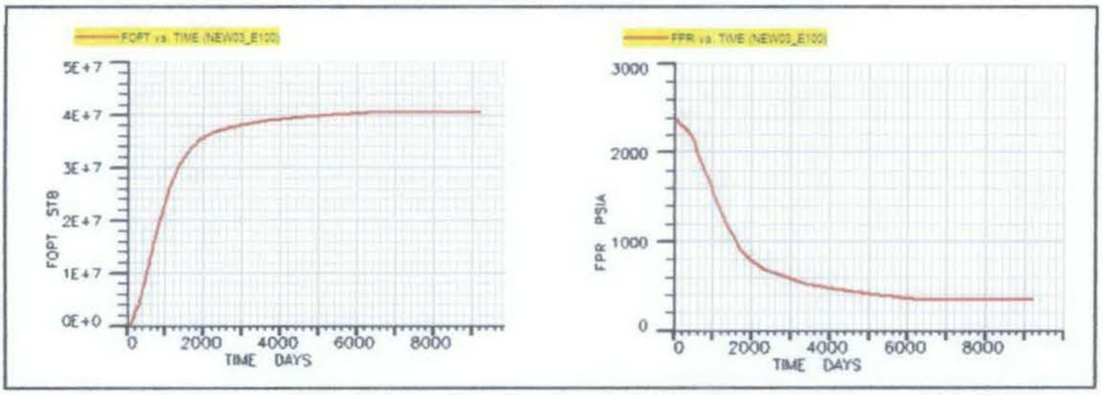


Figure4.8: Cumulative oil (FOPT)and field reservoir pressure (FPR) for basecase of Angsi Field

The total cumulative oil produced at the end of twenty six years time of field production is 40.47 MMbbl of oil which consist of 17.50% oil recovery compared to total oil initially in place. The reservoir pressure also depleted significantly from 2370 psi to 345 psi.

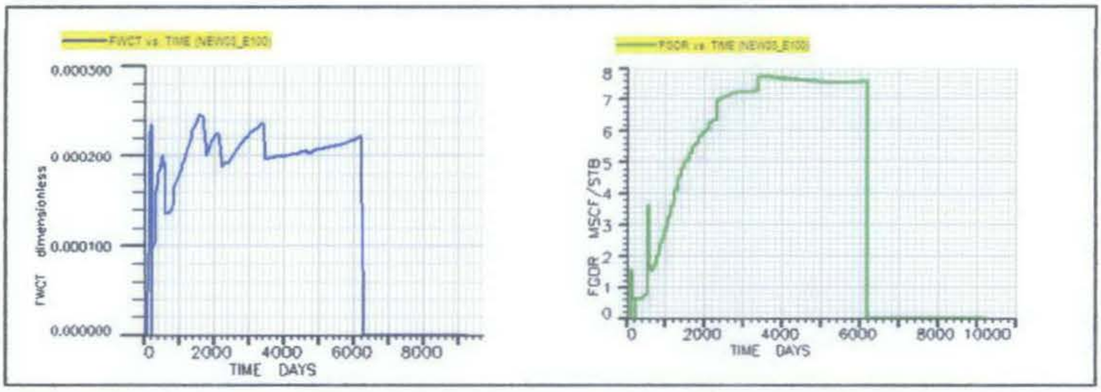


Figure4.9: Field Water Cut (FWCT) and Gas Oil Ratio (FGOR) for basecase of Angsi field

The water cut produced from the field is less which about nearly zero. The gas oil ratio produced is about 7567 scf/stb which is still considered less value for gas field production total.

4.7CASE 1 INJECTION

In this case, secondary oil recovery which is water injection is applied for eleven wells. From eleven wells, four of it will permanently inject water from the start of the field production until the end of twenty six years period while the others came from producer well that been converted to injector well due to economic limit. Figure below shows the reservoir model after twenty six year of water injection.

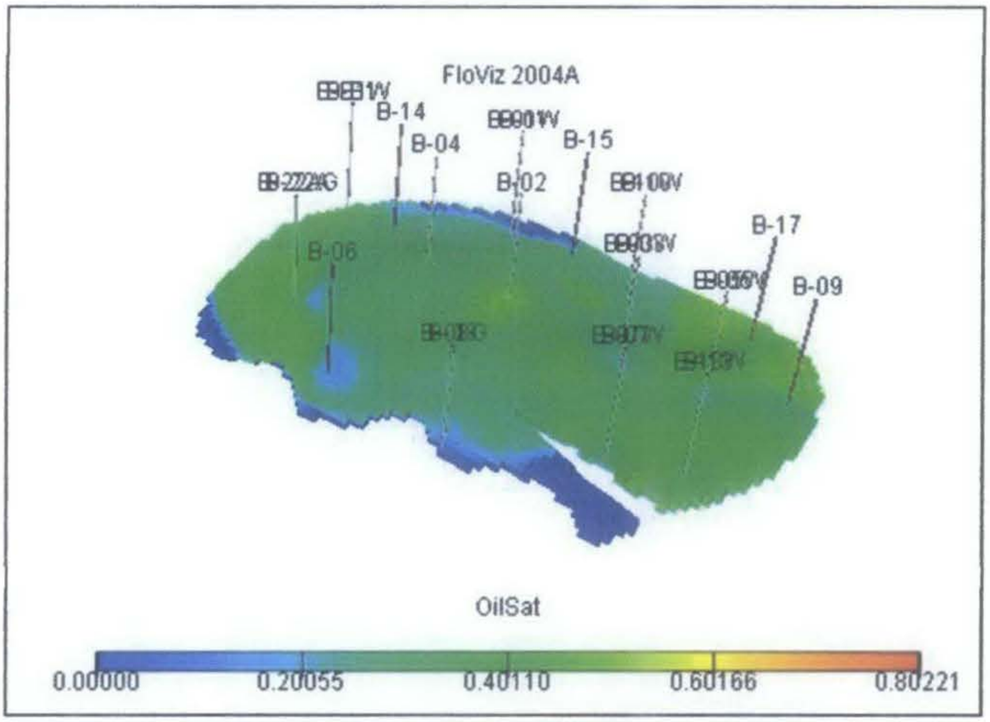


Figure 4.10: Reservoir Simulation of Case 1Model after 26 years timeline

Below are the result of reservoir cumulative oil as well as reservoir production including reservoir pressure, field watercut and field gas oil ratio.

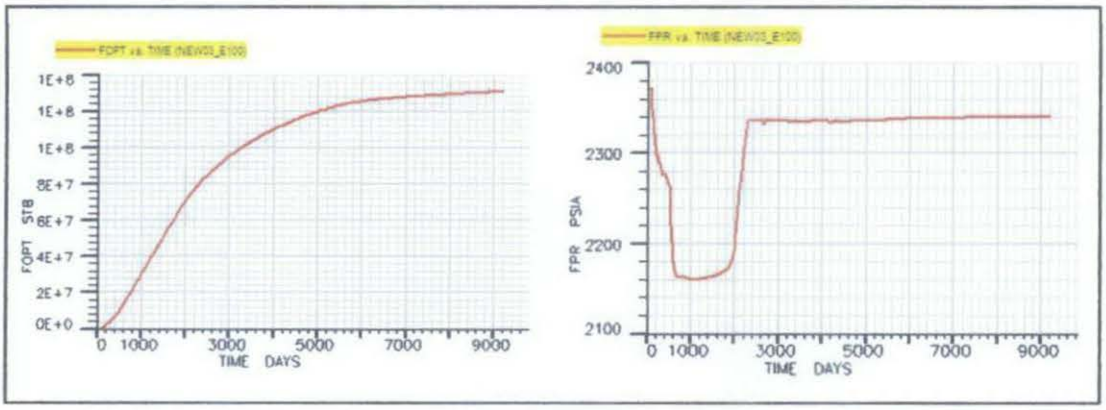


Figure 4.11: Cumulative oil (FOPT) and field reservoir pressure (FPR) for Case 1

The total cumulative oil produced at the end of twenty six years time of field production is 130.74 MMbbl of oil which comprise of 56.56% oil recovery compared to total oil initially in place. The reservoir pressure depleted significantly from 2370 psi to 2161 psi and increase back to 2341 psi to the end of field life due to pressure support from water injection.

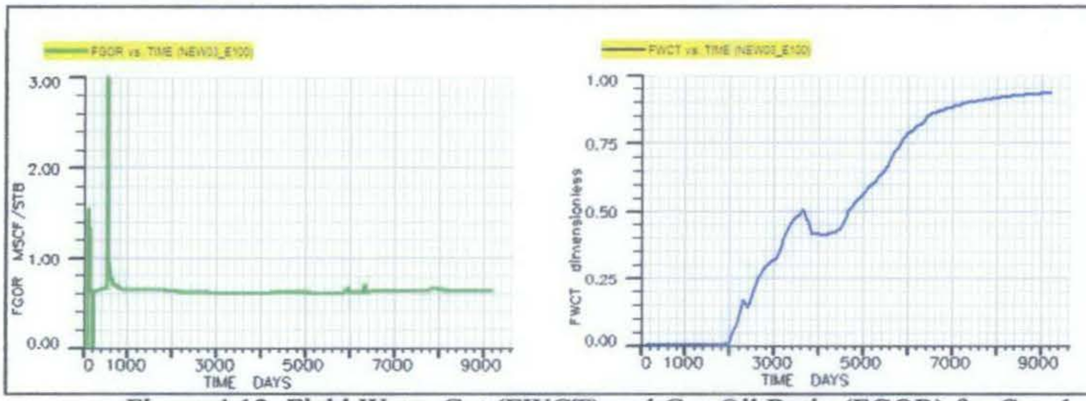


Figure 4.12: Field Water Cut (FWCT) and Gas Oil Ratio (FGOR) for Case1

The average gas oil ratio produced from the field is about 800 scf/bbl and is lesser compared to the basecase model of Angsi field. On the other hand, the field watercut increase significantly to almost 90% since the water injected has reached the production well through the end of field production.

4.8<u>CASE 2 INJECTION</u>

For this case, the injection fluid is changed to gas injection where the gas used is carbon dioxide, CO2 gas.The reason of using CO2 injection is because it is cheaper and does not give much problem to the tubing and pipeline. Figure below shows the figure of Angsi field after twenty six years gas injection process.

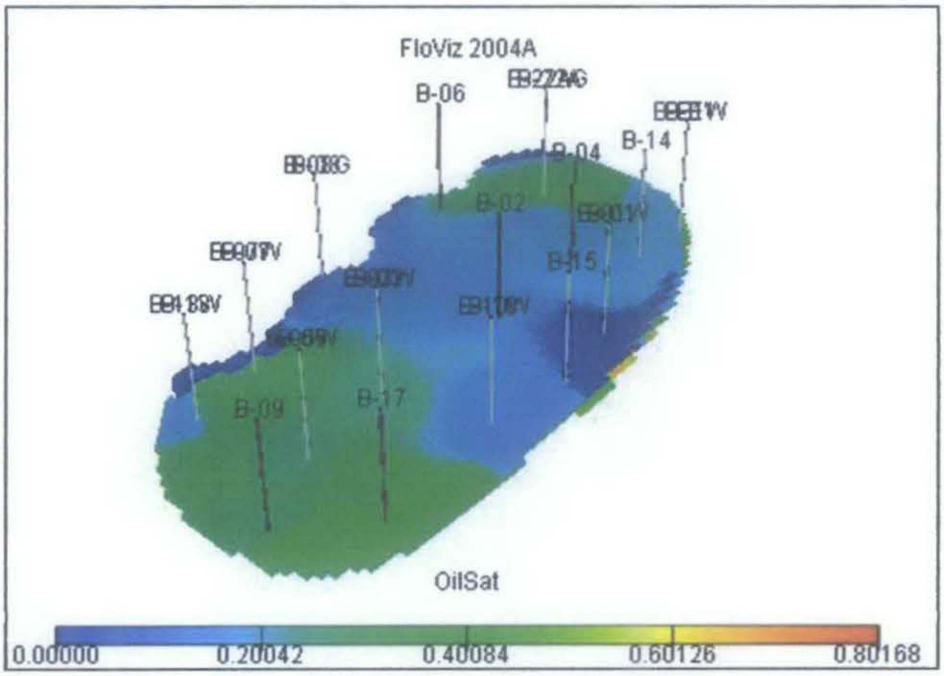


Figure 4.13: Reservoir Simulation of Case 2 Model after 26 years timeline

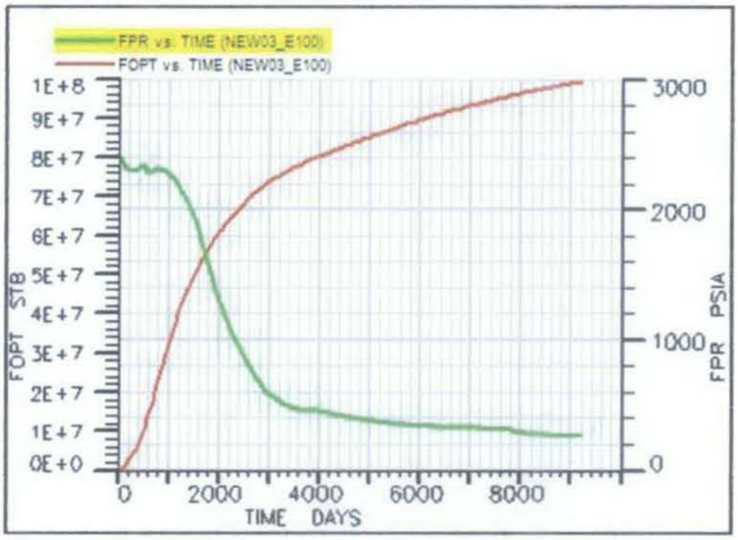


Figure4.14: Field reservoir pressure and field oil production total of Case 2

The field oil production total at the end of twenty six years of production by using gas injection is 99.48 MMbbl and the reservoir pressure depleted significantly from 2370 psi to 261.153 psi. This shows that the gas injection is not a suitable injection fluid since it fails to increase or maintain the reservoir pressure throughout the field life.

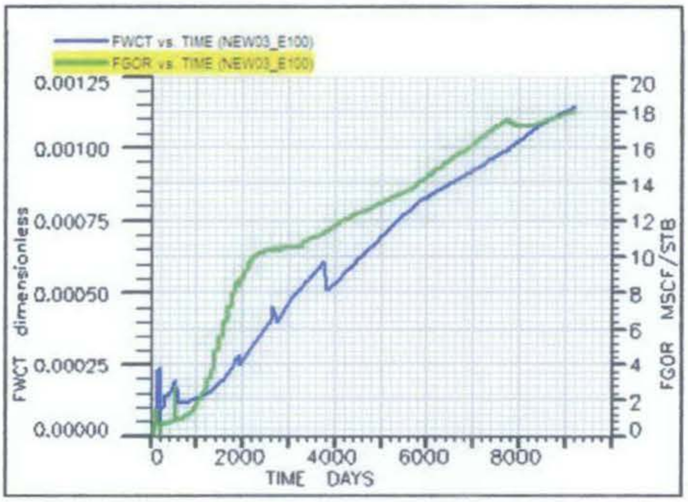


Figure 4.15: Field water cut and field gas oil ratio of Case 2

Based on the graph shown above, the water cut production is very low which is nearly zero. However the field gas oil ratio is quite high which can reach up to 18 000 scf/bbl.

4.9 CASE 3 INJECTION

Case 3 injection involves water alternating gas (WAG) strategy where there are many factors to be considered including:

i. Number of wells to be conducted WAG injection.
ii. WAG ratio between water and gas injection volume.
iii. WAG cycle.

For the first factor which is the number of wells to be conducted WAG injection, there are four well candidates to be conducted WAG injection. In the Angsi field, the wells are B-22A, B-06, B-08 and B-17. All of the wells are good candidates since the well previously operating under fully water injection from the start until the end of field life. Below shows the location of the wells based on the Eclipse model.

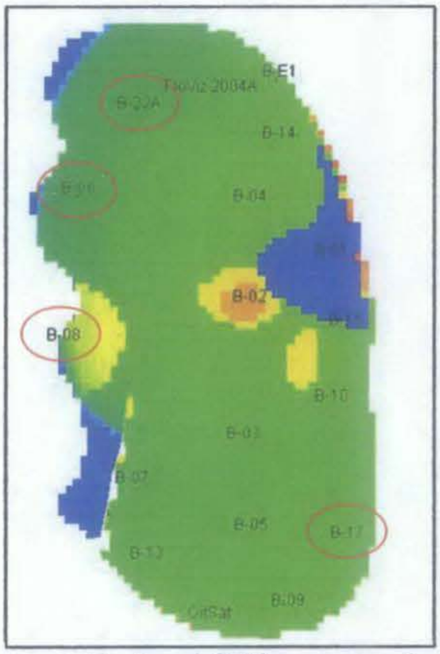


Figure 4.16: Angsi field map overview

All of the four wells are selected to conduct WAG injection. However, one of the wells which is B-17 located nearly to production wells as can be seen in the map above (B-09, B-05, B-03 and B-10). This can affect the performance of the production wells since the injection might increase the volume of watercut and gas oil ratio inside the well.

Based on the reason above, only three wells are selected to further the simulation studies for WAG injection. Two cases were generated which consist of:

i) Three of the wells are chosen to conduct WAG injection.
ii) Only two are selected to conduct WAG injection (B-08 and B-22A) and the other one is maintained for water injection pressure support (B-06).

Below shows the result of the simulation studies for these two cases.

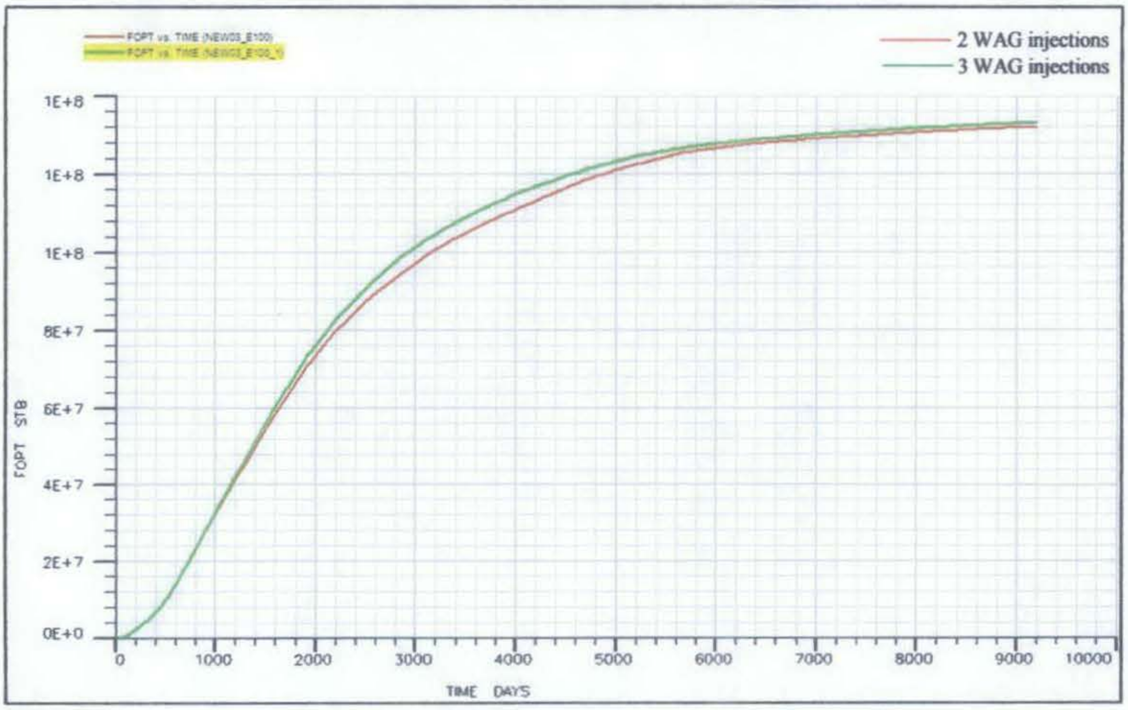


Figure 4.17: Cumulative Oil at the end of field production

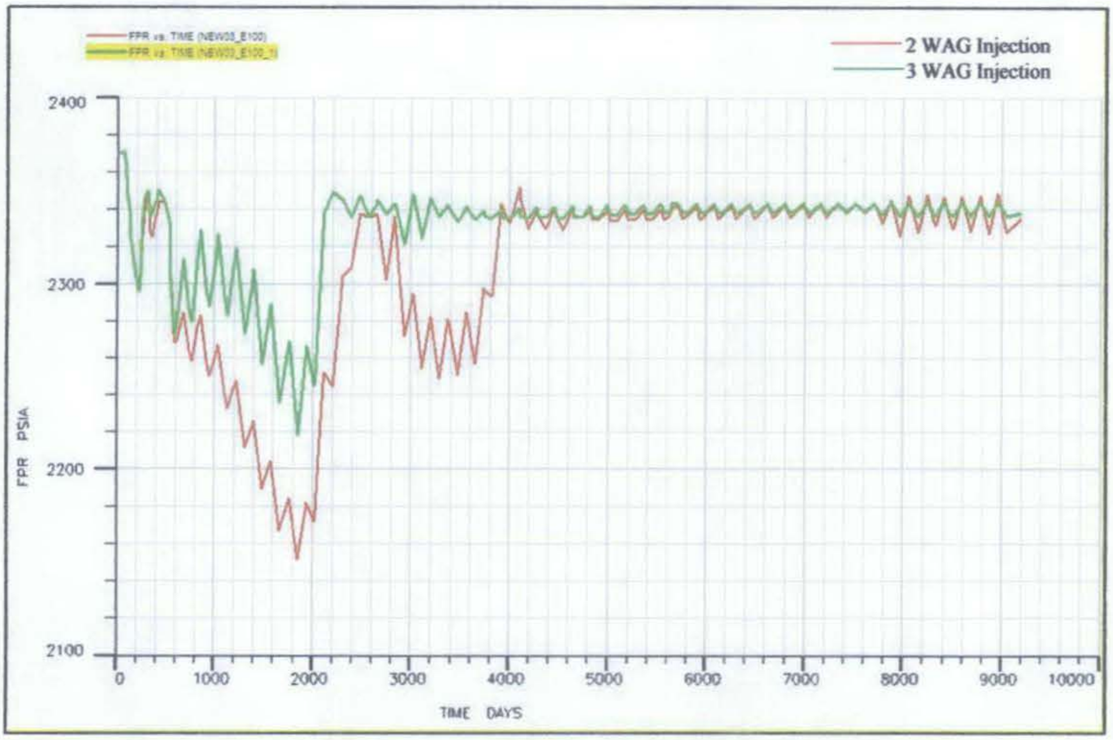


Figure 4.18: Field Reservoir Pressure at the end of field production

Based on the result above, a table can be generated comparing these two cases.

Table 4.4: Comparison between 2 and 3 WAG injection

Cases	2 WAG Injection	3 WAG Injection
FOPT (STB)	1.32E+08	1.33E+08
RF (%)	57.12	57.57
FPR (psia)	2334	2337

Results shown that 3 WAG injection wells improved the recovery factor for about 0.4% compare to 2 WAG injection wells. This is because 3 wells that been conducted WAG injection increase the sweep efficiency in order to push oil inside the reservoir to the production wells. Eventhough the field reservoir pressure shows that there is not much difference, but as shown in the graph above, the reservoir pressure starts to maintain faster in 3 WAG injections compare to 2 WAG injections. This can increase the field life and affect the cumulative oil at the end of production.

For the second factor which is WAG ratio, two cases were generated which consist of:

i) Gas Volume Sensitivity

Water volume remains constant and gas volume is changed based on different WAG ratio. Five simulation cases consist of different WAG ratio were generated and the cumulative oil, reservoir pressure as well as oil recovery are compared. The WAG cycle is remained default for each case which is 6 month where 3 months water injection and another 3 months gas injection.

Table 4.5: Gas Volume sensitivity with different water injection (WI) and gas injection (GI) rate.

Case	WAG ratio		WI rate	GI rate
	Water	Gas	STB/d	Mscf/d
1	1	1	10000	7900
2	1	0.5	10000	3940
3	1	1.5	10000	11815
4	1	2	10000	15750
5	1	3	10000	23620

Below shows the result of graph and table of comparison related to the different cases depends on the cumulative oil, field reservoir pressure, as well as oil recovery.

Legend:

Case 1 (1:1)

Case 2 (1:0.5)

Case 3 (1:1.5)

Case 4 (1:2)

Case 5 (1:3)

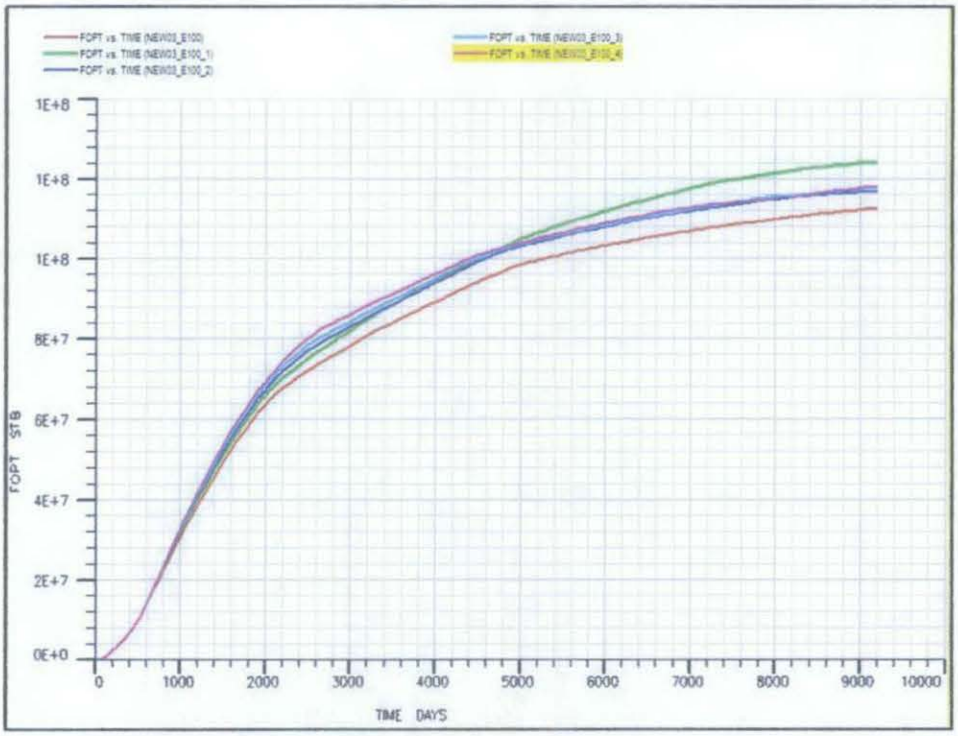


Figure 4.19: Field Oil Production Total for different WAG cases

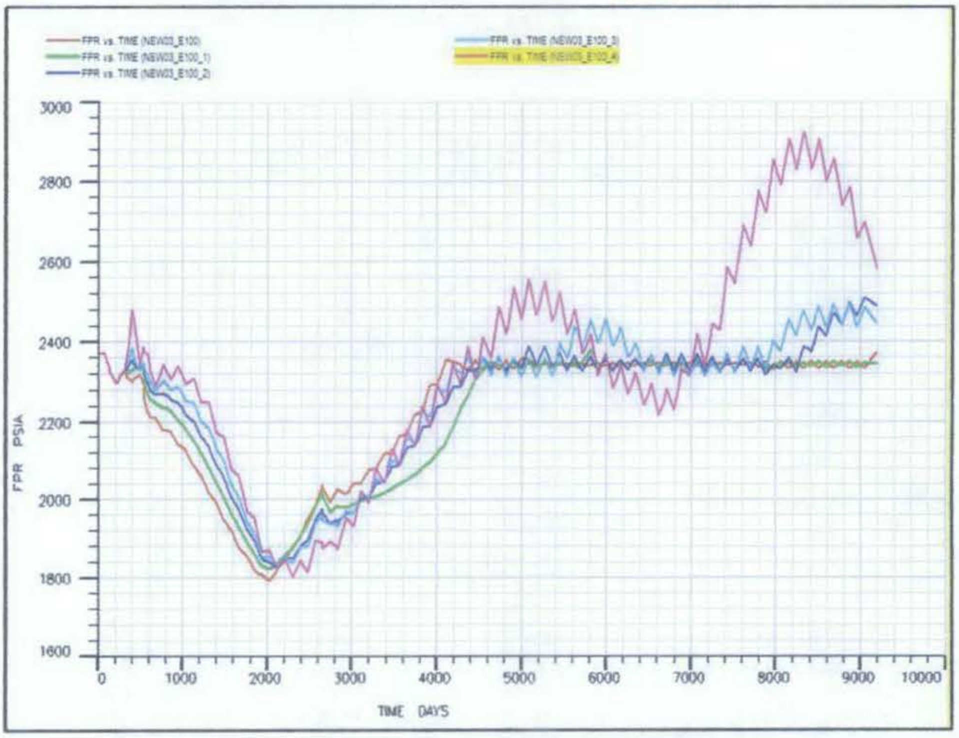


Figure 4.20: Field Reservoir Pressure for different WAG cases

Table below shows the comparison between cases 1 until case 5 WAG ratio with percentage recovery factor with respect to total oil in place.

Table 4.6: Percentage oil recovery for different WAG ratio

Case	WAG ratio		FOPT	RF (%)
	Water	Gas		
1	1	1	124.313	53.78
2	1	0.5	112.506	48.67
3	1	1.5	116.928	50.59
4	1	2	117.832	50.98
5	1	3	118.161	51.12

Based on the result shown above, WAG ratio of 1:1 from case 1 shows the highest oil recovery which is 53.78% with respect to oil initially in place compare to the other cases. From the graph of field reservoir pressure, case 1 shows the most stable or maintained reservoir pressure depletion.

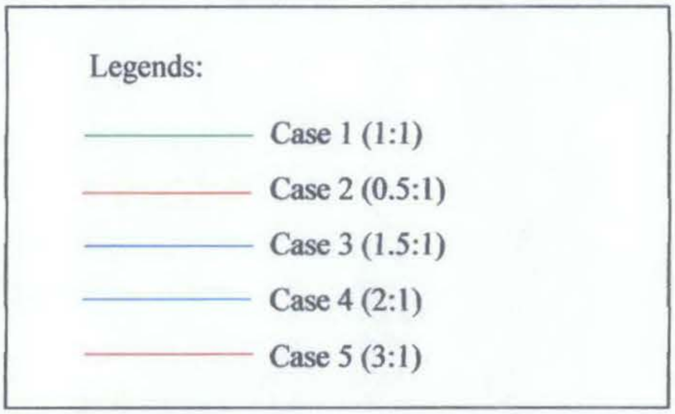
ii) Water Volume Sensitivity

Based on most efficient Gas Volume ratio from gas volume sensitivity case, water volume ratio is changed based on different WAG ratio by making gas volume as constant variable. From previous gas sensitivity case, WAG ratio of 1:1 is the most efficient ratio for gas injection volume. So, another 5 cases were generated and the cumulative oil, reservoir pressure as well as oil recovery is compared. The WAG cycle is remained default for each case which is 6 month where 3 months water injection and another 3 months gas injection.

Table 4.7: Water Volume sensitivity with different water injection (WI) and gas injection (GI) rate.

Case	WAG ratio		WI rate	GI rate
	Water	Gas	STB/d	Mscf/d
1	1	1	10000	7900
2	0.5	1	5000	7900
3	1.5	1	15000	7900
4	2	1	20000	7900
5	3	1	30000	7900

Below shows the result of graph and table comparison related to the different cases depends on the cumulative oil, field reservoir pressure, as well as oil recovery.



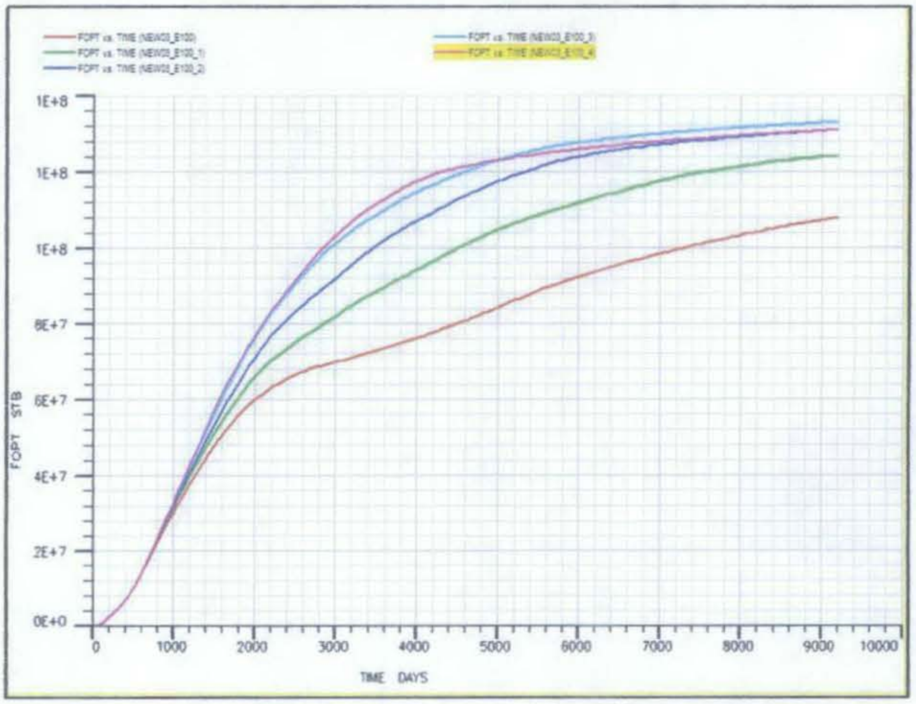


Figure 4.21: Field Oil Production Total for different WAG cases

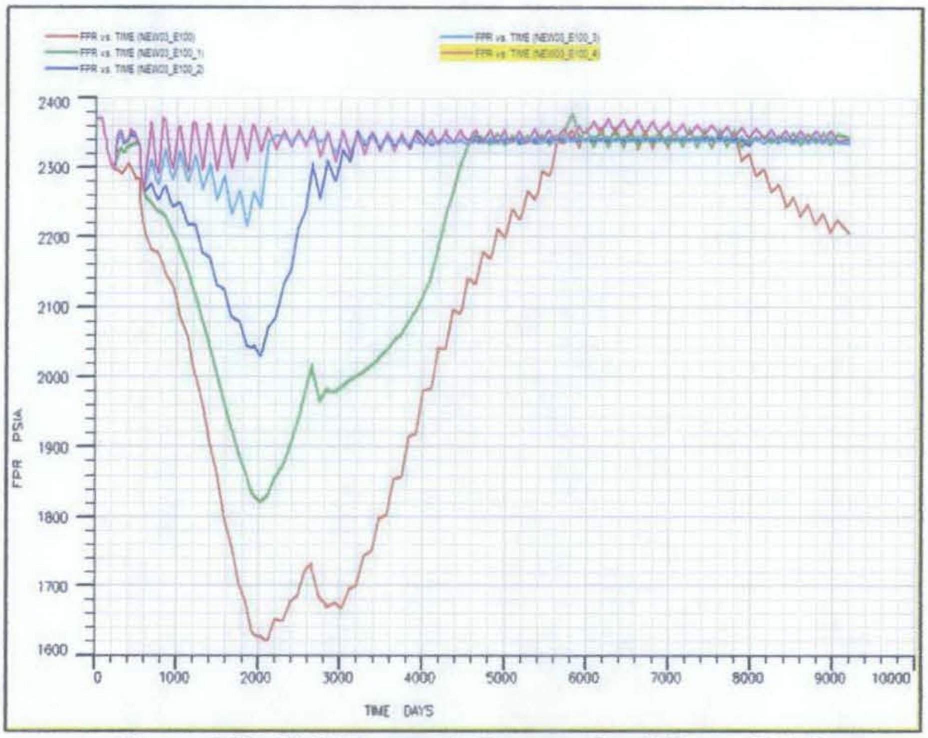


Figure 4.22: Field Reservoir Pressure for different WAG cases

Table below shows the comparison between cases 1 until case 5 WAG ratio with percentage recovery factor with respect to total oil in place.

Table 4.8: Percentage oil recovery for different WAG ratio

Case	WAG ratio		FOPT	RF
	Water	Gas	(MMSTB)	(%)
1	1	1	124.313	53.78
2	0.5	1	108.061	46.75
3	1.5	1	130.95	56.65
4	2	1	133.062	57.57
5	3	1	130.943	56.65

Based on the result shown above, WAG ratio of 2:1 from case 4 shows the highest oil recovery which is 57.57% with respect to oil initially in place compare to the other cases. From the graph of field reservoir pressure, case 1 shows the most stable or maintained reservoir pressure depletion.

Increase in water volume shows significant increase in oil recovery due to increasing in water injection pressure. The most effective WAG ratio occurred when the water injection volume is twice to the gas injection volume. However, when increase the water injection volume to triple as much as gas injection volume, the total field oil production start to decrease since the water injected start to sweep inside the production well and cause the oil production to deplete.

The third factor, which is WAG cycle also should be considered in the Water Alternating Gas strategy. Three simulation cases have been done which comprises of different WAG cycle. First case is 6 months cycle, then 1 year cycle and lastly 2 year cycle. Below is the graph and table of comparison between these three cases of WAG cycle.

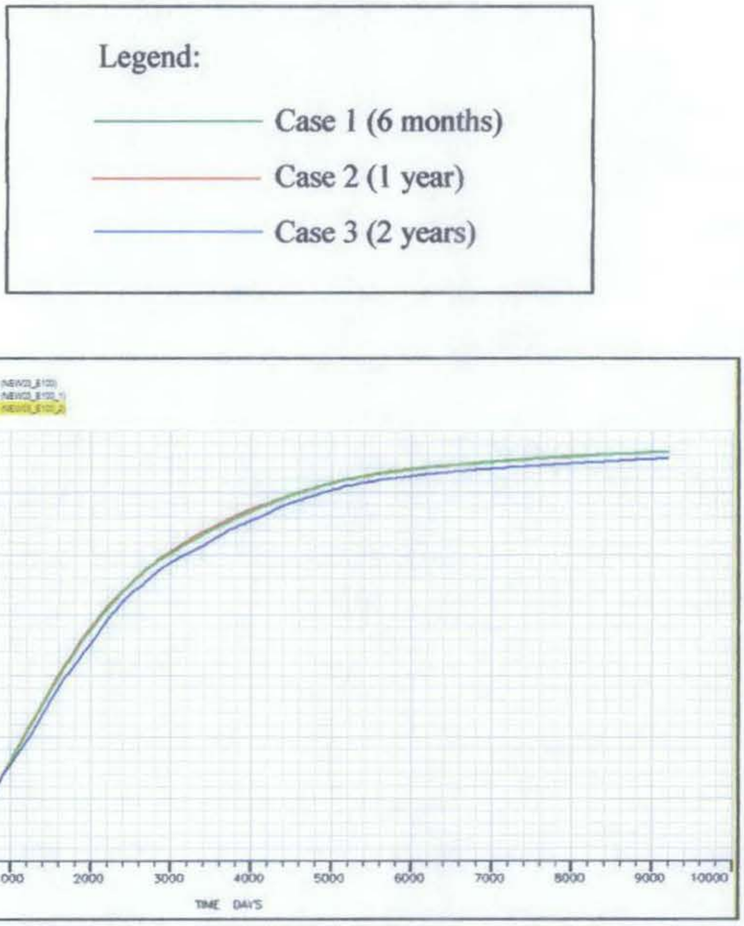


Figure 4.23: Field Oil Production Total of different WAG cycle cases.

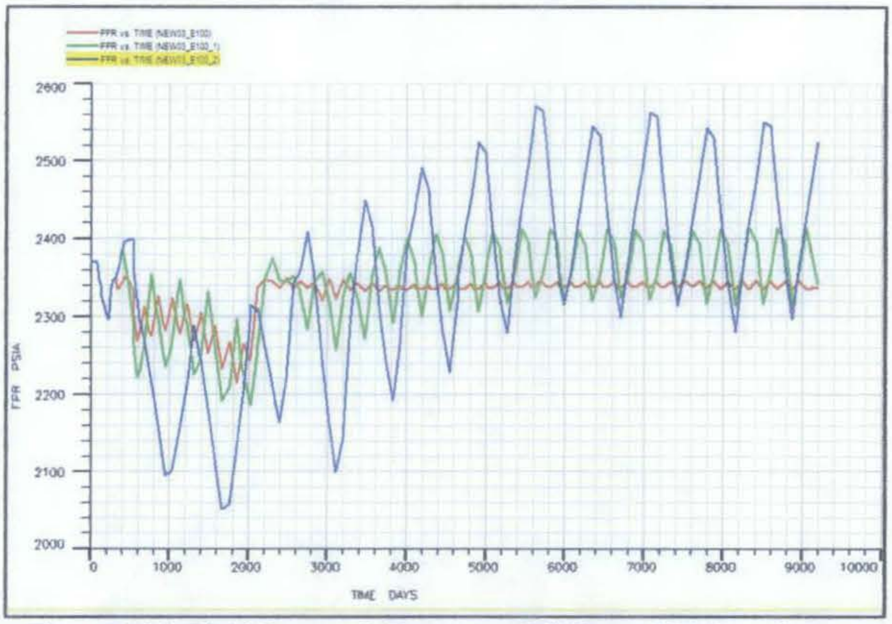


Figure 4.24: Field Reservoir Pressure of different WAG cycle cases

Based on the result shown, a table of comparison between different cases of WAG cycle can be generated as below.

Table 4.9: Percentage oil recovery for different WAG cycle cases

Case	WAG Cycle	Water Injection	Gas Injection	FOPT (MMSTB)	RF (%)
1	6 months	90	90	133.062	57.57
2	1 year	180	180	133.047	57.56
3	2 years	360	360	130.944	56.65

As shown in the graph and table above, case 1 WAG cycle is the best WAG cycle since the total oil production at the end of field life is the highest compare to the other two cases. The increment of WAG cycle to 1 year period did not affect much to the oil recovery since the volume of water and gas injected to the field is the same as 6 months WAG cycle period. However, the third case shows slightly decrease in oil recovery with the increment of WAG cycle to 2 years period. This is because the field not affected much with water alternating gas operation since the period is too long and not reliable.

4.10ANALYSIS COMPARISON OF BASECASE, CASE 1, CASE 2& CASE 3

By analyzing the results from basecase, case 1, case 2,and case 3, a table of comparison for each case is generated based on field oil recovery or cumulative oil, field reservoir pressure, field watercut as well as field gas oil ratio at the end of twenty six years time line.

Table 4.10: Comparison between basecase, case 1, case 2 and case 3.

Date: *20 Sept 2015*	*Basecase*	*Case 1*	*Case 2*	*Case 3*
Cum. Oil (MMbbl)	40.47	130.74	99.48	133.06
Oil Recovery (%)	17.50	56.56	43.04	57.57
Reservoir Pressure (psi)	345	2341	261	2337
Water Cut (Fraction)	0.0	0.9	0.0	0.9
Gas Oil Ratio (scf/bbl)	7567	800	18 000	10 693

Based on table 4, the highest cumulative oil is from Case 3 injection which is water alternating gas case. The oil recovery is about 57.57% of total oil initially in place of Angsi field which is the highest compared to the other cases. Case 3 injection also proved successful in maintaining reservoir pressure depletion from 2340 psi from initial reservoir pressure of 2337 psi. The watercut is quite high for Case 3 which is about 0.9 at the end of field life compared to the other cases and the total gas oil ratio is not too high which about 10 693 scf/bbl.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1CONCLUSIONS

It is important to determine which injection pattern and injection fluidtechniqueswill result in highest oil recovery in order to maximize the profit gain for certain company. Based on the cases generated from different injection strategies, there are many possibilities that can be happen.

Sometimes, the application of certain regular injection pattern like 5-spot pattern is not reliable and less efficient compared to the other cases generated.Through the conceptual model, it is proved that the regular injection from one corner of the reservoir at the bottom to another corner located at the upper reservoir is more efficient than 5 spot injection.

In the other case, the application of secondary recovery specifically water injection is enough to increase oil recovery. However there is still much oil left inside the reservoirwhich is trapped called residual oil that can further be produced by application of tertiary recovery like water alternating gas injection. This can be proved which the implementation of water alternating gas that managed to further increase oil recovery by 1% compared to water injection.

The understanding of different injection strategy is important in order to further optimize production of certain field.This includes injection pattern, injection fluids type and application of further recovery technique like water alternating gas injection.

6.2 RECOMMENDATIONS

Based on the results and discussions obtained from the above injection strategy project, there are several plans can be done to further improve the project for future works recoveries which are:

(i) Apply other kinds of tertiary recovery including polymer injection, thermal injection and effects of using surfactant towards oil recovery.

(ii) Compare the effects of peripheral injection pattern and the others regular injection patterns like 4 spot, 5 spot and 7 spot injection in the real field model.

(iii) Consider different types of well geometry including horizontal, vertical and deviation well to the production and injection well.

(iv) Further define the conceptual model of injection pattern strategies for different reservoir characteristics.

(v) Apply the same injection strategies to the other fields around Malaysia to further increase the relevancy of the acquired conclusions.

(vi) Further improve the accuracy of the injection pattern modeling by increase the number of grid cell at least $5 \times 5 \times 5$ cells.

(vii) Consider the transmissibility of conceptual model in x, y and z direction to determine the suitable location of injection and production wells.

(viii) Visually present the results in terms of other suitable graphical representation such as bar chart, pie chart and graph.

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