Study of Well Trajectory and Distribution of Injection and Production Wells for Enhanced Oil Recovery

By

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14409

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(PETROLEUM)

SEPTEMBER 2014

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CERTIFICATION OF APPROVAL

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Petroleum Engineering Programme
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Approved by,

____

(AP Dr Xianhua Liu)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

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.

(IZZATI BT AZIZAN)

ABSTRACT

This report is written to purposely discuss about Final Year Project entitled "A study of well trajectory and distribution of injection and production well for Enhanced Oil Recovery (EOR)". Oil and gas industries are looking for new ways to maximize their production and at the same time maximize their profit. One of the main focuses of the oil and gas industry is to increase oil production rate by (EOR) method. In this report, the main purpose is to design different well trajectory for injection well and production well to boost oil production rate. Well trajectory become more popular over the last two decades. It is quite challenging for the team of directional drilling to determine the location, type and trajectory of the well. Usually selection of optimal well trajectory is a very complex task. However, all the design of well trajectory will be explained in details in this report. Development of directional drilling technology nowadays is rapidly. This drilling industry had to improve their technology by focussing on the design of well trajectory such as horizontal well, radial hydraulic jet drilling, sideway curves well and etc.

In order to achieve the objective, the project process flow has been planned. Literature survey and case study are performed. A lot of improvement need to be perform based on the previous literature surveys. One of the concern is to get an optimum oil production rate, it must start with a right concept of well trajectories within the productive zones. In this report, several types of well trajectories has been designed. The ECLIPSE 100 Simulator is used for illustrating and simulating well trajectory for injection and production wells. From this software, analysis of different well trajectory in the same reservoir data is carried out. All the design of well trajectory for injection and production well will be by software by defining target geometry from Planning Module. Finally, get the reports from the Results and Office in the software to be completed along the well trajectory.

After discussion of the methodology, this report will present with the results of the project. The expected result are calculated data for designing the well trajectory through ECLIPSE 100 Simulator suitable type of well trajectory at a certain reservoir condition is proposed. Finally, we can conclude the effect of well trajectory in production and injection wells on EOR for future production.

ACKNOWLEDGEMENT

Praise to God Almighty for his blessings and guidance, my Final Year Final Semester in Universiti Teknologi PETRONAS is successfully completed. A huge appreciation to my supervisor, AP Dr Xianhua Liu for giving me the opportunity to gain as much knowledge and experience that fulfilled the university requirements. Also helped by the platforms set by Universiti Teknologi PETRONAS I managed to have a understanding of the big picture of oil and gas industry.

Apart from that, I would like to express my gratitude to my supervisor, AP Dr Xianhua Liu, and also to the lab technician, Mr Ahmed Ibrahim for giving me this opportunity in learning ECLIPSE software. Besides, the opportunity he had given me, Mr Ahmed Ibrahim consistently gives advices and shares his experiences that can help me develop into becoming a well-rounded engineer. Same goes to other lecturers for all the knowledge shared, suggestions, and encouragements during the period of my Final Year Project. Thank you for always ensures I have the best opportunity to enhance my knowledge in engineering of oil and gas industry in particular. For all the lecturers and colleagues, thanks for giving me a lots of knowledge in order for me to complete this project and supporting me all through my Final Year Project period.

Lastly, I would like to give my special gratitude to my parents for all the supports and encouragement. Thank you to everyone whose names are not mentioned here for helping me finishing this report. Thank you and May god bless us all.

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ABBREVIATIONS AND NOMENCLATURES

BUR	Build Up Rtae
CB	Length of Hold
D1	Kick off Point (KOP)
D2	True vertical depth (TVD) to EOB
D3	True vertical depth (TVD) to target
DC	Length of curvature
EOR	Enhanced Oil Recovery
FOPR	Field Oil Production Rate
FWPR	Field Water Production Rate
KOP	Kick Off Point
MD	Measured Depth
MSL	Mean Sea Level
r1	Radius of curvature
TVD	True Vertical Depth
X2	Horizontal departure to EOB
X3	Horizontal departure to target
θ	Max. inclination angle

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Enhanced Oil Recovery (EOR) has been one of the most successful method for achieving the highest possible recovery factor (Chan et. al, 2013). This technology is fairly matured in land based development. However, EOR considerations take on a whole new dimension in an offshore environment. For EOR development, various design and operational considerations is needed. One of them is well architecture which mainly composed of trajectory and completions functionality. This project details the well trajectory in a way to optimize production rate.

Concepts of trajectories is the basic thing that need to be studied in order to gain the optimal production rates within the productive zones. Different well trajectory designs, which could be vertical, inclined, horizontal and also the other type of trajectories (J-type, S-type, and Continuous Build) of the well gives variations in difficulty levels for drilling and completion process. There are greater challenges faced in dealing with highly deviated well drilling as compared with a low deviated well. There are also the needs of more treatments for shallow kick-off in horizontal well due to soft formations with larger hole size as compared with deeper kick-off. Additionally, trajectory with a higher Total Measured Depth (TMD) to True Vertical Depth (TVD) ratio are also known to exhibits greater problems in drilling formations compared with lower TMD/TVD ratio which are similar with the applications of 3D well trajectory which does not turn in direction compared with a 2D trajectory. These examples perfectly described the challenges exhibits with the uses of different trajectory designs.

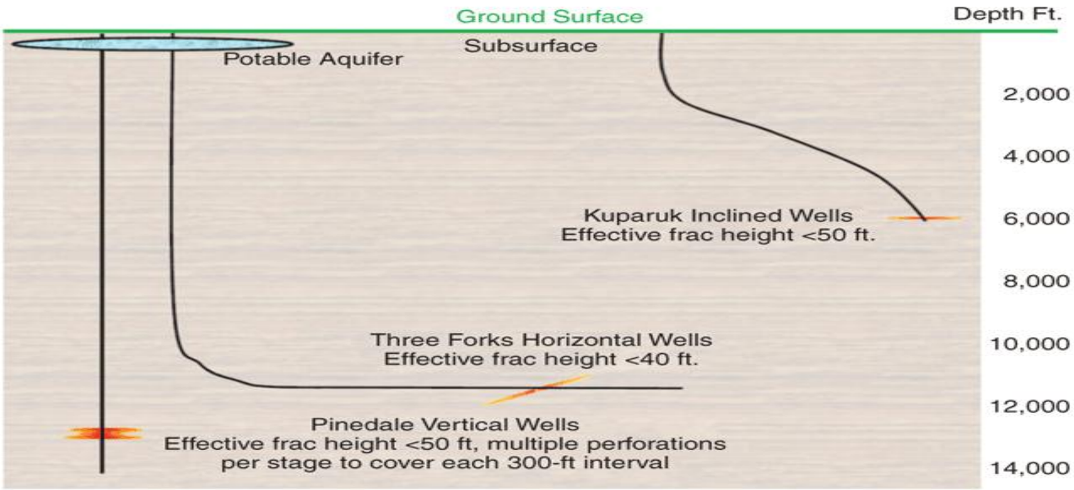


FIGURE 1: Example of Vertical, Horizontal and Deviated W ell Trajectory

In order to save drilling cost, many engineers especially reservoir engineer would like to target multiple well trajectory into one main wellbore and this usually requires well trajectory changing in both azimuth and inclination. Several calculation algorithms need to be used in order to make the right direction of inclination and azimuth.

1.2 Problem Statement

There are EOR methods which are currently under study in the world. Method that are mostly used are chemical injection, water flooding, CO_2 injection, polymer injection and etc. But, one method that can improve reservoir performance or production rate with of EOR is the design of well trajectories for injector and producer since it is depending on reservoir condition. This is because well trajectory and distribution of injection and production wells are major factors that influence the oil and gas flow, hence production rate. Hence, the task in this study is to find the suitable design of well trajectory for optimizing EOR production rate.

1.3 Objectives of the Project

The main objectives of this project are as follows:

i. To determine the effectiveness of Well Trajectory on EOR
ii. To propose better solutions in terms of directional well trajectory and well locations and decide the best design of well trajectory in optimizing reservoir performance

1.4 Scope of Study

There are two (2) scopes of study in this project, which are the scope of study for Final Year Project 1 and the scope of study for Final Year Project 2.

1.4.1 Scope of Study Final Year Project 1

- Make a comparison in terms of literature and research survey of well trajectory and distribution of injection and production wells for EOR.
- Studies on different type of well trajectory

1.4.2 Scope of Study Final Year Project 2

- Learnt to generate reservoir model using ECLIPSE 100 Simulator software.
- Study parameters that need to take into considerations in designing well trajectory.
- Correlate type of well trajectory with the oil flow rate at reservoir condition.
- Compare each type of well trajectories using numerical and analytical approach

1.5 Relevancy and Feasibility of the Project

This project is relevant to petroleum engineering drilling and production because of well trajectory or directional drilling is the science and art of deviating a wellbore along a planned course to a subsurface target whose location is at a given lateral distance and direction. This project may require improved technologies in the casing and cementing program, hydraulics, centralization, and completion techniques. Other than that, this project is very relevant due to the technology and methods used nowadays to improve production rate of oil. The outcome of this project will benefit engineers for achieving their EOR objective.

This project is feasible because it can be programmed by computer and software designed to handle well trajectory problem such as ECLIPSE 100 Simulator. The calculation part can be programmed to help the company to design well trajectory profiles instead of doing it manually and by trial and error method.

CHAPTER 2

LITERATURE REVIEW

2.1 EOR Methods

As stated by Sheng, 2010, *Enhanced Oil Recovery* is oil recovery by injection of gases or chemicals and/or thermal energy into the reservoir. There are several methods for EOR as listed below:

2.1.1 Water Injection

Water injection, the oldest assisted recovery method, remains the most common (80% of the oil produced by enhanced recovery in the United States in 1970 was produced by water injection) (Latil, 1980). Water injection be used in order to maintain the reservoir pressure when the expansion of the aquifer or gas-cap is insufficient for the purpose. In this instance the process should be regarded as one of the pressure maintenance rather than of enhanced recovery. This is the case, for example, in the Parentis field in France and the Zelten field in Libya, in which water injection was not intended to improve the recovery but to increase the production rates (Bardon, 1980). Thousands of other fields throughout the world employ water injection for this purpose. Water injection also can be used to dispose of the brine produced with the oil if surface discharge is not possible (e.g. into lakes or fresh water sources). The water may be injected into underlying or neighbouring aquifer.

2.1.2 Gas Injection for Oil Reservoir

Gas injection in an oil reservoir takes place either into a gas-cap if one exists, or directly into the oil zone. The injected gas is practically always of a hydrocarbon base. Air injection has been attempted, but has many disadvantages. Now, what is the difference between *gas injection into a gas-cap* and *gas injection into an oil zone*?

A. Gas injection into a gas cap

As stated by Latil, 1980, when a gas-cap originally exists in a reservoir, or when one has been formed by segregation during primary production, gas injection helps to maintain the reservoir pressure while forcing gas into the oil zone and driving the oil towards the production wells. This process could be the same as an increasing the oil water contact when water is injected into an underlying aquifer.

B. Gas injection into an oil zone

When gas injection takes place in a reservoir without a gas-cap the injected gas flows radially from the injection wells, driving the oil towards the production wells. The principal factor involved in the decision to commence gas injection is the availability of a nearby source of cheap gas in sufficient quantities. The recycling of produced gas is a major source, but can only slow down the reservoir pressure decline, not halt it. Secondary gas must be obtained either from an adjacent gas reservoir or from a nearby gas pipeline.

2.1.3 Thermal Recovery Method

The difference between thermal recovery methods and other recovery methods lies in the fact that the injected fluid supplies thermal energy to the reservoir. As stated by Burger and Sourieau, 1980, there are two categories of thermal methods: those in which the heat is produced at surface (hot fluid injection) and those in which the heat is created in the formation (in-situ combustion). In the first case, the injected fluid carries the heat produced while in the second case, the injected fluid is one of the reactants involved in an exothermic reaction taking place in the reservoir.

2.1.4 Polymer Flooding

This method first introduces different types of polymers and polymer-related profile control systems used in enhanced oil recovery (EOR), although the list is in no way comprehensive (Sheng, 2010). Polymer flooding have the advantage of being very viscous even when highly diluted**.**

2.1.5 Surfactant Flooding

Surfactant flooding, includes microemulsion properties, phase behavior, interfacial tension, capillary desaturation, surfactant adsorption and retention, and relative permeabilities in surfactant flooding. Surfactants, or surface acting agents, when dissolved in minute quantities in water have a large effect on the interfacial properties between the water and oil which it is displacing. The surfactant that dissolves in the residual oil droplets thus raising the saturation above the residual level and, in addition, the surface tension between these enlarged oil droplets and the displacing water is can be seen reduced immediately. Both these effects are active in reducing the residual oil saturation and, in laboratory tests, ninety percent residual oil recovery has been observed. Petroleum sulphonates are one of the surfactants that most commonly used by the industry.

Surfactant flooding description of tertiary recovery mechanisms hardly "scratches the surface" of the subject (Herbeck et. all, 2012). The methods that are described as tertiary in that they are capable of recovering some, if not all, of the residual oil remaining after a waterflood. This does not mean, however, that they must be preceded by a waterflood. Instead, the two can be conducted simultaneously. In all tertiary recovery schemes, continuous injection of the expensive agents is unnecessary. The fluids are injected in batches and frequently the batches are followed by mobility buffers. For instance, to ensure stable displacement in a surfactant flood, the chemical slug can be displaced by water thickened with a polymer, the concentration of which is gradually decreased as the flood proceeds.

2.1.6 Carbon Dioxide (CO_2) Injection

Carbon Dioxide may be used as a gas, dissolved in water or in alternating slug scheme. As explained by Bardon and Latil, 1980, the very high solubility of carbon dioxide in oil and to a lesser extent in water results in:

a) A large reduction in oil viscosity and a small increase in water viscosity. This results in a significant improvement of oil mobility in the reservoir.

b) Swelling of the oil by some 10 to 20%, depending on its type and saturation pressure.

c) A reduction in oil density. This lessens the effect of gravity segregation during injection of gaseous CO_2.

d) A lowering of the interfacial tension. With CO_2 in the gaseous state at high enough pressure, miscibility with oil may be achieved.

e) Chemical reaction on carbonate or shaly rocks.

2.2 Design of Well Trajectory

Well trajectory is one of the important element in drilling technologies. This is because well trajectory can be used to access reservoirs which cannot be accessed by vertical drilling: For example, where a town, city or a lake is above the reservoir. It also can reduce the impact of well drilling has on the environment by decreasing the number of rig moves on the surface. More than that well trajectory is also a safer alternative to drilling relief wells to stabilize a well that is experiencing a blowout and can be used to reach thin reservoirs by cutting at an angle across the reservoir, thereby increasing the contact area of the reservoir. There are some applications of well trajectory that can be discussed in detail as below:

i. **Sidetracking**

Sidetracking is the result of having to avoid materials which cannot be retrieved from the well, such as: tools, drillpipes, drill collar, scrap metal etc.

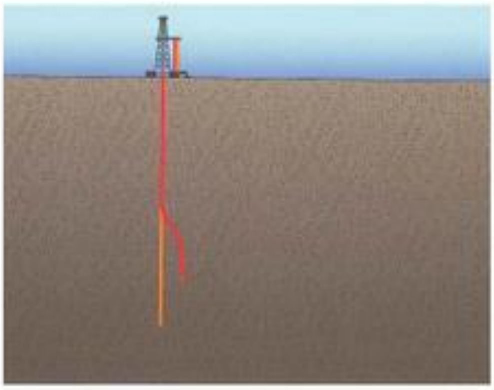


FIGURE 2: Sidetracking

ii. **Inaccessible Location**

Reservoirs may be situated under inaccessible locations such as populated towns/cities, environmentally sensitive areas, or water bodies where the use of offshore infrastructure is inefficient and costly.

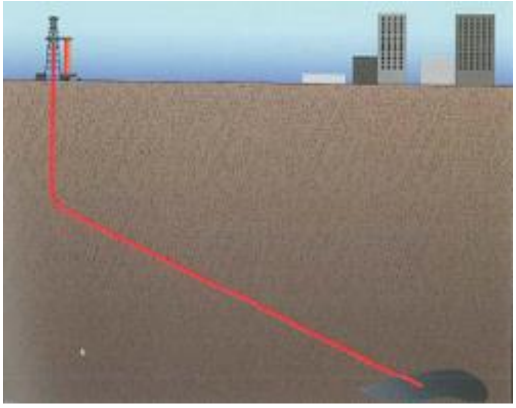


FIGURE 3: Inaccessible Location

iii. Cluster/ Platform Drilling

This involves drilling multiple wells from a single location especially offshore, where it is easier to access a range of wells from one location.

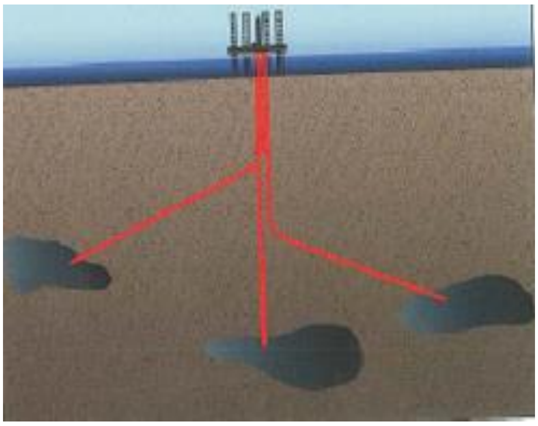


FIGURE 4: Cluster/ Platform Drilling

iv. Salt Dome Drilling

A Salt dome is a mushroom-shaped diaper made of salt. Hydrocarbons are commonly found around salt domes because of the abundance and variety of traps created by the salt movement.

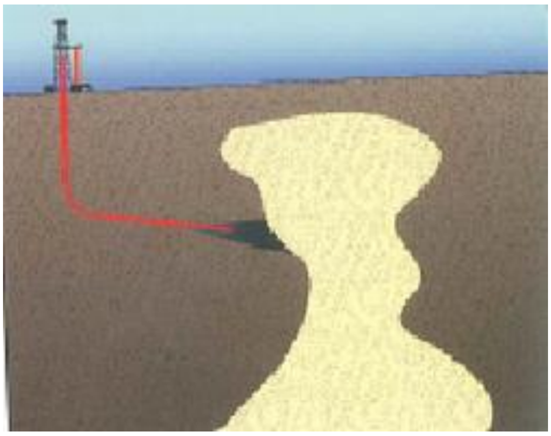


FIGURE 5: Salt Dome Drilling

v. **Fault Control**

The well is intentionally deviated around the fault plane to avoid excessive mud loss and any possible damage to the casing due to instability.

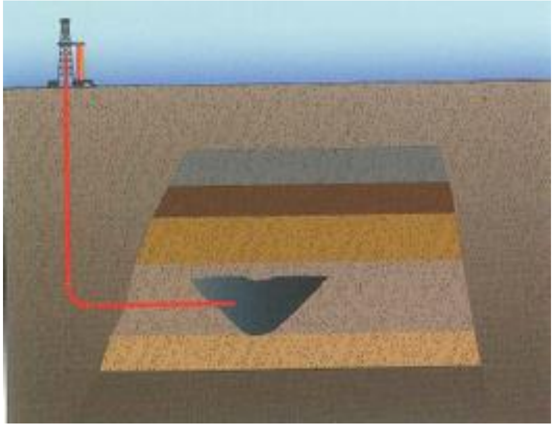


FIGURE 6: Fault Control

vi. **Relief Well**

Relief wells are drilled to wells suffering a blowout. Heavy mud is pumped through the relief well into the reservoir in an attempt to overcome the pressure and halt the blowout.

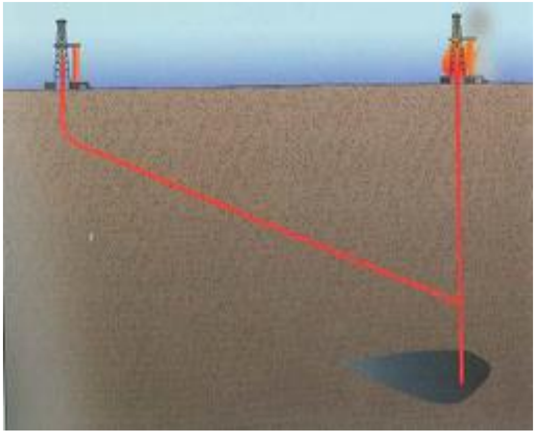


FIGURE 7: Relief Well

vii. Horizontal Well

This is normally used extensively to install infrastructure such as: oil, gas, and water pipelines or power cables running underground.

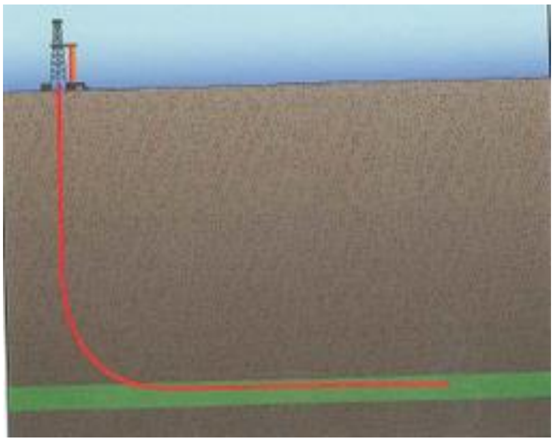


FIGURE 8: Horizontal Well

viii. Multilateral Drilling

Multilateral wells are single wells with one or more sidetracks from the original (mother) well. Production is often commingled. Although this is a high capital intensive well, yet, higher production rate is achieved than normal wells.

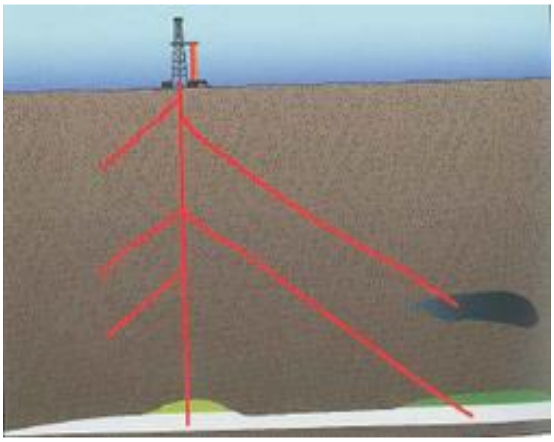


FIGURE 9: Multilateral Drilling

To deepen this project, several types of well profiles/ trajectory been discussed as below:

2.2.1 Horizontal Trajectory

Horizontal Trajectory is mainly allows for access to previously unattainable bottom hole targets. In addition, horizontal and directional drilling is used when the specific subsurface target is unattainable using conventional vertical trajectory practices. The well is made up of a vertical section, build section, tangent section (hold), 2nd build section horizontal to the target. Kick off point (KOP) below the well surface is in the range of 3000-5000ft. Applicable for thin oil zones with water or gas coning problems. It also maximizes productivity from low permeability reservoirs by increasing the reservoir's contact area.

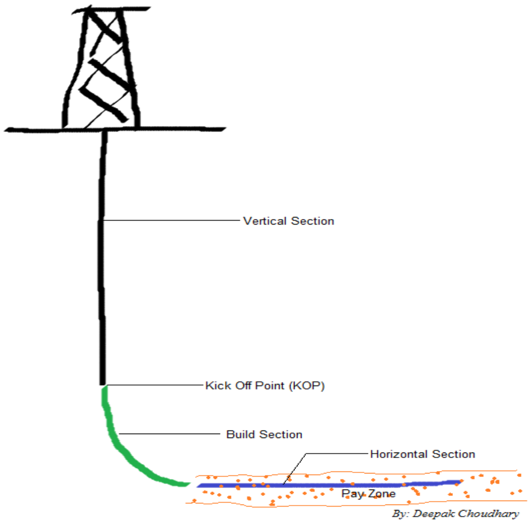


FIGURE 10: Horizontal Trajectory

2.2.2 Vertical Trajectory

Vertical trajectory is when the wellbore is drilled straight down until the oil or natural gas reservoir is reached. Vertical trajectory is most efficient when reservoir pressure is high and the formation has high permeability.

2.2.3 Continuous Build Trajectory

For the continuous build trajectory, as stated by Shanzou et. al., 1998, it has the smallest drag and the shortest well length in sliding and tripping out operation, and torque in rotating operation is not too high. It still have the disadvantages such as high build up rate and long build up length. The well is made up of a vertical section and a build section to the target. This well has relatively deep initial deflection at which point hole angle is maintained to the target. Applicable for salt dome drilling, fault drilling, sidetracking and re-drilling.

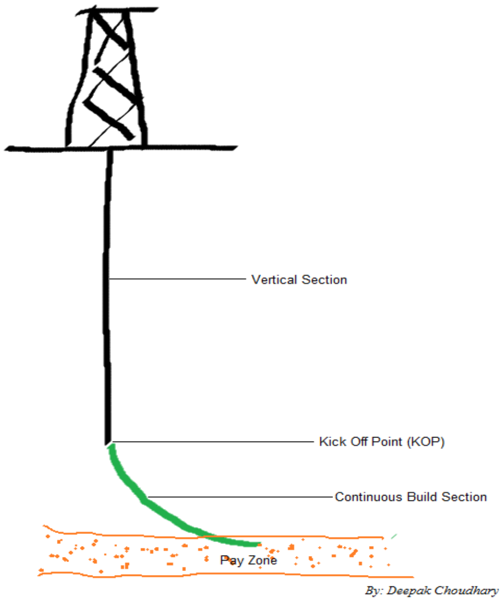


FIGURE 11: Continuous Build Trajectory

2.2.4 S-Type or Build, Hold and Drop Trajectory

Build, Hold and Drop trajectory show that well length and hold angle increase with the increase of kick off point depth, and torque and drag of tripping out decease (Jianguo et. al., 1998). The well is made up of a vertical section, build section, tangent section (hold), and drop section to the target. Applicable to target multiple pay zones, or to avoid fault regions. Limitations include generation of more torque and drag for the same horizontal departure.

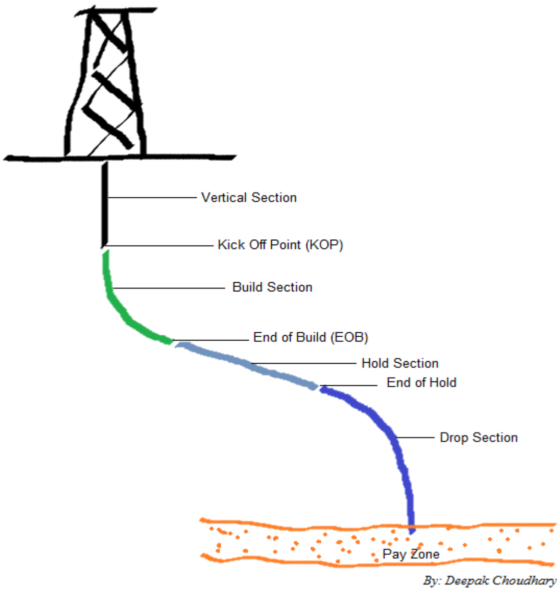


FIGURE 12: Build, Hold and Drop Trajectory

2.2.5 Build and Hold Trajectory

As explained by Zhiyong et. al., 1998, build and hold trajectory has smallest and constant build up rate that is favourable for trajectory control. Other than that, torque and drag also is small but the disadvantage is longer well length. This type is made of a vertical section, one build section and a tangent section (hold) to the target. The well is drilled vertically from the surface to the kickoff point (KOP) at a relatively shallow depth. From the KOP, the well is steadily and smoothly deflected and a straight angle approach is used to reach the target. Applicable for single producing zones with shallow-to-moderate depth.

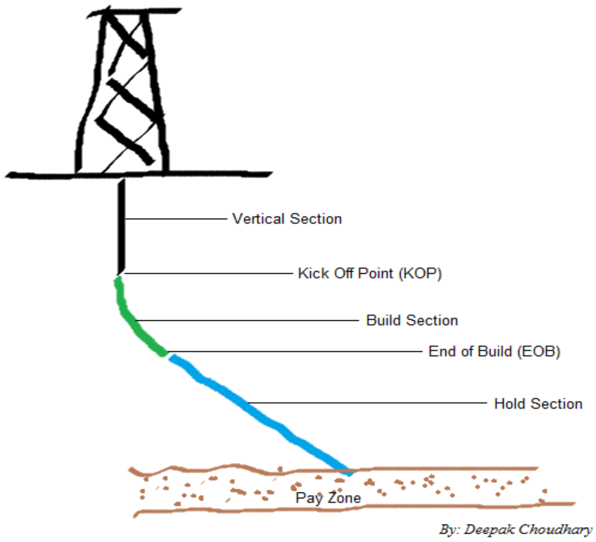


FIGURE 13: Build And Hold Trajectory

2.2.6 Radial Hydraulic Jet Drilling

One of the common radial drilling technique used in the industry is radial hydraulic jet drilling. It is regarded as a highly cost-effective Enhanced Oil Recovery (EOR) method, which is able to triple the standard oil well drainage halo (Sino-Australia, 2014). This technique are known as an economical friendly technique as it is associated with short construction cycle without any impact on the reservoir.

The technology of radial hydraulic jet drilling expands the accessible drainage area of oil and gas reservoir by 300 feet from 120 feet by using traditional vertical wells. The difference were greatly observed. Increment of the drainage area range enhanced the control area with extended oil and gas extraction amount, ultimately increase the oil well productivity.

There are several research paper and case study that quite similar with this report. As an example from the SPE Paper, entitled The Effect of Well Trajectory on Horizontal Well Performance by Bond, 2006. But, in this paper, they are only focussing on the theoretical approach (slanted well trajectory only) on horizontal well, meanwhile in this report, the writer will include several design of well trajectory (horizontal, vertical, sideway curves, circular arc and etc.) at certain reservoir condition by using dynamic modelling; (ECLIPSE 100 Simulator) and analytical (analysis) approach. Another research paper is Mathematical Modeling of Wellbore Flow Behavior in Multilateral Wells by Amalina, 2012. The main objective in this research paper is to develop the computer codes to model the flow behavior in the lateral of multilateral well by using MATHLAB and mainly generate the typical well condition for the reservoir. Some of the data can be a reference in this report since, the previous research paper only discuss the theoretical calculation instead of design using a software. However, this report will improve the design of well trajectory based on the previous research studies.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The research methodology of this project is focusing on applying design of well trajectory by using ECLIPSE 100 Simulator Software from Schlumberger to get the production rate. Thus, the method will be planned based on the process flow to achieve the objective of this project which is to determine the effectiveness of well trajectory on injection and production of EOR and also to compare the effective of each type of well trajectory at the same reservoir condition.

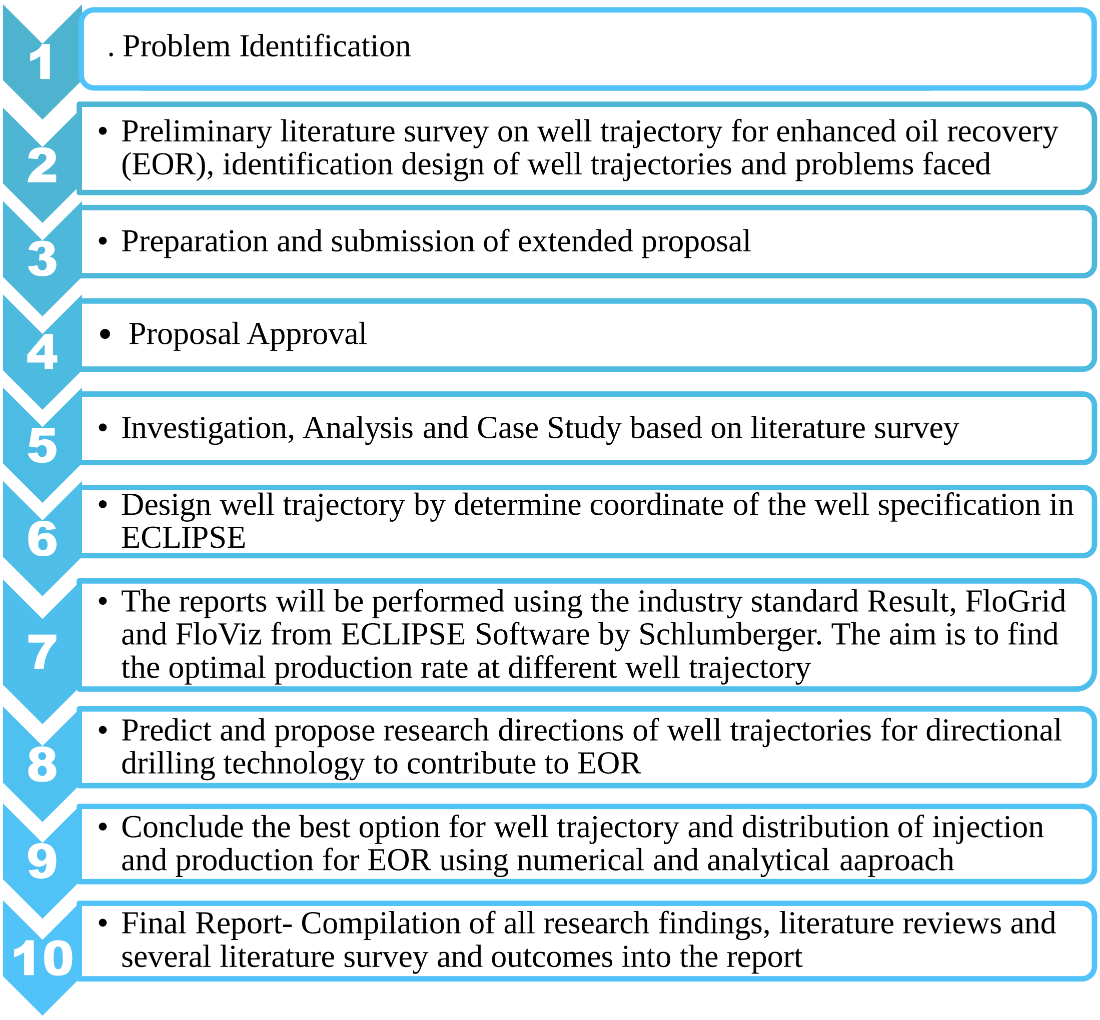


FIGURE 14: Flowchart of Research Methodology

3.2 Tools Used

In the making of this project, there are several tools that been used.

TABLE 1: Tools Used

Tools Used
One Petro Journal
End Note 7
Microsoft Office
ECLIPSE 100 Simulator Software

3.3 Project Activities

The figure 3 below shows the section header keywords for the software in the project. In this part, all the activities which need to be done under each of the main method for this project will be listed down.

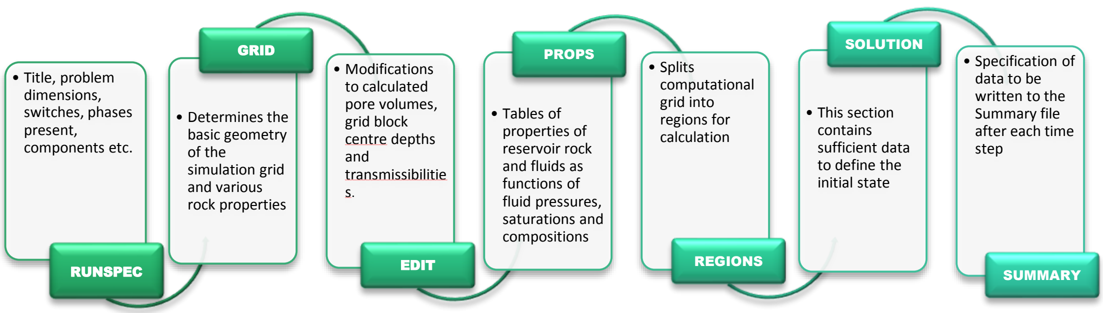


FIGURE 15: Section Header Keywords for the ECLIPSE Simulator

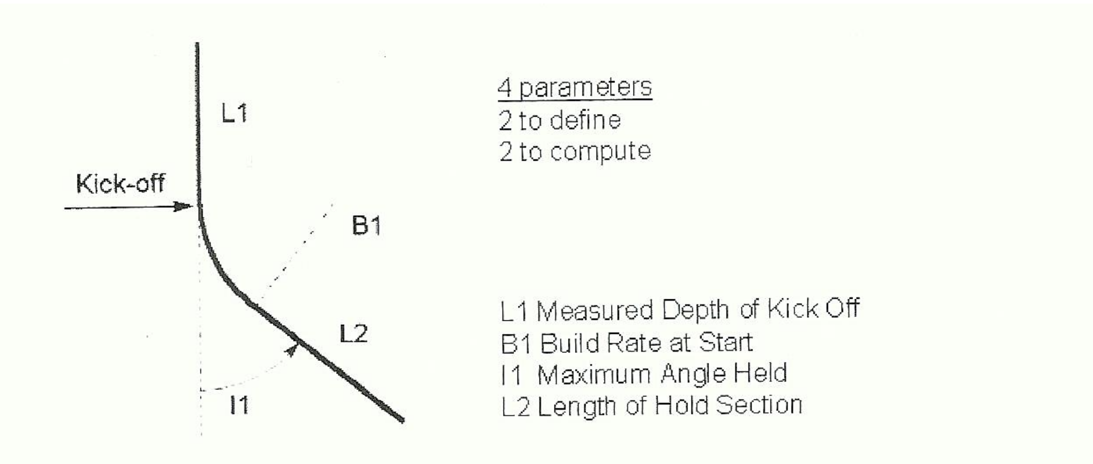
This may be used to inspect the interior of reservoir simulation models to identify the distribution of phases or components within a phase at any given time step in the simulation. For example, this can be helpful in identifying the location of unrecovered oil during a water-flood, and whether continued injection of water, say, will help displace this oil, or whether the oil will in fact be bypassed, and infill well drilling in this location is required to maximise recovery.

2D Directional Well Planning

The two-dimensional well planning tools construct well path trajectories that follow the plane of a vertical section, that is, there is no change in azimuth angel. This software provides two methods from planning 2D wells; Slant Well and S-Well. A slant well is a simple hold-build-hold profiles; whereas, an S-Well can be a build-hold-drop-hold profile or a build-fold-build-hold profile.

<u>*Slant Well Design*</u>

The following graphic depicts 2D Slant Well Design Parameters:



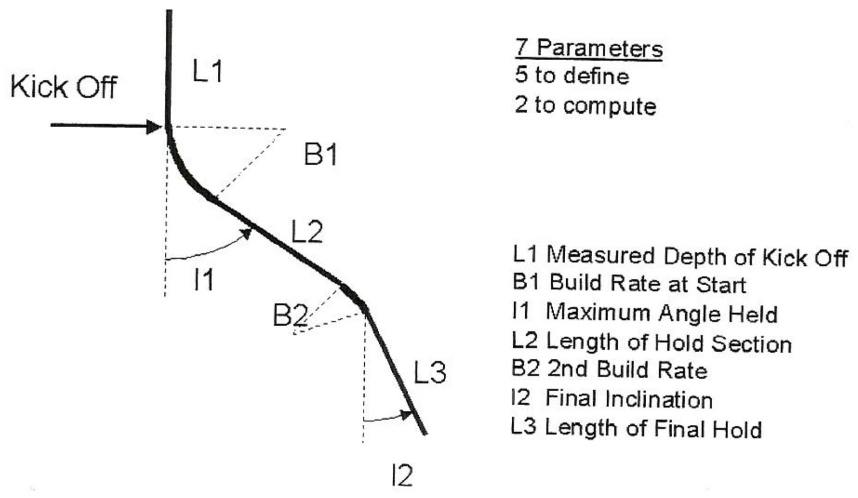
To design a Slant Well:

1. Type in the coordinates of the point to aim for or select a target
2. Check two of the unknown from the list of four below. Example unknowns are 2nd hold length and maximum angle held
3. Enter the two known parameters:
    a. 1st Hold Length is the length of initial hold section before the kick-off point, or more simply, the kick-off depth. Enter zero for no kick-off length
    b. 1st Build is the build-up rate
    c. Maximum Angle Held is the tangent angle of the profile
    d. 2nd Hold Length is the length of the tangent hold section
4. Click Calculate to compute

S-Well Design

An S-well has three sections, Build-Hold-Build/Drop, and is defined by seven parameters. You can also add a hold for the kick off.

The following graphic depicts 2D S-Well Design parameters:



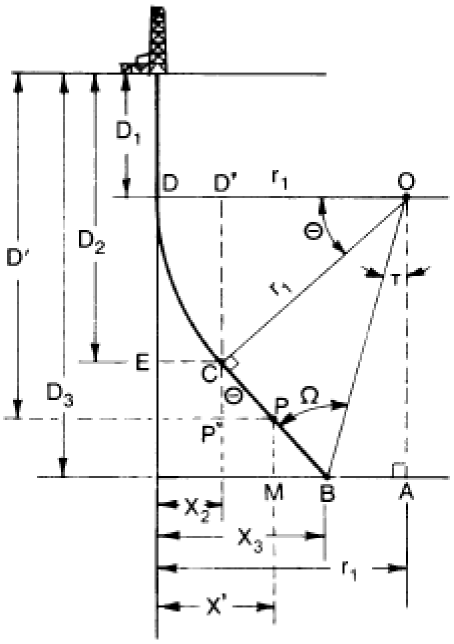
To enter a 2D S-well Profile:

1. Type in the coordinates of the point to aim for, or select a target
2. Check two of the unknown from the list of seven below. Example unknowns are 2nd hold length and maximum angle held
3. Enter the five remaining parameters:
    a. 1st Hold Length is the length of initial hold section before the kick-off point, or more simply, the kick-off depth. Enter zero for no kick-off length
    b. 1st Build is the build-up rate
    c. Maximum Angle Held is the tangent angle of the profile
    d. 2nd Hold Length is the length of the tangent hold section
    e. 2nd Build Rate is the second build or drop rate, which is a positive (+) or negative (-) value
    f. Final Inclination is the inclination you want to achieve at the target
    g. Final Hold Length is the distance from the end of the last build to the target. Enter zero if you do not want a straight section before the target

Theoretical Approach

In order to develop a model to estimate productivity of oil, a simplified mathematical equation is been calculated. Different well trajectory will have different mathematical equation.

Build and Hold Well Trajectory



Radius of Curvature

$$r1 = \frac{18{,}000}{\pi}\pi \times \frac{1}{BUR};;(BUR = °/100ft)$$

Length of Curvature

$$L_{DC} = \frac{\pi}{18{,}000}x\, r1\theta = \frac{\theta}{BUR}$$

Horizontal Departure to EOB

$$X2 = r1(1 - cos\theta)$$

Max Inclination Angle

$$\theta = \arcsin\left[\frac{r1}{\sqrt{(r1 - x3)^2 + (d3 - d1)^2}}\right] - arc\tan(\frac{r1 - x3}{d3 - d1})$$

Length of Hold

$$L_{CB} = \frac{x3 - x2}{\sin \theta}$$

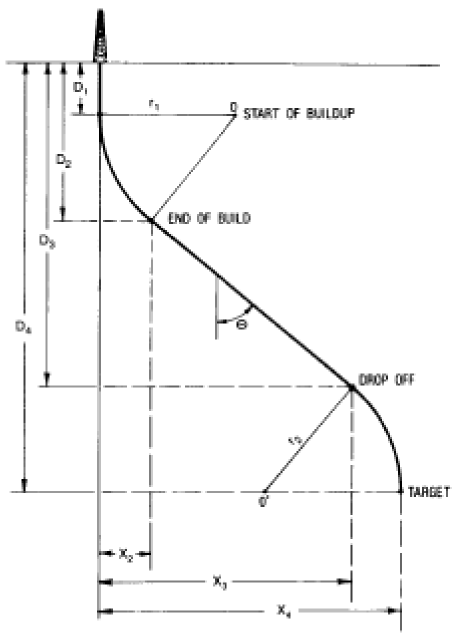
Total Measured Depth

$$D_M = D_1 + L_{DC} + L_{CB}$$

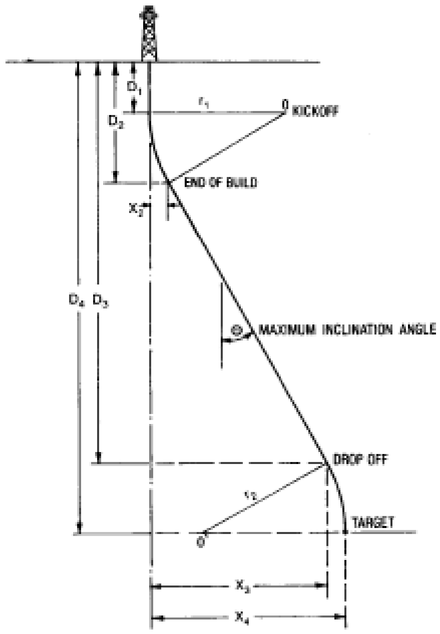
Build, Hold and Drop Well Trajectory

There are two cases for this type of trajectory.

For the **1st case, r1<x3 and r1+r2<4**.



Meanwhile for the 2nd **case, r1<x3 and r1+r2>4.**



<u>Max Inclination Angle</u>

Case 1:

$$\boldsymbol{\theta = arc\ tan\left(\frac{D_4-D_1}{r_1+r_2-x_4}\right) - arc\ cos\{\left(\frac{r_1+r_2}{D_4-D_1}\right) x\ sin\left[arc\ tan\left(\frac{D_4-D_1}{r_1+r_2-x_4}\right)\right]\}}$$

Case 2:

$$\boldsymbol{\theta = arc\ tan\left(\frac{D_4-D_1}{x_4-(r_1-r_2)}\right) - arc\ cos\{\left(\frac{r_1+r_2}{D_4-D_1}\right) x\ sin\left[arc\ tan\left(\frac{D_4-D_1}{x_4-(r_1-r_2)}\right)\right]\}}$$

3.3 Gantt chart

TABLE 2: Gantt chart

Gantt Chart	Period (Weeks)													
Description of planning	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1 (May 14 – Aug 14)														
Doing research on the project - search literature survey and case study - summarize the literature survey														
Proposal Defence presentation														
List down all type of well trajectory														
Develop design of well trajectory														
Design Well Trajectory and geometry manually														
Interim Report Submission														
FYP 2 (Sept 14 – December 14)														
Apply mathematical order for designation of well trajectory by using ECLIPSE Simulator														
Apply the effectiveness of well trajectory by doing simulation														
Get the report from Results in the ECLIPSE Simulator and compare each type of well trajectory and oil production rate														
Repeat the steps for different well trajectory														
Present the project in front of evaluators														
Report the result to supervisor														

3.4 Key milestone

Based on the Gantt chart, the key milestone is denoted as the symbol for FYP 1 and for FYP 2.

Key milestone for FYP 1

- Research study on the project title and summarize literature survey which related to the to the title
- Proposal Defence presentation
- List down all type of well trajectory
- Develop design of well trajectory based on case study
- Design Well Trajectory and geometry profiles manually
- Report the result to supervisor

Key milestone for FYP 2

- Apply mathematical order for designation of well trajectory by using ECLIPSE Simulator from Schlumberger
- Apply the effectiveness of well trajectory by doing simulation
- Get the report from Results and FloViz in ECLIPSE Simulator and compare each type of well trajectory and oil production rate
- Repeat the steps if necessary
- Report the result to supervisor

CHAPTER 4

RESULTS AND DISCUSSION

All the data been used are from the real data and are listed asbelow:

TABLE 3: Reservoir Data

Properties	Value
Structure size (STOOIP)	75 mmstb
Connate water saturation	17%
Reservoir depth	-8500 ft TVD SS
Reservoir thickness	110 ft
Reservoir pressure	4000 psia
Reservoir temperature	190 deg F
Reservoir permeability	150 mD
Reservoir compressibility	3.2e-6 psi-1
Aquifer permeability	50 mD
Aquifer porosity	22%
Oil gravity	32 deg API
Gas gravity	0.76 S.G.
Solution GOR	450 scf/stb
Bubble point	2050 psia
Water density	1.04 S.G.
Field & wells elevation	250 ft above MSL (mean sea level)
Separator pressure	150 psig

In this report, there are only 2 groups of well which are injector and producer. All the well are located based on certain coordinates to enhance the productivity of the oil. Water is used as the fluid in the injector well. Total number of grid blocks are (x=10, y=10, k=3). PVT properties was attached at the appendices section at the end of this report.

Locations of the wells (Coordinates)

Producer: (i=5, j=5, k=3)

Injector 1: (i=1, j=1, k=3)

Injector 2: (i=1, j=10, k=3)

Injector 3: (i=10, j=1, k=3)

Injector 4: (i=10, j=10, k=3)

4.1 Results for Vertical Well

All the wells (injectors and producers) was designed to be vertical well. The results below shows that flowing of oil after water is injected and production rate of the oil and water. The red colour indicates that there are some oil in the reservoir meanwhile the blue grid blocks indicates reservoir was filled with water since water used as fluid in the injection well.

4.1.1 Before Water Injection

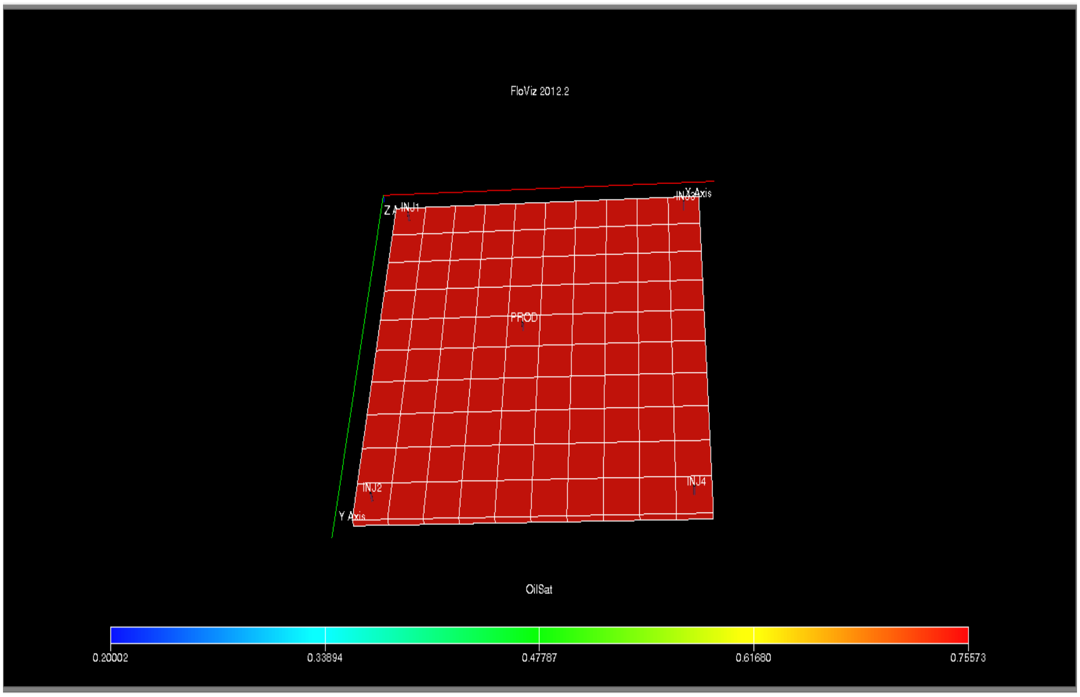


FIGURE 16: Image of the Grid blocks before water injection

4.1.2 Middle of Water Injection

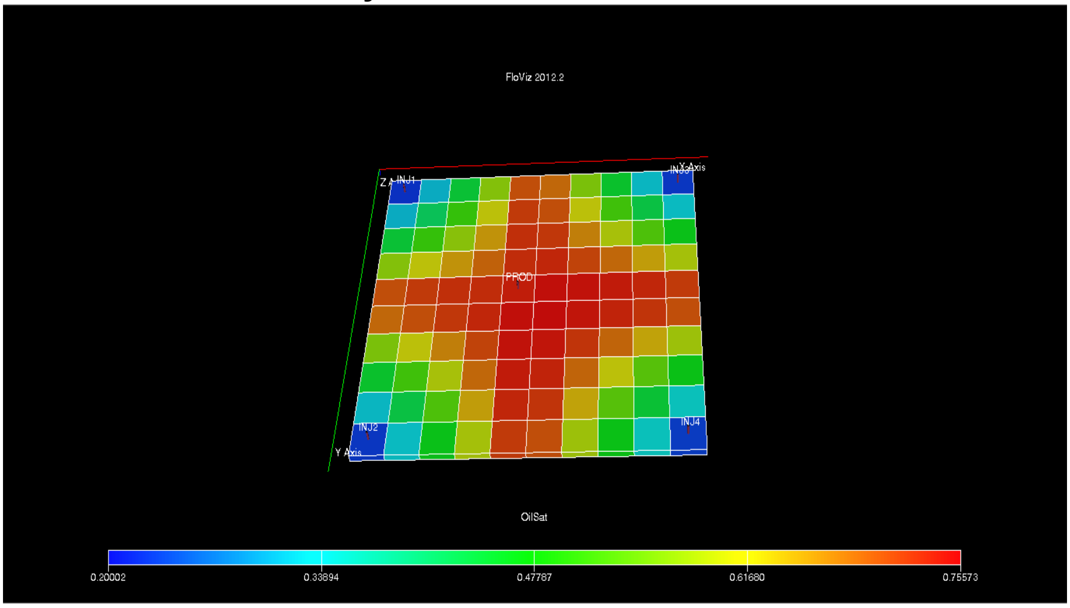


FIGURE 17: Image of the Grid blocks in the middle of water injection

4.1.3 After Water Injection

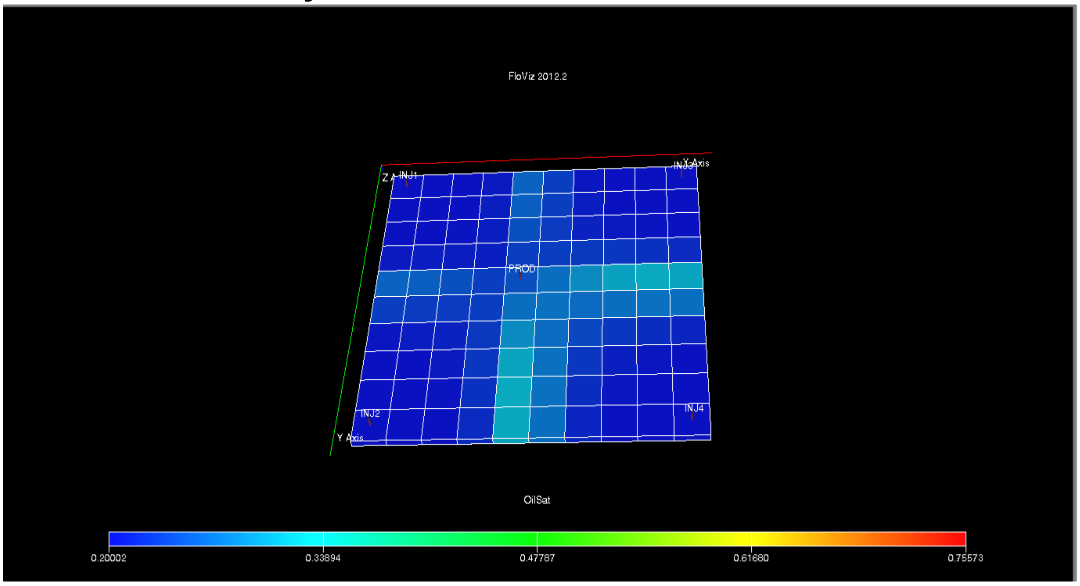


FIGURE 18: Image of the Grid blocks after water injection

And here is the production profiles (Field Oil Production Rate and Field Water Production Rate) for vertical well been recorded.

4.1.4 Production rate of Oil vs Time

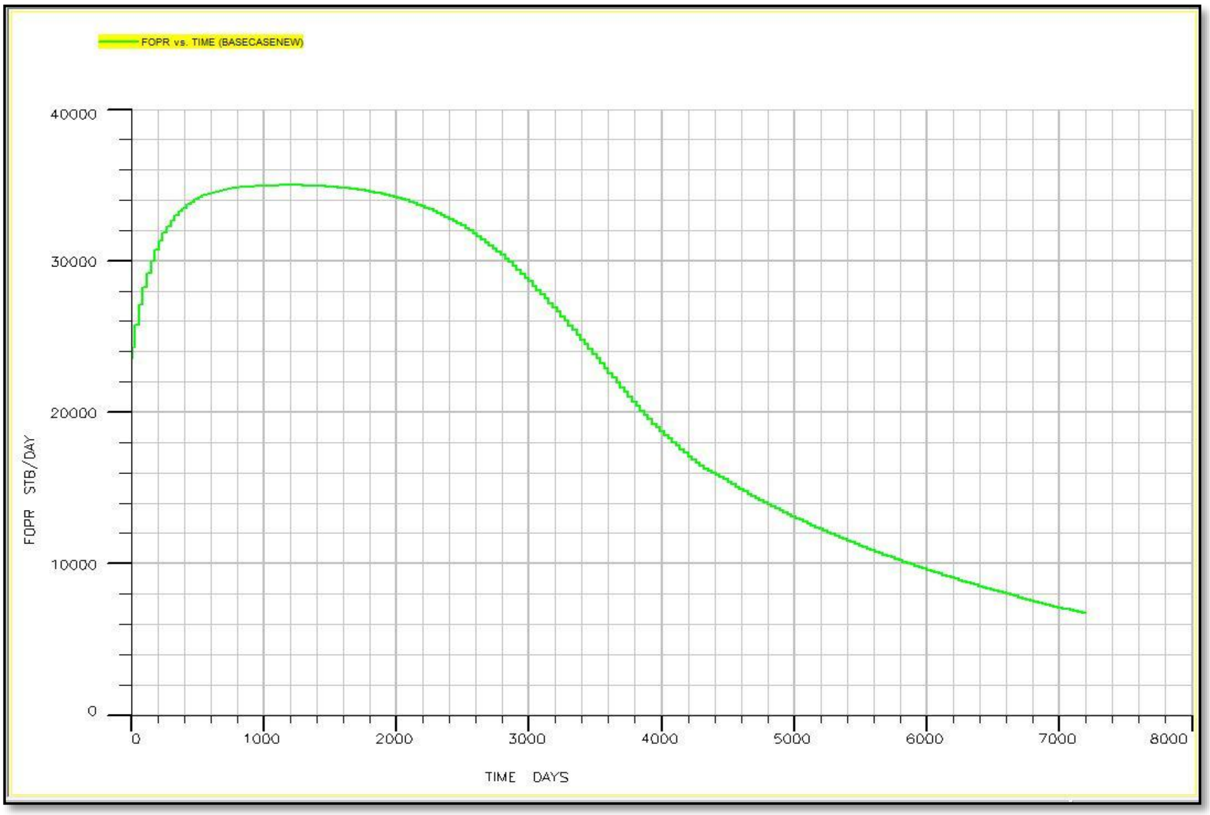


FIGURE 19: Graph of Field Oil Production Rate vs Time

4.1.5 Production Rate of Water vs Time

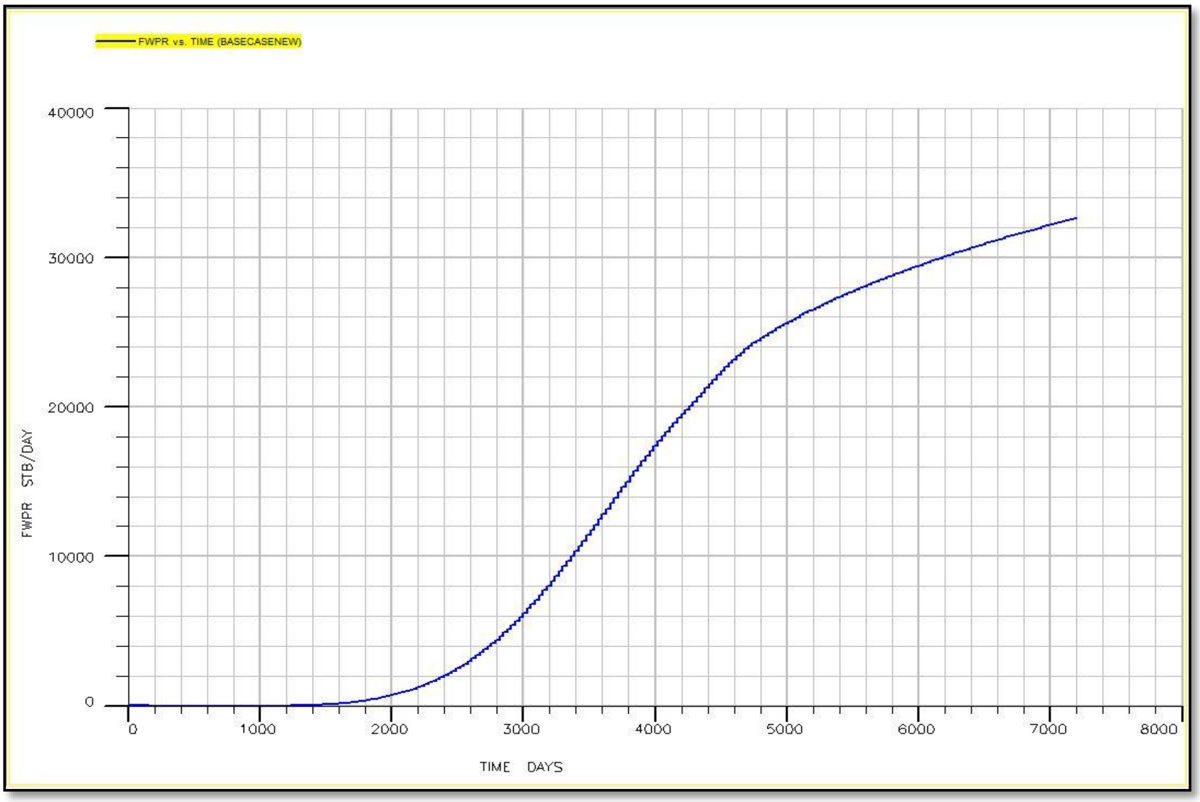


FIGURE 20: Graph of Field Water Production Rate vs Time

4.2 Results for Deviated Well (Producer)

Mathematical Approach

Radius of Curvature

$$r1 = \frac{18{,}000}{\pi}\pi \times \frac{1}{2};;\left(BUR = \frac{2°}{100ft}\right)$$

$$\boldsymbol{r1 = 2864.79\ ft}$$

Maximum Inclination Angle

$$\theta = \arcsin\left[\frac{r1}{\sqrt{(r1-x3)^2+(d3-d1)^2}}\right] - arc\tan\left(\frac{r1-x3}{d3-d1}\right)$$

$$\theta = \arcsin\left[\frac{2864.79}{\sqrt{(2864.79-2655)^2+(8500-1600)^2}}\right] - arc\tan\left(\frac{2864.79-2655}{8500-1600}\right)$$

$$\boldsymbol{\theta = 19.35°}$$

Length of Curvature

$$L_{DC} = \frac{\pi}{18{,}000}x\ r1\theta = \frac{\theta}{BUR}$$

$$L_{DC} = \frac{\pi}{18{,}000}x\ 2864.79(19.35°)$$

$$\boldsymbol{L_{DC} = 967.5\ ft}$$

Horizontal Departure to End of Build

$$X2 = r1(1-cos\theta)$$

$$X2 = 2864.79(1-cos\ 19.35)$$

$$\boldsymbol{X2 = 161.826\ \text{ft}}$$

Length of Hold

$$L_{CB} = \frac{x3-x2}{\sin\theta}$$

$$L_{CB} = \frac{2655-161.826}{\sin 19.35°}$$

$$\boldsymbol{L_{CB} = 7524.567\ ft}$$

Total Measured Depth

$$D_M = D_1 + L_{DC} + L_{CB}$$

$$D_M = 1600 + 967.5 + 7524.567$$

$$\boldsymbol{D_M = 10{,}092.067\ ft}$$

From the calculation above, deviated well for injector and producer being generated. And below is the results of oil production rate and water injection rate for deviated well.

4.2.1 Production rate of Oil vs Time

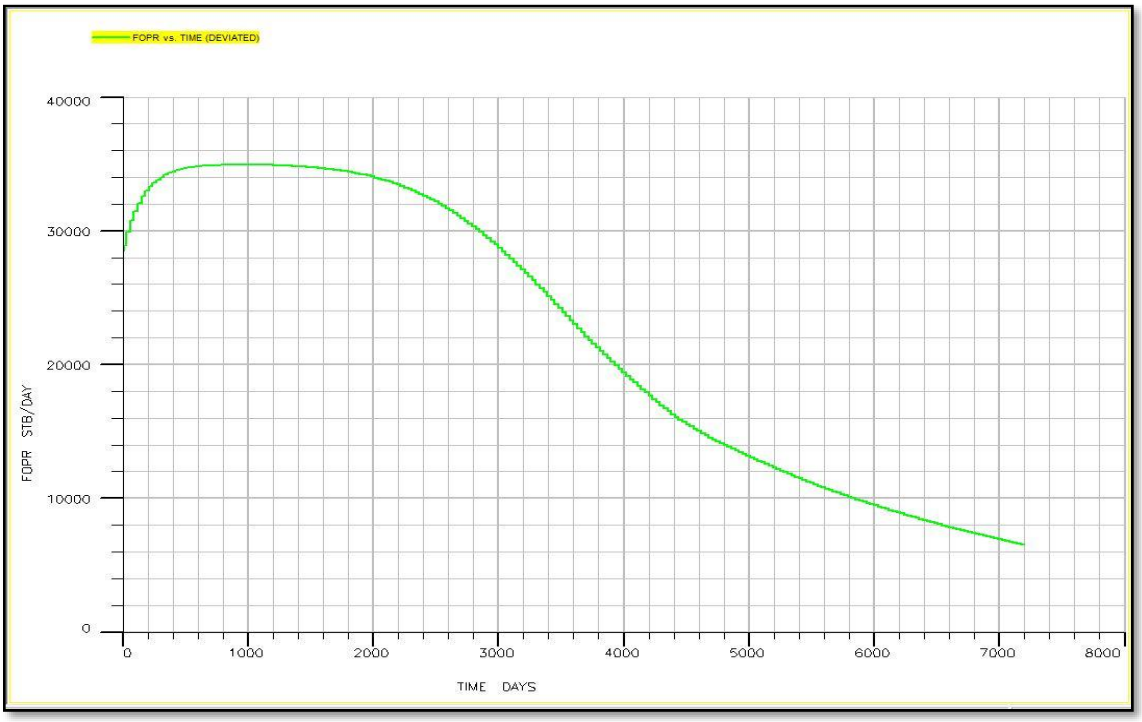


FIGURE 21: Graph of Field Oil Production Rate vs Time

4.2.2 Production rate of Water vs Time

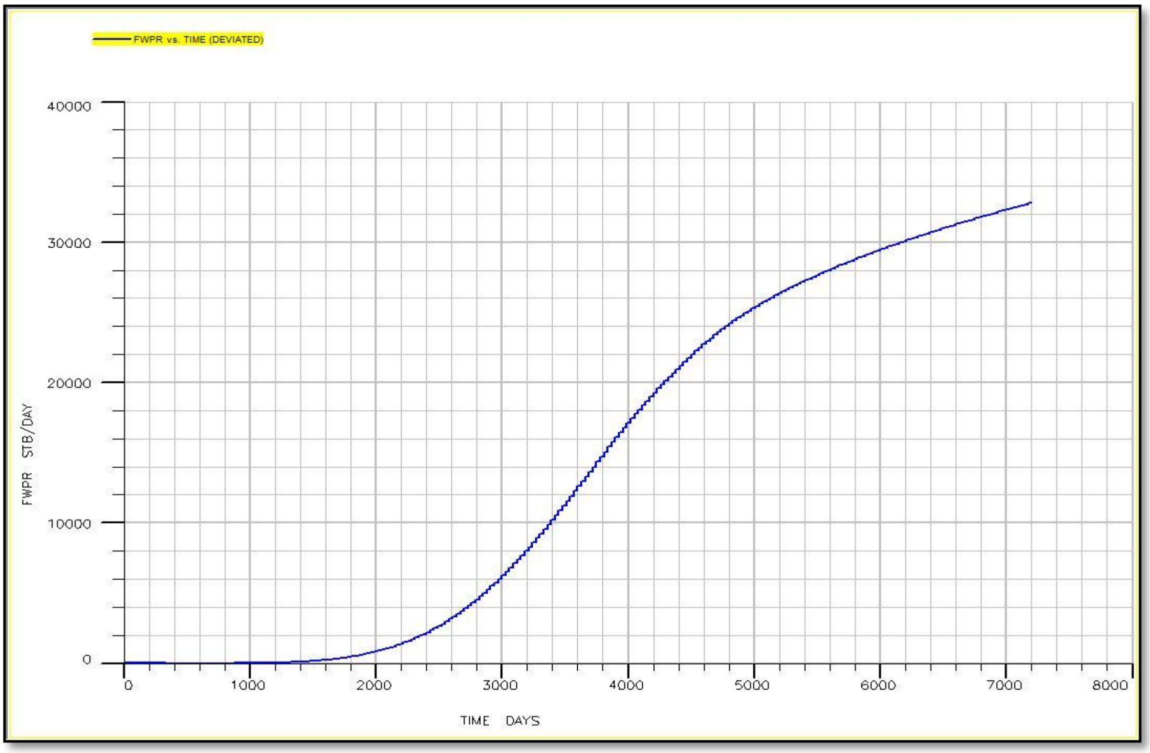


FIGURE 22: Graph of Field Water Production Rate vs Time

4.3 Results for Deviated Well (Injector)

4.3.1 Production rate of Oil vs Time

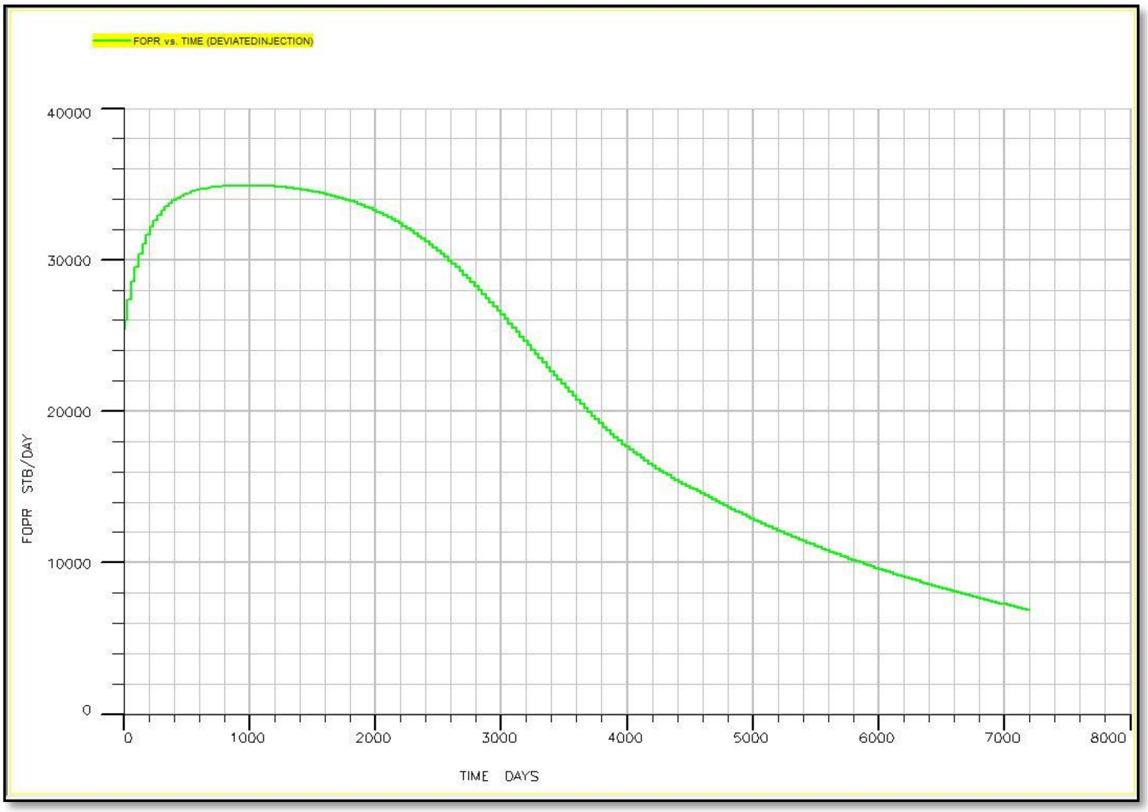


FIGURE 23: Graph of Field Oil Production Rate vs Time

4.3.2 Production rate of Water vs Time

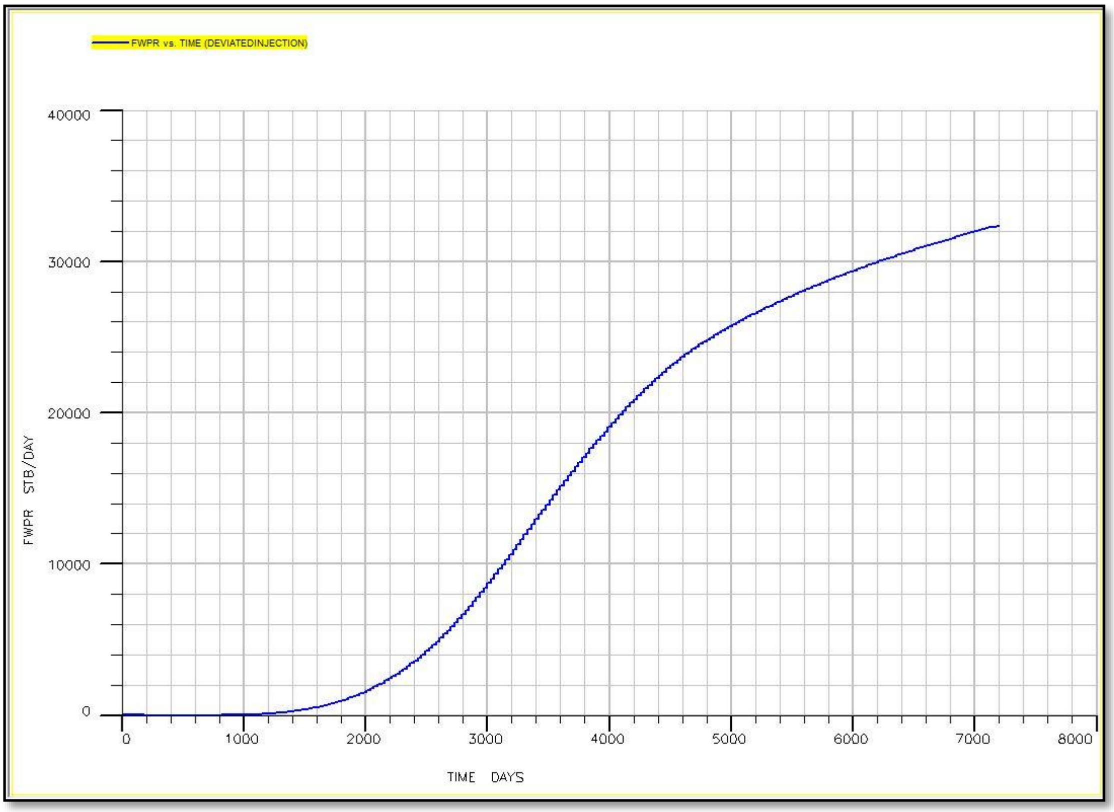


FIGURE 24: Graph of Field Water Production Rate vs Time

Based on the graph above, it is confirmed that deviated well trajectory (Producer) can improve production rate by 30% of vertical well trajectory. From Figure 20, oil production rate at early stage of production is 2900stb/day meanwhile vertical well is 2600stb/day. It shows that deviated well can improve injection and production rate of EOR.

4.4 Results for Injection Rate Well 1

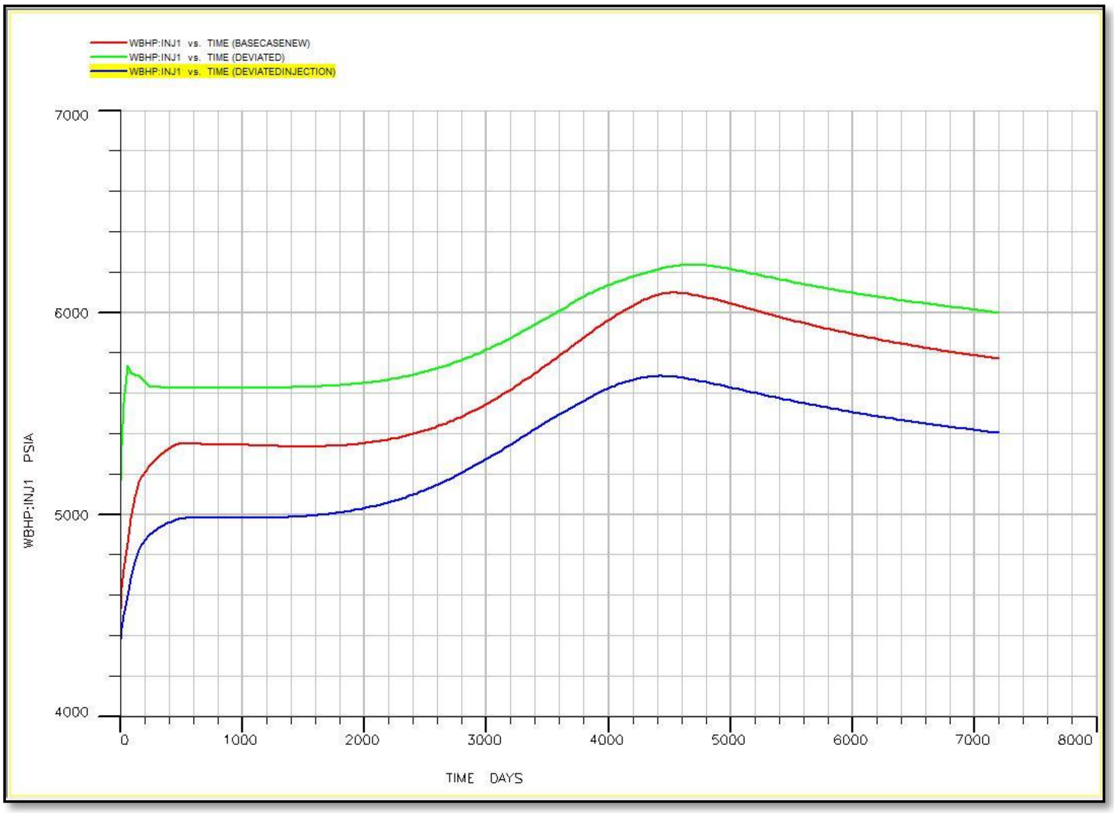


FIGURE 25: Comparison of injection rate for Injector 1

Meanwhile from Figure 24, shows that deviated well for producer had high injection rate compared to vertical well. It is proven that deviated well will increase injection and production rate of EOR.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project aims to do literature survey and simulation on well trajectory in relation to oil production rate in order to design more effective well trajectory to reduce the number of wells to be drilled. This is because oil and gas industry is focussing on cutting the cost and at the same time optimize the reservoir performance. It is also expected that the results of this project will be able to increase the efficiency as well as total oil recovery

From the study, it is confirmed changing well trajectory is able to increase the efficiency of oil recovery for various condition reservoirs. It can be concluded that deviated well managed to get more production rate compare to vertical well.

Drilling deviated wells requires extraordinary accuracy and control. Deepwater and high-pressure, high-temperature wells offer additional challenges. Wells are being drilled in tectonically active and remote areas where the infrastructure may be less well developed. The emergence of this new drilling technology is driven by the needs of the industry.

Drilling engineers wishing to improve drilling efficiency, avoid potential hazards, and optimize well placement need a detailed understanding of reservoir characteristics and how these affect drilling operations in each well. Data collection during drilling enables rapid and effective modifications of the drilling plan.

5.2 Recommendation

These are some recommendation to improve designing well trajectory to achieve an optimum production rate.

There are several factors that would be a concern to develop an optimum production rate depending on the different well trajectory. There are three (3) main factors that should be taken seriously when planning a well trajectory profiles.

5.2.1 Alterations of Models

While using this reservoir model, when specifying changes or requesting modifications to a specific parameter, keep in mind that the systems are not independent and a change to one system may require a change to another.

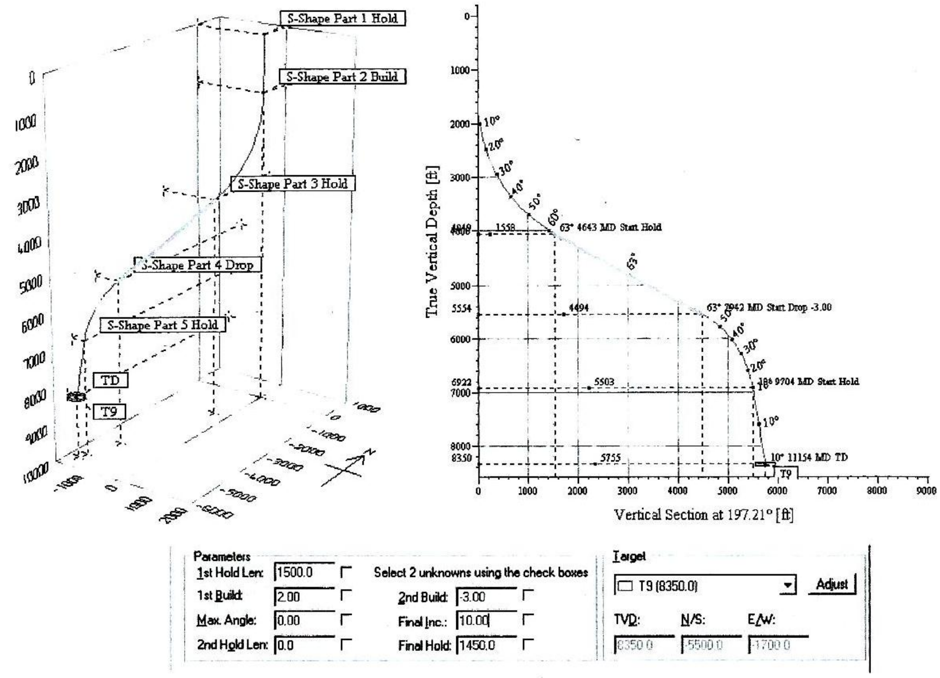
5.2.2 Determination of Well Plan and Trajectory

Determining the best well plan and design is an iterative process. Always consider the factors affecting critical or marginal components. Determine if the assumptions were reasonable or overly conservative. Evaluate the well requirements and design to determine how changes may affect the specifications.

5.2.3 Drilling Operation Needs

Different operations in drilling programs such as tripping out, tripping in, sliding drilling, rotating drilling, forward reaming, back reaming and etc. would produce different forces on the drill strings as their torque and drags exerted is variable. For that, the operations which are known to have the most impacts towards the success of well trajectory on the projects need to be identified and properly planned. Difficulty would be emerged in different conditions of operations particularly the one that associated with the tripping out, sliding drilling and rotating drilling operations. The recommended approach taken involve the identifications of the optimum well path by calculating the torque and drag simultaneously and compare the finding with other drilling operation.

APPENDICES



Coding for Vertical Well

```
-- Adding Well Oil Production Rate
--
--
--
--===============================================================
RUNSPEC


TITLE
3D - 2 Phase Model


--        Number of cells
--       NX      NY      NZ
--       --      --      --
DIMENS
              10            10            1 /


-- Phases
OIL
WATER
/


-- Units
FIELD


-- Maximum well/connection/group values
--     #wells  #cons/w  #grps  #wells/grp
--     ------  -------  -----  ----------
WELLDIMS
              15            16            5              1 /
```

```
-- Unified output files
UNIFOUT


-- Simulation start date
START
  1 Jan 2017 /



--==============================================================
GRID


-- Size of each cell in X, Y and Z directions
DX
100*549.03/


DY
100*549.03/


DZ
100*110/


--TVDSS of top layer only
--        X1  X2     Y1  Y2     Z1  Z2
--        --  --     --  --     --  --
BOX
              1    10      1   10      1   1 /

TOPS
100*8500/

ENDBOX


-- Permeability in X, Y and Z directions for each cell
PERMX
100*150  /


PERMY
100*150  /


PERMZ
100*150    /


-- Porosity of each cell
PORO
100*.22/


-- Output file with geometry and rock properties (.INIT)
INIT


--==============================================================
PROPS


-- Densities in lb/ft3
--          Oil      Wat      Gas
--          ---      ---      ---
DENSITY
                53.31349       64.92509       47.45 /


-- PVT data for dead oil
--        P        Bo        Vis
```

```
--      ----      ----      -----
PVDO
              300       1.25      1.0
       800       1.20      1.1
      6000       1.15      2.0
/
-- PVT data for water
--       P       Bw       Cw        Vis      Viscosibility
--      ----      ----      -----      -----     -------------
PVTW
      4000       1.02       3.0E-06    1.0        0.0  /


-- Rock compressibility
--       P         Cr
--      ----       -----
ROCK
      4000        3.2E-06 /



-- Water and oil rel perms & capillary pressures
--       Sw      Krw     Kro     Pc
--      -----    -----    ---    ----
SWOF
      0.25     0.0       0.9      4.0
      0.5      0.2       0.3      0.8
      0.7      0.4       0.1      0.2
      0.8      0.55      0.0      0.1 /




--================================================================
SOLUTION

-- Initial equilibration conditions
--       Datum   Pi@datum    WOC    Pc@WOC
--       -----   --------   -----   ------
EQUIL
       8500     4000       8900    0.0 /


-- Output to Restart file for t=0 (.UNRST)
--    Restart file     Graphics
--    for init cond     Only
--    -------------    -------
RPTRST
     BASIC=2          NORST=1 /

--================================================================
SUMMARY

-- Field average pressure
FPR

-- Bottomhole pressure of all wells
WBHP
/


-- Field Oil Production Rate
FOPR

-- Field Water Production Rate
FWPR

-- Field Oil Production Total
FOPT

-- Field Water Production Total
FWPT

-- field Recovery factor
FOE
```

```
-- Well Oil Production Rate
WOPR
PROD /

-- Water cut in PROD
WWCT
PROD /


-- CPU usage
TCPU

-- Create Excel readable Run Summary file (.RSM)
EXCEL

--===============================================================
SCHEDULE

-- Output to Restart file for t>0 (.UNRST)
--    Restart file
--     every step
--    ------------
RPTRST
     BASIC=2         NORST=1 /

-- Location of wellhead and pressure gauge
--     Well  Well   Location   BHP    Pref.
--     name  group   I    J   datum   phase
--     -----  ----    -    -   -----   -----
WELSPECS
      PROD   G1     5    5    8500   OIL /
      INJ1    G2     1    1    8500   WATER /
             INJ2   G2    1    10    8500   WATER/
             INJ3    G2     10    1    8500   WATER/
             INJ4    G2     10    10    8500   WATER/
/

-- Completion interval
--     Well   Location  Interval  Status          Well
--     name    I    J    K1  K2   O or S          ID
--     ----    -    -    --  --   ------          ------
COMPDAT
      PROD    5    5    1    1   OPEN    2*      0.6667 /
      INJ1     1    1    1    1   OPEN    2*      0.6667 /
             INJ2     1    10    1    1   OPEN    2*      0.6667 /
             INJ3     10    1    1    1   OPEN    2*      0.6667 /
             INJ4     10    10    1    1   OPEN    2*      0.6667 /
/


-- Production control
-- Well  Status  Control   Oil   Wat   Gas    Liq  Resv   BHP
--  name          mode     rate  rate  rate   rate  rate  limit
--  ----  ------  ------    ----  ----  ----   ----  ----  -----
WCONPROD
  PROD   OPEN    LRATE         3*          150000  1*    2900 /
/


-- Injection control
-- Well  Fluid  Status  Control   Surf   Resv    Voidage   BHP
--  NAME  TYPE           mode     rate   rate  frac flag  limit
--  ----  -----  ------  -------   ----   ----  ---- ----  -----
WCONINJ
   INJ1   WATER  OPEN     RATE     10000   3*             10000 /
              INJ2   WATER  OPEN     RATE     10000   3*             10000 /
              INJ3   WATER  OPEN     RATE     10000   3*             10000 /
              INJ4   WATER  OPEN     RATE     10000   3*             10000 /
/


-- Number and size (days) of timesteps
TSTEP
240*30 /
```

END

Coding for Deviated Well

Adding Well Oil Production Rate

```
--
--
--
--=================================================================
RUNSPEC


TITLE
3D - 2 Phase Model


--       Number of cells
--      NX      NY      NZ
--      --      --      --
DIMENS
             10            10            3 /


-- Phases
OIL
WATER
/


-- Units
FIELD


-- Maximum well/connection/group values
--     #wells  #cons/w  #grps  #wells/grp
--     ------  -------  -----  ----------
WELLDIMS
             15            16            5             1 /


-- Unified output files
UNIFOUT


-- Simulation start date
START
  1 Jan 2017 /



--=================================================================
GRID


-- Size of each cell in X, Y and Z directions
DX
300*549.03/


DY
300*549.03/


DZ
300*110/


--TVDSS of top layer only
--        X1  X2     Y1  Y2     Z1  Z2
--        --  --     --  --     --  --
BOX
              1    10      1   10      1   3 /

TOPS
300*8500/
```

```
ENDBOX


-- Permeability in X, Y and Z directions for each cell
PERMX
100*150   100*200   100*150 /


PERMY
100*150   100*170   100*150/


PERMZ
100*150   100*180   100*200/


-- Porosity of each cell
PORO
300*.22/


-- Output file with geometry and rock properties (.INIT)
INIT


--===============================================================
PROPS


-- Densities in lb/ft3
--           Oil     Wat     Gas
--           ---     ---     ---
DENSITY
                    53.31349       64.92509       47.45 /


-- PVT data for dead oil
--        P        Bo       Vis
--       ----      ----     -----
PVDO
                300       1.25      1.0
        800       1.20      1.1
       6000       1.15      2.0
/



-- PVT data for water
--        P        Bw       Cw         Vis     Viscosibility
--       ----      ----     -----      -----    -------------
PVTW
       4000       1.02      3.0E-06    1.0        0.0  /


-- Rock compressibility
--        P          Cr
--       ----       -----
ROCK
       4000        3.2E-06 /



-- Water and oil rel perms & capillary pressures
--        Sw      Krw      Kro      Pc
--       -----    -----    ---     ----
SWOF
       0.25      0.0       0.9      4.0
       0.5       0.2       0.3      0.8
       0.7       0.4       0.1      0.2
       0.8       0.55      0.0      0.1 /



--===============================================================
```

```
SOLUTION

-- Initial equilibration conditions
--       Datum   Pi@datum    WOC    Pc@WOC
--       -----   --------   -----   ------
EQUIL
        8500     4000       8900    0.0 /


-- Output to Restart file for t=0 (.UNRST)
--     Restart file     Graphics
--     for init cond     Only
--     ------------    -------
RPTRST
     BASIC=2          NORST=1 /

--==============================================================
SUMMARY

-- Field average pressure
FPR

-- Bottomhole pressure of all wells
WBHP
/


-- Field Oil Production Rate
FOPR

-- Field Water Production Rate
FWPR

-- Field Oil Production Total
FOPT

-- Field Water Production Total
FWPT

-- field Recovery factor
FOE

-- Well Oil Production Rate
WOPR
PROD /

-- Water cut in PROD
WWCT
PROD /


-- CPU usage
TCPU

-- Create Excel readable Run Summary file (.RSM)
EXCEL

--==============================================================
SCHEDULE

-- Output to Restart file for t>0 (.UNRST)
--     Restart file
--      every step
--     ------------
RPTRST
     BASIC=2          NORST=1 /

-- Location of wellhead and pressure gauge
--      Well  Well   Location   BHP    Pref.
--      name  group   I    J   datum   phase
--     ----- ----    -    -   -----   -----
WELSPECS
      PROD   G1     5    5    8500   OIL /
      INJ1    G2     1    1    8500   WATER /
             INJ2   G2     1    10    8500   WATER/
             INJ3    G2     10    1    8500   WATER/
```

```
          INJ4    G2     10    10    8500   WATER/
/

-- Completion interval
--     Well   Location  Interval  Status          Well
--     name    I    J    K1  K2   O or S          ID
--     ----    -    -    --  --   ------          ------
COMPDAT
     PROD    5    5    1    1   OPEN    2*      0.6667 /
          PROD    5    6    2    2   OPEN    2*      0.6667 /
          PROD    5    7    3    3   OPEN    2*      0.6667 /
     INJ1    1    1    1    1   OPEN    2*      0.6667 /
          INJ2    1    10    1    1   OPEN    2*      0.6667 /
          INJ3    10    1    1    1   OPEN    2*      0.6667 /
          INJ4    10    10    1    1   OPEN    2*      0.6667 /
/


-- Production control
-- Well  Status  Control   Oil   Wat   Gas    Liq  Resv   BHP
-- name          mode      rate  rate  rate   rate  rate  limit
-- ----  ------  ------    ----  ----  ----   ----  ----  -----
WCONPROD
  PROD   OPEN    LRATE          3*          150000  1*    2900 /
/


-- Injection control
-- Well  Fluid  Status  Control   Surf   Resv   Voidage  BHP
-- NAME  TYPE           mode      rate   rate   frac flag  limit
-- ----  -----  ------  -------   ----   ----   ---- ----  -----
WCONINJ
   INJ1   WATER  OPEN     RATE     10000   3*            10000 /
          INJ2   WATER  OPEN     RATE     10000   3*            10000 /
          INJ3   WATER  OPEN     RATE     10000   3*            10000 /
          INJ4   WATER  OPEN     RATE     10000   3*            10000 /
/


-- Number and size (days) of timesteps
TSTEP
240*30 /

END
```

REFERENCES

Bond., A. Zhu, D., and Kamkom, R. (2006). The Effect of Well Trajectory on Horizontal Well Performance. SPE International Oil and Gas Conference and Exhibition 2006, China.

Chan, K.S., Chong, D., Masoudi, R., Othman, M. (2013). The Role of Advanced Well Architecture in Cost Efficient Offshore EOR Field Redevelopment. Enhanced Oil Recovery Conference 2013, Kuala Lumpur.

Ehlig-Economides, C.A., Anadrill, Mowat, G.R., and Corbett, C. (1996). Techniques for Multibranch well Trajectory design in the Context of a Three-Dimensional Reservoir Model. European 3-D Reservoir Modelling Conference 1996, Stavanger

Liang, Q.J. (2007). Trajectory Risk Index- an Engineering Method To Measure Risks of Multiples-Well Complex Trajectories. Offshore Technology Conference 2007, Houston

Shanzou, M., Genlu, H., Jianguo, Z., and Zhiyong, H. (1998). Study on Design of Extended Reach Well Trajectory. SPE International Conference and Exhibition 1998, Beijing.

Spe.Org (2014). Daqing: An Old Field at The Center Of New EOR Testing. Retrived From **http://www.spe.org/news/article/daqing-an-old-field-at-the-center-of-new-eor-testing** on 4/7/2014.

Vlemmix, S., Joosten, G.J.P., Brouwer, D.R., and Delft, T.U.(2009). Adjoint-Based Well Trajctory Optimization in a Thin Oil Rim. 2009 SPE EUROSPACE Annual Conerence and Exhibition, Amsterdam.

Yeten, B., Durlofsky, L.K., and Aziz, K. (2002). Optimization of nonconventional Well type, Location and Trajectory. SPE Annual Technical Conference and Exhibition 2002, San Antonio.