Optimization Of Well Location And Number Of Production Well

by

Ong Chin Kwang

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(Mr. Muhammad Sanit Bin Maulut)

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TRONOH, PERAK

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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.

ONG CHIN KWANG

ABSTRACT

The optimal location of drilling the wells in the oil and surrounding application has caused a significant economical impact on the reservoir management. The wells location issue in a productive formation is a vital aspect in order to have an effective field development. However, the determination of the optimal wells location in the specific geographical locations is a challenging matter since it depends on the geological and the fluid properties, reservoir characteristics and as well as on the economic parameters. Hence, reservoir simulation is recognized as one of the most reliable tools for defining the optimum strategy of production. Nevertheless, using the simulation approach in doing the forecasting bears the risk of uncertainty in the input data. Due to the reservoir inhomogeneity and the uncertainty in the reservoir description, solution to the problem is impossible at the intuitive level. Using the conventional approach to define the number of production wells and its locations is a costly trial and error process as the outcome is fully depends on the ability of the reservoir engineer to understand the reservoir behavior and its operational limits. Thus, an alternative approach in optimizing the well location which is by determining the high productivity zone within the reservoir where the hydrocarbon production is expected to reach the maximum field production. It is performed by evaluating each of the possible well position at different locations and defining the sensitivity of several reservoir properties which will have the significant impact to the optimum well placement. The studied was carried out on an actual Malaysia reservoir model which is the Gelama Merah field located in offshore Sabah. By utilizing the Eclipse 100 – A black oil model simulator software, several studies have been made and the predicted values of production were significantly promising. Furthermore, it was found that the optimal well production duration is a function of well spacing with respect to the number of production well drilled. Apart from that, changing of oil saturation (S_O) will always contribute to the high impact for the optimal well placement and oil productivity. Hence, the method proposed could be one of the useful tool to assist the progress in the decision making for the field development and strikes towards the optimal and effective hydrocarbon recovery.

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CHAPTER 1
INTRODUCTION

Choosing the optimal well placement and number of production well in recovering the optimal hydrocarbon from the reservoir is one of the vital field development decision making. The geology formation and zone connectivity have a major impact on the well location because they define the well productivity.

Several researchers have studied the production optimization of the well placement using a variety of methods and approaches. *Seifert et al.* [1] developed a method for locating horizontal and highly deviated wells. Their approach attempts to find the well trajectory that penetrates the most productive geological units. They numerically simulated a number of wells and then ranked them according to this criterion. *Bittencourt and Horne* [2] optimized the placement of multiple vertical and horizontal wells using a hybrid optimization algorithm. *Santellani et al.* [3] presented an automatic well location estimation algorithm using a Genetic Algorithm (GA) applied in conjunction with several acceleration routines that include an artificial neural network, a hill climber, and a near-well up scaling technique. They used the used the recovery factor or the discounted oil production rate penalized by excessive water or gas production, as their cost function.

These researchers first identified the grid blocks that honored specified constraints on petrophysical properties and satisfied potential production requirements. They then generate all of the possible vertical production wells connecting the selected grid blocks. Following a screening, which eliminated a number of possible solution, they performed the actual optimization using GA.

On the other hand, *Centilmen et al.* [4] presented a neurosimulation technique that forms a bridge between a reservoir simulator and a predictive Artificial Neural Network (ANN). They selected several key well scenarios either randomly or by intuition. They numerically simulated these scenarios and then used them to train the network. Following the training step, numerous well scenarios could be evaluated efficiently. *Güyagüler et al.* [5] applied a hybrid optimization algorithm that utilized a GA, a polytypic method, kriging, and an ANN (used as proxies for the function evaluations), along with a reservoir simulator. Güyagüler et al. optimized up to four vertical water injection well locations for a real field water flood project. And in later work, they introduced a utility function approach to account for the reservoir uncertainty. *Montes et al.* [6] also used a GA to optimize the locations of vertical production and injection wells.

Apart from that, *Cullick et al.* [7] also applied a quality measure of the reservoir for locating the wells. The quality measure of a grid cell is the sum of the oil volume around that cell, adjusted by connectivity and tortuosity. The evaluation was carried out based on the important parameters, such as horizontal and vertical permeability, distance to water or oil and gas or oil contacts, and the presence of faults are not considered in this measure.

1.1 GELAMA MERAH FIELD BACKGROUND

The actual Malaysia reservoir model that is used for the case study is the Gelama Merah field, which is located in 76' PSC block offshore Sabah and it is about 43 km NW of Labuan and 130km West of Kota Kinabalu in a water depth of about 50m as shown in Figure 1.1 and Figure 1.2. [18]

The well was discovered in the year of 2002. The location for the Gelama Merah field is at the Southern Inboard Belt (Ridge and Syncline Province) north of Glayzer Gas field in Sabah state, which is the innermost structural belt basin ward of the Crocker Fold-Thrust Belt. The Inboard Belt does not appear to continue onshore in northern Sabah although there isolated outcrops of Middle sediments which are probably equivalent to the sequences in the belt. The northern and the southern segments of the Inboard Belt, both have the characteristic structural style of anticlines and wide deep synclines, are separated by the northward-dipping Kinarut-Mangalum Fault and the Kinabalu accumulation, that is a basement high area underlain by a relatively shallow sub crop of the Crocker Fold-Thrust Belt.

The southern belt consists of a large N-trending Labuan-Paiseley Syncline which is bound to north by the Morris-Padas-Saracen fault line, and numerous folds to the east and south of it. The Southern belt is bounded by Morris fault in the west. The post-Deep Regional Unconformity (DRU) sedimentation history of the Inboard Belt can be simplified into three phases, which are an early Middle Miocene regression (Stage IVA), a late Middle Miocene transgression (Stage IVB), and a late Miocene to Pliocene regression (Stage IVC, F/G; Stag IVD and IVE are thin or absent). The initial deltaic progradation in the Southern Inboard Belt can be traced as far as the Labuan-Paisley Syncline and it was followed by a rapid northwestward progradation of a major delta toward the Semarang area. This subsequent outbuilding is maintained by uplift of the hinterland and erosion of older forests.

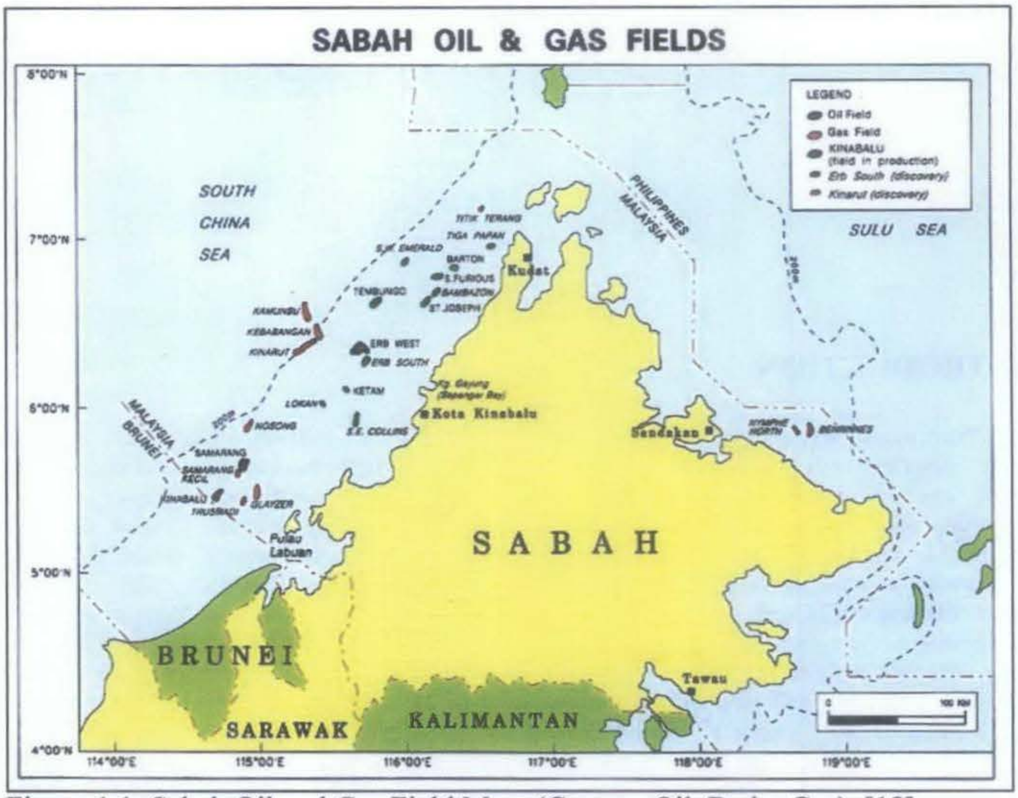

Figure 1.1: Sabah Oil and Gas Field Map (Green – Oil, Red – Gas). [18]

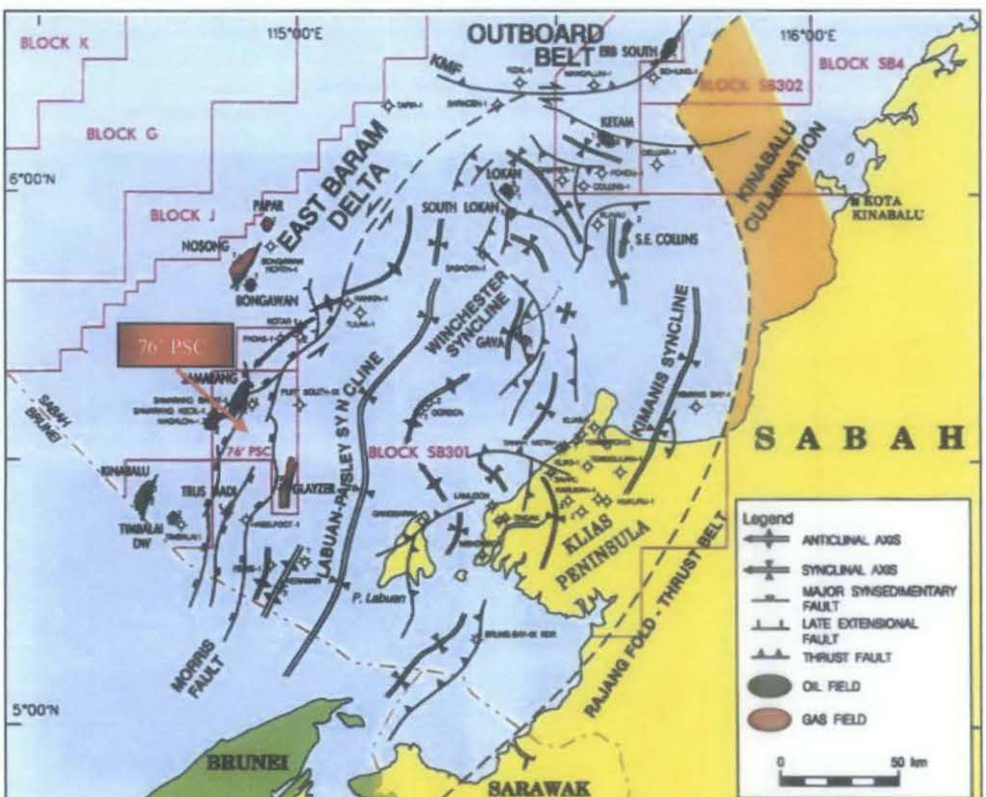

Figure 1.2: Structural elements of the Southern Inboard Belt of Sabah. [18]

1.2 PROBLEM STATEMENT

The drilling of new wells in a specific geographical area has significantly affected the productivity of the economic benefits of the hydrocarbon recourses recovery in a subsurface reservoir. The oil and gas industry with the current well placement selection process is time very time consuming and costly, which requires analyzing numerous development options by performing a large number of flow simulations.

However, the determination of the optimal wells location is a challenging problem since it depends on geological and fluid properties as well as on economic parameters. The problem is addressed through a tedious process of locating a set of well locations through case studies with the reservoir simulation and with the repeating of this process until some convergence to a optimum set of wells is reached. Thus, the effect of reservoir uncertainty and the inefficient approach in determining the optimal wells placement in specific geographical locations may often lead to incorrect decisions, which will lead to a high economic impact and other aspects as well.

Hence, the present study relates generally to the methods in minimizing the costs of extracting the hydrocarbon recourses from the inhomogeneity and the uncertainty in the underground reservoirs. More specifically, the study is relates to the determination of optimal wells placement and number of production wells on a specific geographical area from a three-dimensional model of an subsurface reservoir.

1.3 SIGNIFICANCE OF STUDY

The cost of drilling a new well is depending strongly on the remoteness of the location. On the other hand, optimal number of wells placement in a specific geographical location is also playing a very vital role in the cost management. Without proper approach, the optimal hydrocarbon recourses in a subsurface reservoir will not be recovered effectively. Besides that, inefficient way of approach will also lead to time consuming as it will cause unnecessary waste of manpower and recourses during the petroleum exploration activities. Thus, this research and study will provide an alternative and an effective approach in minimizing the cost and the time usage in which it is used to optimize the wells placement and number of production wells in specific geographical locations.

1.4 OBJECTIVES

One of the crucial field development decision making is to seek for the optimal well placement and number of production well in recovering an optimal hydrocarbon from the reservoir. The optimal location has to be based on the seismic interpretation, sequence stratigraphy, geological modeling and flow simulations. Besides that, the target locations for the well placement also based on the reservoir characteristics, reservoir architecture and the presence of no-flow boundaries from the geological and petrophysical aspects point of view. Thus, the objectives for this project are as followed:

1. To determine an optimal geographical locations for drilling the new wells.
2. To determine the factors affect the well placement using an actual Malaysia's reservoir model as a case study by utilizing Eclipse 100 simulator.
3. To evaluate the sensitivity of each reservoir properties that highly affects the well oil productivity and hydrocarbon recovery.
4. To obtain an optimal well spacing and number of production well with respect to the well production duration.

1.5 SCOPE OF STUDY

The heterogeneity and uncertainty of the reservoirs is so significant in which the parameters of the reservoir is dynamically govern the fluid flow inside the porous media. Due to its nonlinear and complex interaction between each of the reservoir parameters, it has makes the decision making process becomes very tedious and time consuming.

Thus, the Eclipse 100 – a black oil simulator suite was used to evaluate the significant effect of the reservoir parameters such as the oil saturation, permeability and porosity on the wells productivity with the variance of types of well used such as the vertical, horizontal and deviated well by evaluating the Field Oil Production Total (FOPT) and Well Oil Production Rate (WOPR) from the wells drilled. Thus, the reservoir storage characteristics and the pathway of the flowing fluids in the optimal geographical locations for the wells placement can be determined.

CHAPTER 2
LITERATURE REVIEW

A crucial responsible of the reservoir management teams is to provide an efficient and effective reservoir development plan with a selection of a set of well drilling sites and completion locations that maximizes the recovery volumes and productivity of the hydrocarbon resources. Bring into such an existence of the efficient plan generally begins with a set of reservoir property maps and a set of the infrastructure constraints. Basically, the team typically consists of geologists, geophysicists, and engineers whom are responsible to work together in choosing the optimal well locations using the reservoir models.

The wells are located in order to optimize some desired property of the reservoir that is related to hydrocarbon productivity. In the early field development, these models might consist of porosity or lithology maps based primarily on seismic interpretations tied to a few of the appraisal wells. Hence, the team is often asked to propose a set of locations that maximize production within a short period of time based to on the given model.

Complicating this endeavor is the requirement that the selected sites obey a set of specified constraints, such as the maximum well length, the minimum distance from fluid contacts or reservoir boundaries, the minimum inter-well spacing and the well configuration constraints. These set of problems are highly combinatorial and therefore it is time consuming when solving such a complex problem.

As a reservoir is developed with production wells, a more comprehensive reservoir model is built with detailed maps of stratigraphy. The pressure distribution maps or maps of fluid saturation from history matching may also become available. Thus, the choice of selecting well locations throughout the development of a reservoir can become increasingly complicated. Finding solutions to the progressively-more complex well placement problem can be a tedious and iterative task. Furthermore, there have been several reported studies that have attempted to use simulation software and mathematical models to determine the new well locations and configurations in the field development.

On the other hand, all types of geological heterogeneity – from millimeter-sized pores to meter-sized rock units, from porous sands to impermeable shale. All these factors do influence the reservoir performance. Hence, understanding all of the processes involved in fluid flow through sedimentary rocks is the key to understand the contaminant migration and the petroleum production.

Several approaches and alternatives have been proposed in the optimization of well placement matter. These approaches could be categorized under three main frameworks which are algorithmic, economical and reservoir descriptive generated maps approaches.

Nevertheless, some approaches are considered as independent from the stated categories, which is the planning of well locations on the static data, which is implemented through a series of processes and the target contact is minimized by generating a set of targets with a ranked property measurement such as within the drainage area, the pore volume that are subjected to the data filters on secondary properties such as saturation, permeability or depth. The targets are placed in the order of ranking, subject to the constraints such as target spacing. Followed by a set of plans generated in order to connect targets to another target to a surface location. Besides that, the plans honor a set of design criteria and constraints which can include well reach, dogleg severity and platform coverage. The plan can be vertical, horizontal deviated (slanted) or multi-lateral designs. Finally, to use the well trajectories in reservoir simulation, the perforations within each simulation model grid cell are subjected to perforation criteria which include permeability-thickness, minimum thickness, net pay, saturation and etc.

As for Schiozer and Mezzomo [8] in 2003, they developed a methodology to support their decision making process in the field development planning optimization and well placement under the uncertainties and regarding the operational and economical restrictions. Because of the large numbers of parameters to be optimized and the difficulty to generalize the solution to the type of reservoirs, their work has been divided into 7 steps which are recovery method and well type definition, production and injection patterns evaluation, assessment of the amount of wells, obligatory optimization, evaluation on the impact of the uncertainties, economic sensitivity analysis and refinements.

On the other hand, Ozdogan and Horne [9] used the history matching approach to conduct the well optimization. This approach consists of the time-dependent information and feeds it into the optimization scheme. The history matched models that honor all of the preceding history are used to model the future (time-dependent) response of the wells. This model of the "future history", which they called the "pseudo history" has enabled the integration of the time-dependent information.

Besides that, for Santellan, Hansen and Herring [3], they used a "Survival of the Fittest" concept in the optimization of well location using the optimized well location algorithm for the reservoir simulation. The optimization programme has been constructed in the connection with the in house 3D simulation model. However, the code is generally in nature and could be adapted to any commercial simulator changing the reading format of the data. Furthermore, the routine is a combination of FORTRAN codes and simulation runs. A UNIX scripts controls and executes the FORTRAN codes and simulation runs. And the optimization process is divided into 3 phases which are well generation, static well screening and dynamic optimization.

2.1 Algorithmic Approaches

First, Guyagular and Horne [10] proposed a way to evaluate the well placement using a numerical simulator as an evaluation tool within a direct optimization context. The problem is transform into a deterministic situation through the utility function by the used of numerical simulation that quantify the risk attitudes. The studies was done within the decision analysis framework since the problem consists the decision of the location to drill the new well. The whole process of decision tree construction and the definition of the problem is consider as the maximization of expected utility rather than the monetary value constitutes a transformation of the problem according to the decision maker's attitude towards the risk. Besides that, the used model is a standard test case that was based on a real field and was used for the PUNQ (Production forecasting with Uncertainty Quantification).

On the other hand, Montes and Bartolome [6] used the GA (Genetic Algorithm) in the optimization of the well placement. GA is based on the theoretical achievements of the evolution theory considering mechanisms of inheritance of attributes in organism populations and on the humanity experience in the animals and plants selection.

The GA methodology is concluded on a selection hypothesis: "the higher fitness of the individual, the higher the probability of that in the posterity received with its participation the attributes defining fitness will be expressed even more strongly". The following are the several advantages of GA above other optimization methods:

1. The search begins with set of potential decisions (population) while other methods begin search with one initial value.
2. The generation of the new solutions submits to stochastic laws instead of deterministic ones in other methods of search.
3. All set of initial problem parameters is coded in alone binary chromosome which is modified during search, thus direct manipulations with values of parameters are not made.

4. The estimation of a chromosome suitability as the final solution of the optimization problem occurs at calculation of the fitness defining a required parameters values combination of the initial task that is very convenient for the multiple parameter optimization problems solving at the designing of the oil and gas fields development.

Besides that, the Ant Colony Algorithm also considered as one of the most effective receptions for the solution of problems on the object accommodation optimization based on the search history analysis. Basically, it follows the analogy that the real ants are capable to find the shortest way between a jack and food for the short time period using a pheromone that they leave on the ground during the movement.

Originally, ants move on different ways. However, for the same period on shorter way more ants will pass. Thus, concentration of a direction richer of pheromone left by the previous ants. Consequently, the search area is presented by a spatial cell matrix of hydrodynamical reservoir model. On each optimization process step, the reservoir development indices are determined for each horizontal well connection and these values (named as the pheromone) are given to a grid cell containing the well connection. Thus, the pheromone matrix updated on each evolution step is formed. During GA performance, the "good" solution (trajectories) pass to a following evolution stage with some changes at a current one, i.e. the subsequent improved well trajectories pass through the same cells where a pheromone amount collects more quickly.

On the other hand, Cullick, Narayanan and Gorell [11] presented a framework for optimizing many well locations with the design constraint simultaneously rather than solve the full problem all at once. This method defines a set of target and well-plan locations based on the static reservoir model and then uses the locations to "seed" the global optimization as initial guesses. The initial target perforation optimization is located using static reservoir properties such as pore volume, porosity, or saturation, with a greedy-search algorithm. These locations are used as initial decision variables by the optimizer, which tunes the variables using a global, met heuristic optimizer and flow simulation. The location are risked, based on subsurface uncertainty, through analysis of the statistical character of the oil recovery or net present value within the optimization procedure. The mean recovery can be maximized with requirements on the statistical risk, such as the standard deviation.

2.2 Economical Approaches

In 1995, Beckner and Song [12] used a simulated annealing (SA) to search the optimum location for the wells by applying the travelling salesman framework on the problem of well placement. The concept is mainly about the method in optimizing the net present value of a full field development by varying the placement and sequence of the production wells. By utilizing Mobil's PEGASUS simulator, the optimization program basically consists of three major components which are a driver part to parse the simulation input and output, an algorithm part for continuous iteration and an economics module to calculate the net present value.

The process start with a program calling the simulator to run the given simulation model with a given sequence of well placement. The production output data file for the oil and gas productions rates were read by the driver part of the program after the PEGASUS runs. These rate are passed to the economics part for the net present value calculation, which include the data for costs of drilling and other economic parameters. Apart from that, the algorithm part of the program generates the new well placement sequence and passes the new sequence to the driver based on the net present value. Then, the driver generates a restart input deck file for another simulation run. The iteration will stopped until it converges. In other words, the solution of the optimization problem consists of several iterations of equations until an optimal well location have been determined.

In 2007, Gaoming Li, Wang and Reynolds [13] approach was to convert the problem of optimizing on the discrete variables into an optimization problem on continuous variables for the optimal well placement. By putting an injection well in every grid block that does not contain a producing well and constraining the problem by specifying a maximum total injection rate that must be allocated among the wells remaining at each iteration of the optimization process which is the idea in initialize the optimization problem.

Furthermore, the drilling cost is assigned for each well so the greater the number of injection wells, the greater the drilling cost in the net present value. By decreasing the number of injectors , decreases the drilling costs which by itself results in an increase of net present value but may also cause a decrease in net present value because of the decreased in the oil production. The well is eliminated from the system if an injection well rate is decreased to zero. Initially, all the injection wells produce at the same rate which is determined by dividing the total allowable injection rate by the number of injection wells. Then they used a steepest ascent algorithm to adjust rates to maximize the net present value over a specified reservoir lifetime. Some wells rate are decreased to zero and are removed from the system as the optimization proceeds.

As for J.D. Jansen and Handels [14], they used "Adjoint – Based Well Placement Optimization Under Production Constraints" approach. Basically, their approach is based on the concept of surrounding the wells whose locations have to be optimized by so called pseudo wells. The pseudo wells produce or inject at a very low rate and thus have negligible influence on the overall flow throughout the reservoir. The gradients of the net present value over the lifespan of the reservoir with respect to the flow rates in pseudo wells are computed using an adjoint model. These are subsequently used to approximate " improving directions", such as the directions in which to move the wells in order to achieve an increased in net present value based on which improving well positions that can be determined.

An optimal injection and production rate that maximizes the net present value is obtained by the used of gradient-based algorithm adjoint method. They were enabled to use the adjoint method in the well optimization problem, where their goal was to find the well location that maximize the net present value with the application of some alteration to their approach. Starting from initial well locations, improved location are found using the rate gradient information in order to compute the improving direction.

Besides that, the adjoint method can be used to calculate the rate gradient for every pseudo well at each reservoir simulation time step. Thus, for each well, the gradient are summed, which enabling in determining which on has the largest summed gradient. These are subsequently used to obtain the improved direction. This method computes the improving direction for all wells in only one forward and backward (adjoint) simulation. This process is repeated until no further improvement are obtained.

2.3 Reservoir Description Generated Maps

Davies, Somerville and Narayanasamy [15] produced a map termed Productivity Potential Map that rank the ones of the reservoir according to their productivity potential speed-up in which reducing the cost of the decision making process. It is generated from the numerical reservoir models developed from a standard data measured during the exploration and appraisal process which incorporates both static and dynamic parameters such as the saturation and the porosity respectively. All the basic parameters that define the productivity potential of the reservoir zone which is representative of the geological features of the reservoir are obtained from a 3-dimensional reservoir simulation model.

The properties used are the permeability, porosity, and oil saturation. With a proper proxy function suitable for a 3D reservoir model, the value of the proxy function for the model was evaluated by assuming a vertical well at regular intervals with the mapped values represent the productivity potential at each position, and the 2D map of these values being called the Productivity Potential Map (PPM) which was described by Khargoria et al. This Productivity Potential Map represent the time-dependent changes of the properties and it is independent of the well or field production controls, formation damage and well architecture.

This technique was tested by using the flow simulation models by generating the Productivity Potential Map and by identifying the targets of drilling that could deliver maximum and sustained production potential. Besides that, the field development also using a standard pattern of wells that with fixed spacing with respect to each other has been employed in many fields. Nevertheless, it also has been replaced them with well placement according to the geology of the field with the advent of techniques from the seismic interpretation, sequence stratigraphy, geological modeling and simulation of flows.

Besides that, the reservoir architecture, heterogeneity, characteristics and the presence of no flow boundaries were used by the geologists and geophysicists in order to identify the target locations for the well placement. In order to confirm and optimize the placement of the well decision making, the fluid flow simulation and detailed analysis were carried out. Thus, the Productivity Potential Map claimed to increase the cumulative production of oil by reducing the number of development wells. In addition, in order to improve the flow forecast and minimize the uncertainty in the flow performance, the efforts to reduces the flow simulation is required.

Deutsch, Da Cruz and Horne [16] applied the "Quality Map" concept to come out with a 2-dimensional representation of the reservoir uncertainties and the reservoir responses. This concept may be applied in order to compare the reservoirs, to incorporate the reservoir characterization uncertainty and to rank the stochastic realizations into the decision making. The quality map are obtained by the used of flow simulator through the necessary data point with a single well completed in all the layers and by varying the well location in each run in order to have good coverage for the entire horizontal grid. The horizontal cell quality in which the well is located is considered as the cumulative oil production after a long production time. By running the flow simulator multiples times and by varying the position of a single well in each run in order to cover the entire horizontal grid, the generation of the map can be done. The quality for each cell in the horizontal grid in which the well is located can be evaluated after each run using the flow simulator.

The quality of the cell is an intrinsic characteristic of the reservoir in that position and this characteristic is not supposed to change according the quality map with just one well producing at each run through the utilization of the flow simulator. Thus, the quality unit is the cumulative oil production (Np) of the well after a certain time of the production the total production time is depends on the size o the reservoir but must be long enough in order to allow the well to produce all the possible oil with given the well operational controls. As a result, the quality map built with the results of flow simulations integrates all the parameters in a single value for each cell of the horizontal grid such as the top depth parameter. Hence, as the top depth become smaller, the cumulative oil production will be greater due to the thicker in oil column.

Apart from that, a systematic method for the reservoir description which consist of the foundation for designing, operating, and evaluating the performance of the drainage plan as well as any other reservoir project. Through the reservoir description, the selection of the drainage plan and the model used to estimate the drainage performance was made.

The integration of the geology and engineering is a key in this method in the process of forming the reservoir description. By focusing on the generation of the framework studies, the determination of the number of the distribution of the reservoir zones can be made and the continuity of the reservoir and non-reservoir rocks is also a vital objective to achieve. The framework studies begin by mapping the gross structure from well and seismic data to define the areal and vertical extent of the deposit. The determination of the area and vertical limits and continuity of the reservoir and a non-reservoir zones is consider as the principle activity in this framework studies.

On the other hand, Testerman [17] also introduced a statistical reservoir zonation technique which retains the actual location of the strata within the reservoir. The procedure consists zonation of the permeability data from the top to the bottom of the interval and the statistical tests are used to minimize the variation of the permeability within the zones and to maximizes the variation of the permeability between the zones. A second comparison is made after all the wells have been zoned in order to correlate the zones from well to well throughout the reservoir. Zones in adjacent wells are considered to be continuous if the difference in mean permeability of the two zones in adjoining wells is less than the difference expected from the variation in the measurements within the zones.

Furthermore, there are still a lot more of alternative approaches which are used for the purpose of optimization of well location. However, the reservoir parameters sensitivity analysis, types of well studies and finding of the potential productivity map methodologies will be used in this project so that the objectives can be achieved.

CHAPTER 3
METHODOLOGY

3.1 METHODOLOGY APPLIED IN THE PROJECT WORKS

By utilizing the Eclipse 100 simulator suite for the black oil modeling, simulation of one of the actual Malaysia's reservoir models – Gelama Merah, will be used for the research and several important issues will be taking into consideration in order to determine the factors that affecting the optimal wells placement in specific geographical locations. Thus, one of the main concerns in this research is to observe and analyze on how is the oil saturation, permeability and the porosity of the reservoir storage and the pathway of the flowing fluids, which will affect the optimal placement of the wells.

The reservoir simulator used are complex computer program that simulate multiphase displacement process in two or three dimensions. There are several considerations governs the proper selection of the reservoir simulation to design or manage the well placement. Besides that, the technical considerations control the type of simulation that is required. The reservoir consists of unknowns and complex of distributions of rock properties such as the porosity and the permeability. The hypothesis variation can be account by adjusting the parameters in the reservoir simulators.

The saturation of the fluid always change with respect to the position due to the variation in the rock and fluid properties associated with the geology as well as the equilibrium of gravity and capillary forces. Couples of reservoir assessment have been carried out with an estimation of potential benefits of the simulation is the main drive behind the selection of a reservoir simulator numerical model in predicting the variable drainage operation performance.

Thus, there are several methodologies were utilized in this project in order to identify the factors that affect the optimal well placement on the complex reservoir. The following are the several steps proposed and being conducted with the assistance of the Eclipse 100 simulator software:

1. Several producers and water injectors are placed using a basic conceptual 3D reservoir model. All the possible locations and patterns are evaluated and the field oil production total (FOPT) for each case is analyzed. Several relationships between the producers and water injectors are determined and established.

2. First the reservoir will be divided equally into 24 sectors. Each sectors will be placed with a single well and the production will be run simultaneously. The well that contribute to the high oil productivity will indicate that surrounding area has the potential to provide high oil recovery.

3. By using several reservoir parameters such as the permeability (k), porosity (ø), and the oil saturation (S_o) which have been taken into consideration in determining the optimum wells placement in achieving a high oil recovery factor. The parameter sensitivity analysis is done by initially for the base case, all the reservoir parameters will be kept as unchanged and they are held at constant. Thus, in case 1, case 2 and case 3 each parameters which is to maintain all the variables to be at constant and determine the effect of each single variable that has been reduced by half of its value (50%) in the purpose of evaluating their significant impact towards the grid cells performance. Further details can refer to Table 4.1.

4. The reservoir parameters which are the permeability (k), porosity (ø), and the oil saturation (S_o) will then be ranked accordingly with respect to their level of impact towards the oil productivity of the well placement on the reservoir.

5. Different types of well will be placed into the reservoir such as the vertical well placement, horizontal well placement, and deviated (slanted) well placement. The effect of each well placement toward the productivity of the production well will be studied.

6. Different number of production well configurations are placed with respect to each specific well spacing (feet) in order to evaluate the well production duration (days). A correlation is done by using the formulations and graphs obtained. Thus, an estimation for the number of production well with specific well spacing in order to gain the desired well production duration can be done.

3.2 METHODOLOGY FLOW CHART

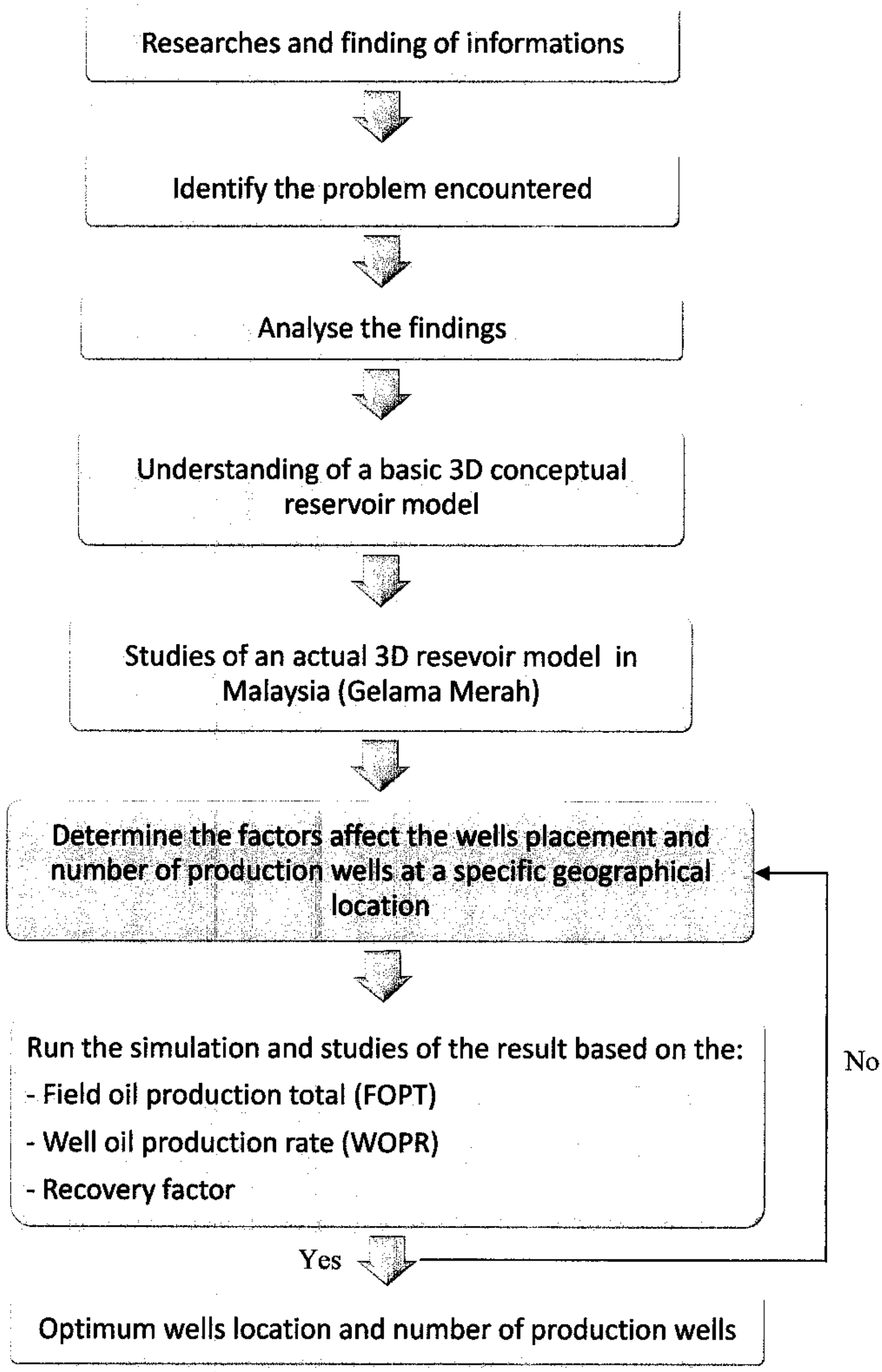

Figure 3.1: The project methodology flow chart

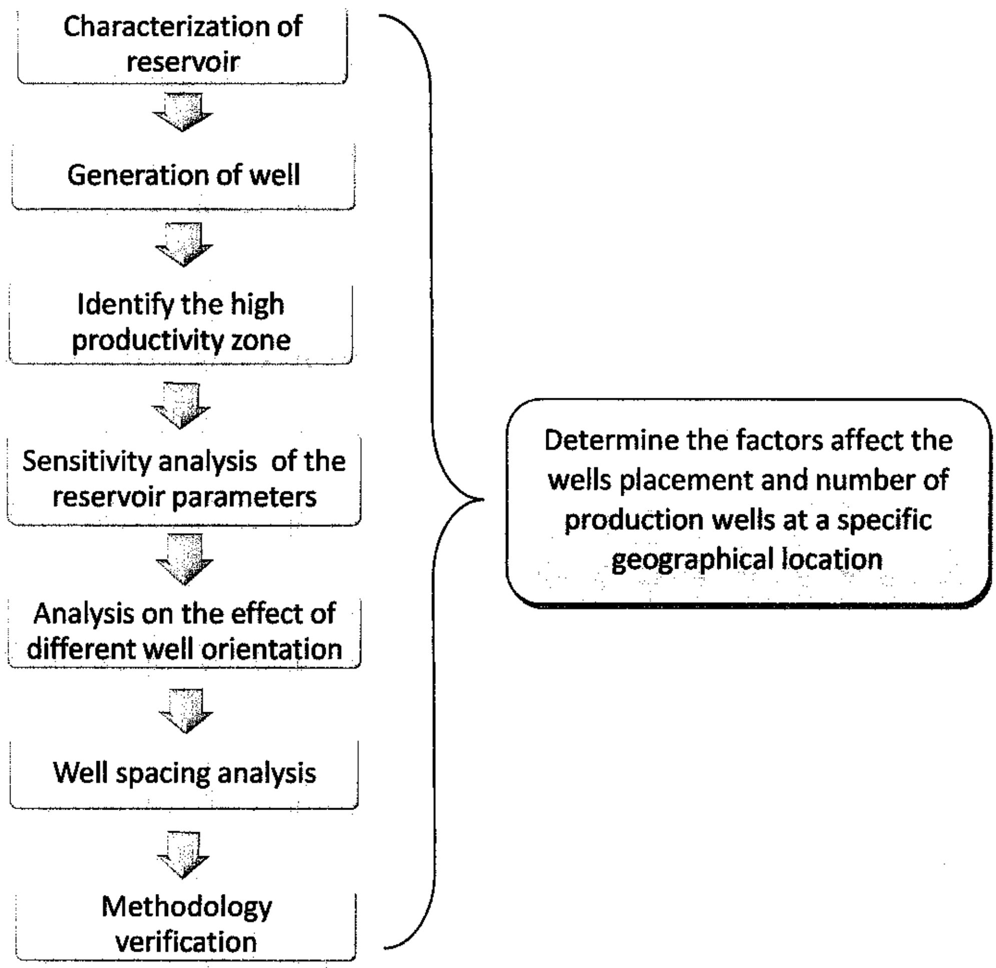

Figure 3.2: The detail flow chart for the factors determination analysis phase

3.3 ASSUMPTIONS

The accuracy and the sensitivity for each of the data obtained in the project works is highly dependent on the approaches used and the utilization of the specific simulator software. Thus, several assumptions have been made in this project works in order to conform with the results obtained, which are stated as followed:

1. In this project, only vertical well is used for case study. All the data and results obtained are based on the vertical well only without the use of any injector.
2. All the fluid flow to the producer consists only radial flow pattern.
3. The perforations were done for 40 ft interval from an average reservoir thickness of 130 ft.
4. Using the black oil simulator software – Eclipse 100, grid orientation effects do arise when we have fluid flow both oriented with the principal grid direction and diagonally across the grid. Thus, the numerical results are different for each of the fluid "paths" through the grid structure as shown in the following Figure 3.3, 3.4 and 3.5. [19]

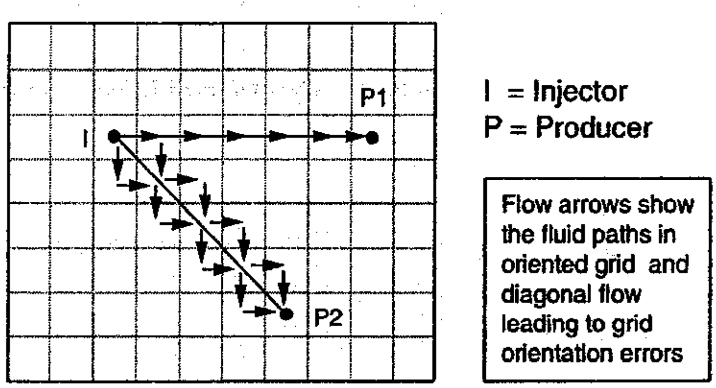

Figure 3.3: Flow between an injector (I) and 2 producers (P1 and P2) where the injector–producer separations are identical but flow is either oriented with the grid or diagonally across it illustrating the grid orientation effect. [19]

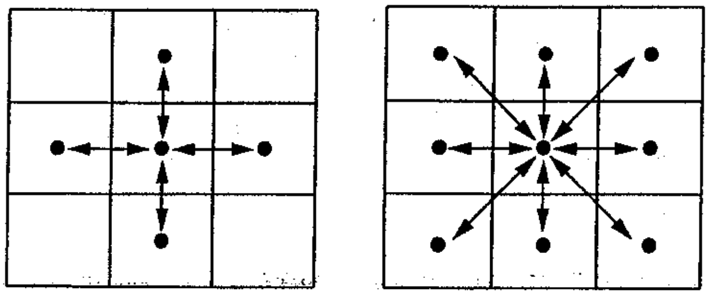

Figure 3.4: The (a) 5-point and (b) 9-point schemes for discretising the grid–the latter helps to reduce grid orientation effects. [19]

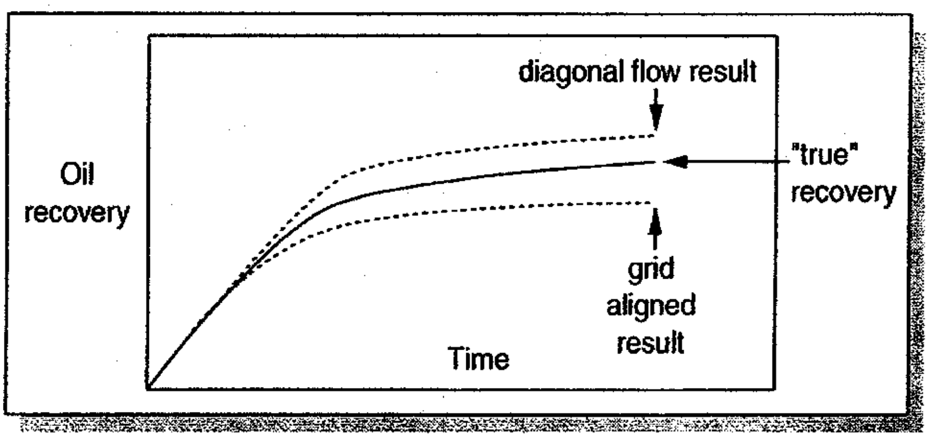

Figure 3.5: Fluid flow due to the grid orientation effects for the black oil simulator with an oil recoveries for "true", aligned and diagonal flows in 2D grid. [19]

CHAPTER 4

RESULTS AND DISCUSSION

4.1 THE BASIC CONCEPTUAL 3D RESERVOIR MODEL STUDIES

An understanding of a basic conceptual 3D reservoir model was done before an actual 3D reservoir model in Malaysia – Gelama Merah was used for the actual case studies for this project. This is an ideal 3D reservoir model. Thus, all the data and results obtained from this basic conceptual 3D reservoir model are for the sake of understanding and comparison purposes.

4.1.1 The Most Favorable Wells Location

In the well placement from Figure 4.1, 2 producers and 3 injectors are used in this pattern. From all the possible well placement evaluations, the studies is limited to only the possibilities for 2 producers and 3 injectors, since the possibilities and the type of wells placement is very broad. From the studies, it seems that this type of this well placement is considered the best and it is the most favorable well pattern in which it has the highest recovery efficiencies, FOE = 0.6889, which is followed by the formula

$$FOE = \frac{(OIP(initial) - OIP(now))}{OIP(initial)} \text{ ; OIP is Oil in Place}$$

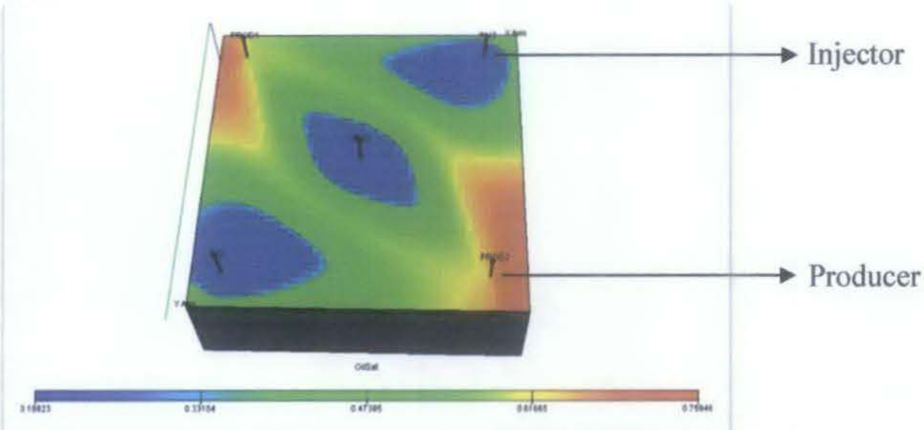

Figure 4.1: The optimum wells location with the profile of the saturation and the distribution of flows speed between the wells for the (3 injectors, 2 producers pattern) using a basic conceptual reservoir model

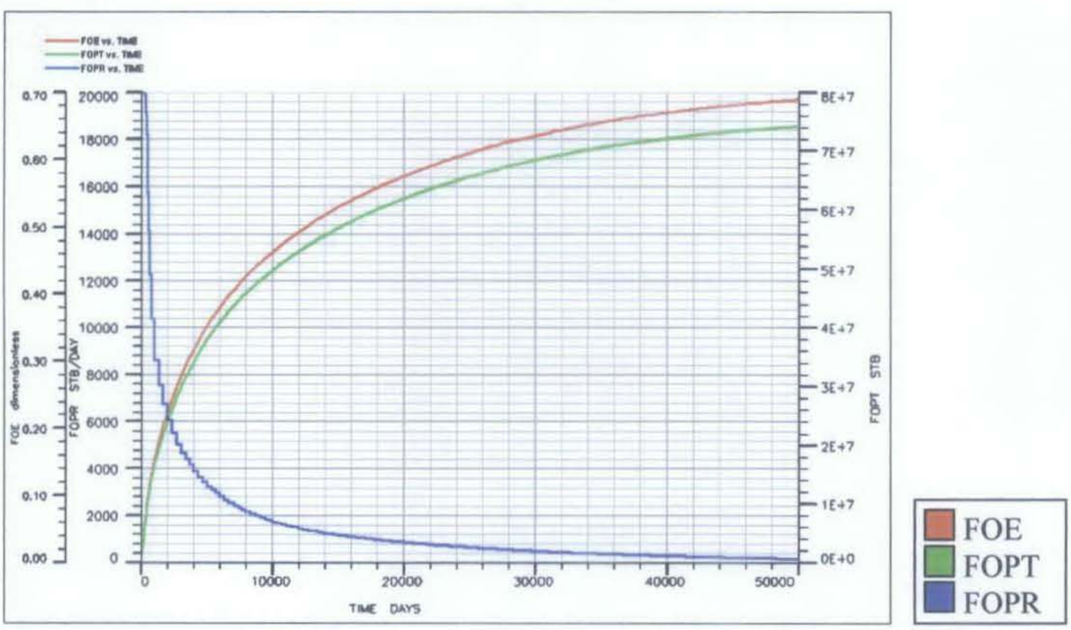

Figure 4.2: The oil recovery efficiencies (FOE), the field oil production total (FOPT), and the field oil production rate (FOPR) vs. time.

Thus, the recovery factor (RF) is 68.89% with the field oil production total (FOPT) that produce around 7.4 E+7 STB as shown in Figure 4.2. Thus, this well pattern can be considering as the best wells location in the wells location optimization studies for this basic 3D conceptual model reservoir.

From the recovery factor value, 68.89% seems to be over optimistic because the averages oil recovery from the reservoir is only 30-35% in places and it also can as low as 5% only. But, in this matter, it is an ideal condition since a conceptual 3D reservoir model is used for the purpose of studies and gaining understanding for the well placement. On the other hand, the data obtained will only be used for the comparison purposes.

4.1.2 The Least Favorable Wells Location

In the well placement as shown in Figure 4.3, the same 2 producers and 3 injectors are used in this well placement pattern. It seems that this type of wells location produce only around 6.27 E+7 STB. And the recovery efficiencies, FOE is 0.5825 as shown in Figure 4.4. Thus, the recovery factor is 58.25%, which is lower than the wells placement pattern in Figure 4.1. As a result, this formation is consider an unfavorable type of wells placement.

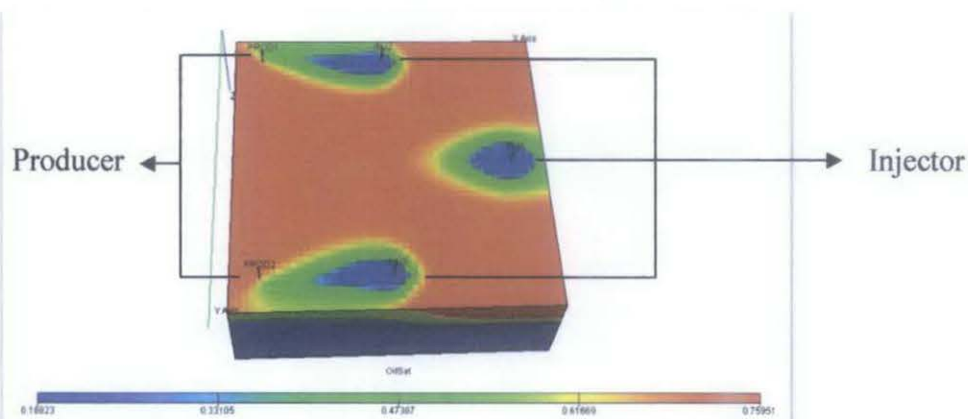

Figure 4.3: The unfavorable wells location with the profile of the saturation and the distribution of flows speed between the wells for the (3 injectors, 2 producers pattern) using a basic conceptual reservoir model

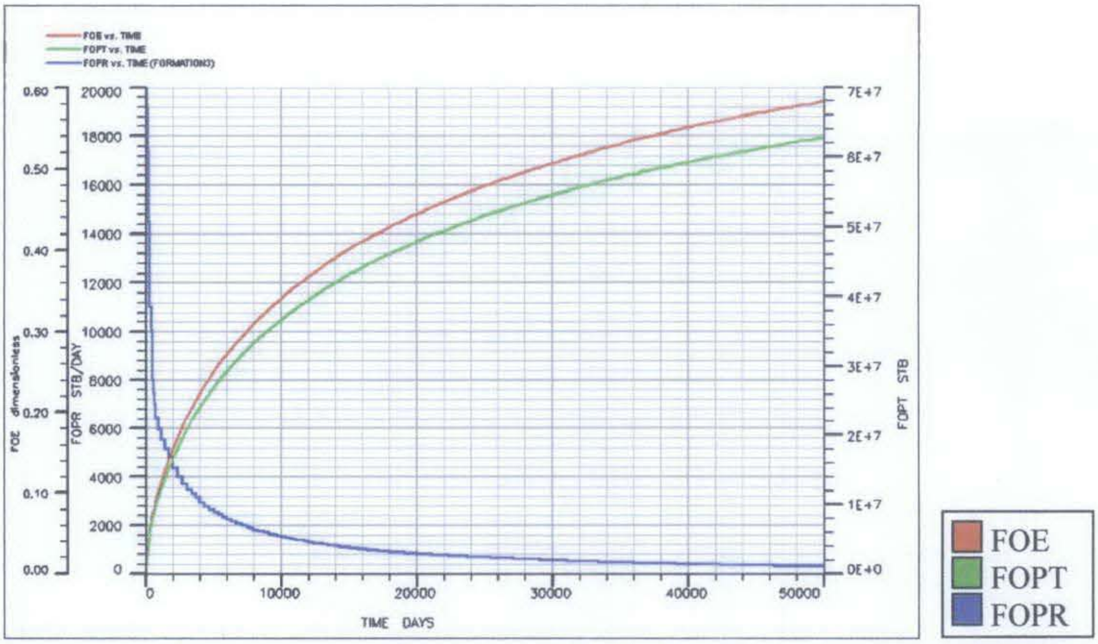

Figure 4.4: The oil recovery efficiencies (FOE), the field oil production total (FOPT), and the field oil production rate (FOPR) vs. time.

4.1.3 The Finding From The Basic Conceptual 3D Reservoir Model Studies

As from the data results obtained from the studies, by utilizing the injecting water through the injection wells in the oil reservoir, it can recovers high volume of hydrocarbon. And in this basic conceptual 3D reservoir model, the reservoir is homogeneous, thus the water flood is efficient because if the reservoir is heterogeneous, the water flood will not be so efficient.

From the 3D reservoir simulation, the injected water flows fastest through the most permeable zones (thief zones) and reach the production well. The water is heavier than oil, so the injection rate should not be too high as it tends to flow furthest along the bottom of the reservoir, hence less efficient with less oil recovered.

Besides that, it also can conclude that the recovery factor of the oil production system can be increased as the locations between the injectors are closely located to each other as possible in order to get a more evenly water injections flows towards the producers in recovering an optimum hydrocarbon from the reservoir. Furthermore, the recovery factor of the oil production system will decrease as the distance between the producers and the injectors are closer to each other.

4.2 THE ACTUAL 3D RESERVOIR MODEL STUDIES – GELAMA MERAH

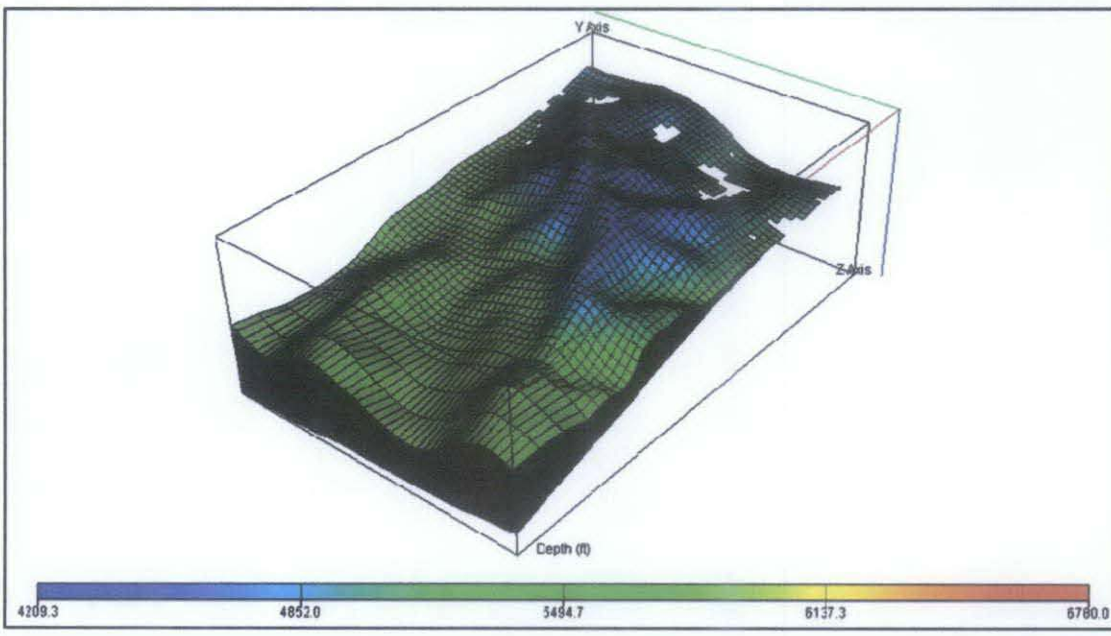

Figure 4.5: The actual 3D reservoir model in Malaysia – Gelama Merah

The 3D reservoir model presented in this study was used to simulate the flow behavior of the fluid in an infinite reservoir as shown in Figure 4.5 above. For the scope of study, the factors that affecting the optimum wells placement is to be determined. In this section, no injectors are to be used as the driving mechanism in achieving a higher oil recovery factor in recovering the oil from the reservoir. Hence, only the producers are to be located.

In this case study, the oil recovery system is fully dependent on the reservoir pressure. Hence, by knowing the right factors that influence the oil recovery factor and with the right location, the cost of drilling an unnecessary wells can be minimized.

4.2.1 Determination Of High Oil Production Area

In order to determine the areas from where the oil production is expected to be the highest, an evaluation has been conducted on the reservoir model by using the Eclipse 100, an black oil simulator suite to simulate the fluid flow for the oil in the reservoir. The 3D reservoir model is equally divided into 24 sectors as shown in Figure 4.6 below.

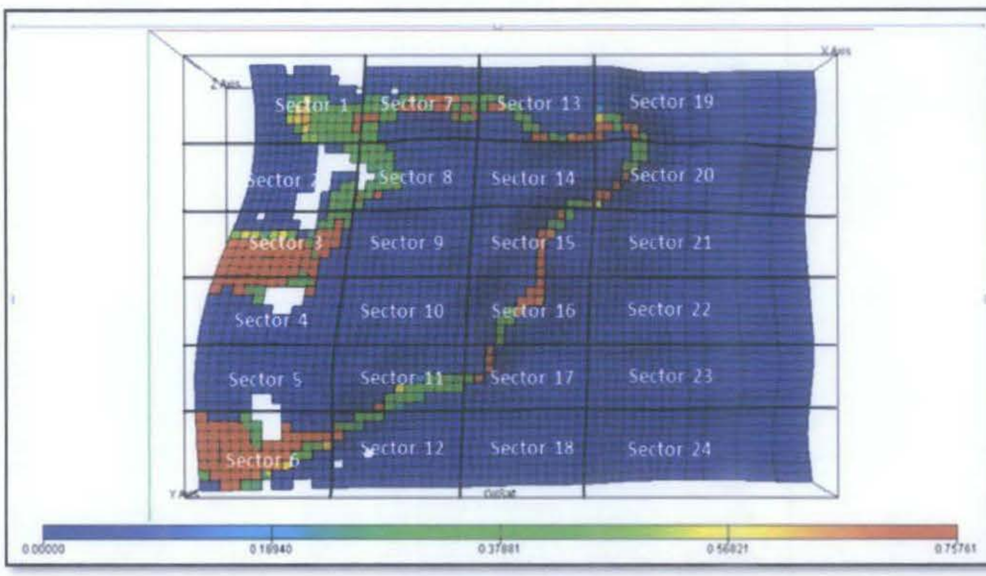

Figure 4.6: The equally divided 24 sectors of the 3D reservoir model.

Each sector will be placed with a single vertical well and the evaluation was done by running all vertical wells simultaneously at different specified locations as shown in Figure 4.7. The Well Oil Production Total (WOPT) for each well will be identified. From the simulation, sector 10 was recorded as the area with the highest oil productivity, followed by sector 15 and sector 8. From here, the attempts and possibilities to place the wells at such a reservoir is reduced to a minimum. For the following case studies, these 3 sectors will be used for the ease of further analysis.

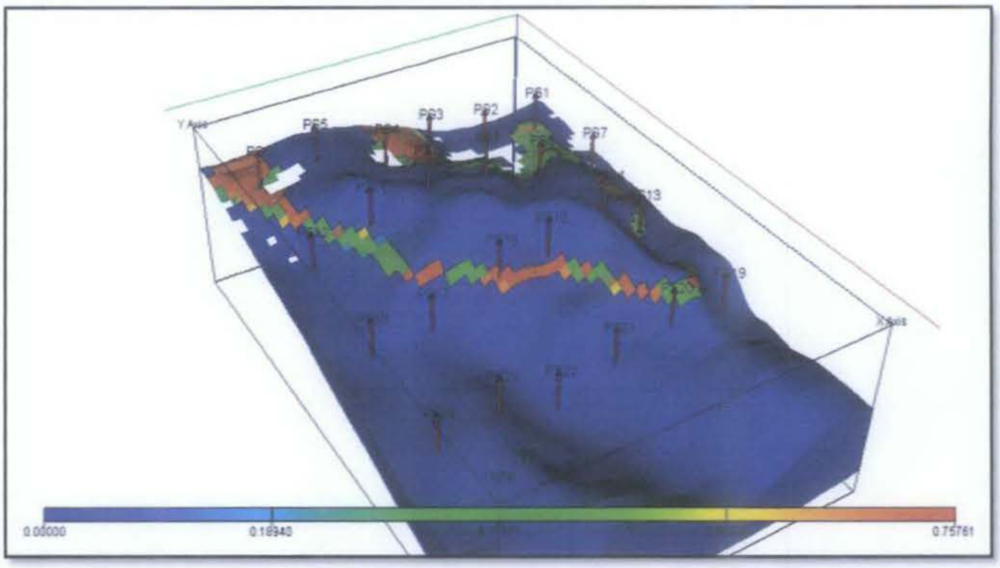

Figure 4.7: The placement of wells adjacent to each others at different sectors.

4.2.2 The Sensitivity Analysis

In addition, the parameters such as permeability (k), porosity (ø), and the oil saturation (S_o) was observed to be have significant effect on the performance of the evaluated grid cells. In order to minimize the number of potential locations for the well positioning, a sensitivity analysis was carried out in evaluating the 3 reservoir parameters as mentioned above.

These parameters will then be ranked accordingly with respect to their level of impact towards the Field Oil Production Total (FOPT) of the wells by using a simple approach, on the productivity of the wells. For the base case, all the reservoir parameters will be kept as unchanged and they are held at constant. Thus, in case 1, case 2 and case 3 each parameters which is to maintain all the variables to be at constant and determine the effect of each single variable that has been reduced by half of its value (50%) in the purpose of evaluating their significant impact towards the grid cells performance.

Sensitivity Analysis	Reservoir Parameters			FOPT (Mil. STB)	Factor (x)
	Permeability (%)	Porosity (%)	Oil Saturation (%)		
Base Case	100	100	100	5.03	1.00x
Case 1	50	100	100	4.06	0.80x
Case 2	100	50	100	3.28	0.65x
Case 3	100	100	50	0.75	0.15x

Table 4.1: Parameters sensitivity analysis

As shown in Table 4.1 above, the results have clearly demonstrate that the oil saturation (S_o) is the most vital parameter that has significant effect towards the well performance, followed by porosity (ø), and for the permeability (k) which is consider to be the least effect toward the FOPT of the well placement. The Figure 4.8 shown below is the comparison of the impact towards the FOPT between each of the case with respect to the base case. Thus, the result shows that the changing of oil saturation (S_o) will always give to the high impact for the FOPT of the well placement.

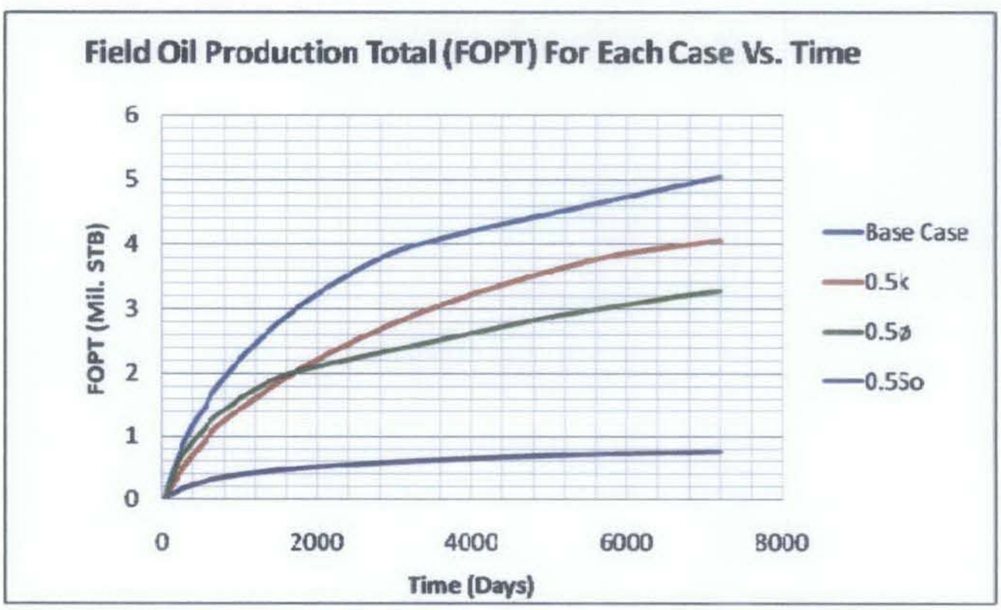

Figure 4.8: The graph of field oil production total (FOPT) for each case vs. time.

For the graph shows in Figure 4.9, the sensitivity analysis has identified the oil saturation (S_o) to be the most sensitive parameter among others due to the plotted graph with the lowest slope value and it is deviated farther away from the Y-axis, in which it has the highest percent of decrease in Field Oil Production Total (FOPT) with respect to the 50% reduction in the oil saturation (S_o) property.

Thus, once again oil saturation (S_o) is consider as the most sensitive reservoir parameter that could contribute to the significant productivity for each of the well placement. Thus, the analysis of the above methods has revealed that not all the basic properties used in building the 3D reservoir model are directly used when come to identify the high productivity zones and wells placement within the reservoir.

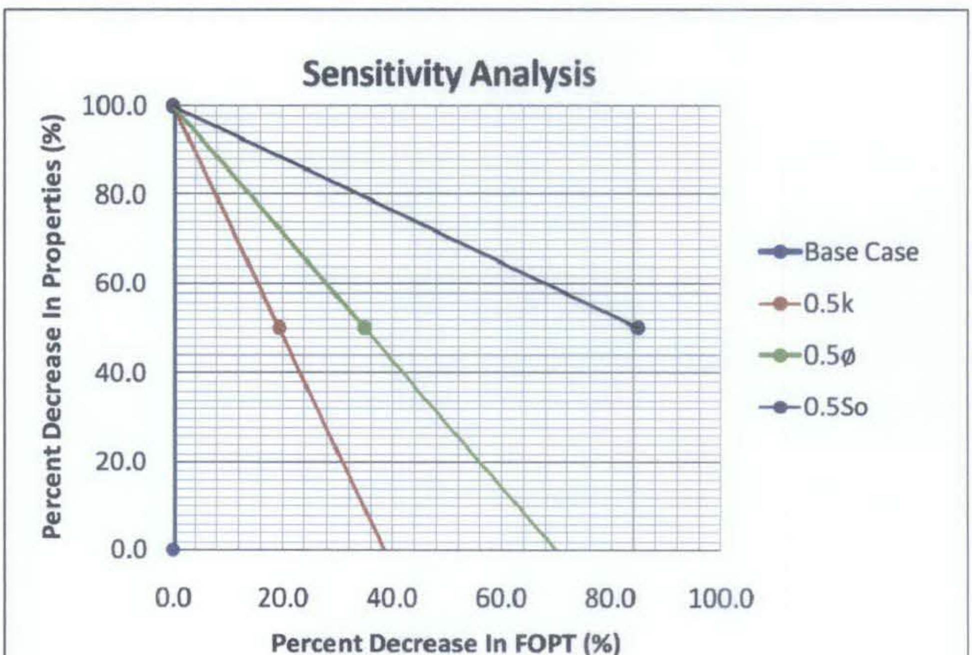

Figure 4.9: The sensitivity analysis graph with the percent decrease in properties (%) vs. the percent decrease in FOPT (%) for each of the parameters.

4.2.3 Effect Of Different Well Orientation

Even when a new well is drilled, the decision whether to drill a vertical, deviated (slanted), or horizontal well and how to complete the productivity interval can profoundly affect the well's productivity and the size of the volume drained by the well. From the study that has made, the horizontal well placement has contributed to the highest Well Oil Production Total (WOPT). In this case, horizontal well placement is best suit the current reservoir model used is because the reservoir has a high vertical permeability with a thin formation which may produce the entire formation thickness.

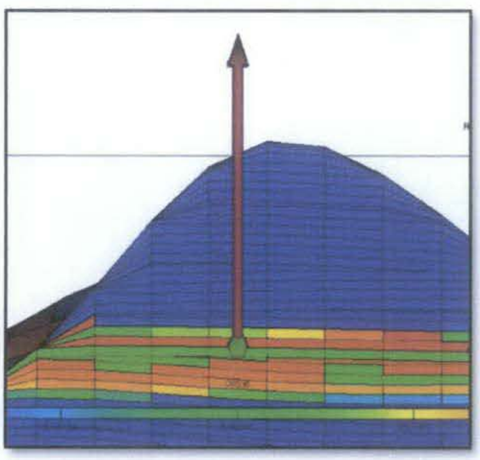

Figure 4.10: Vertical well placement

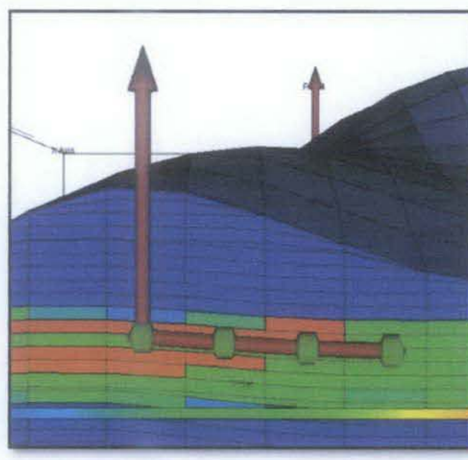

Figure 4.11: Horizontal well placement

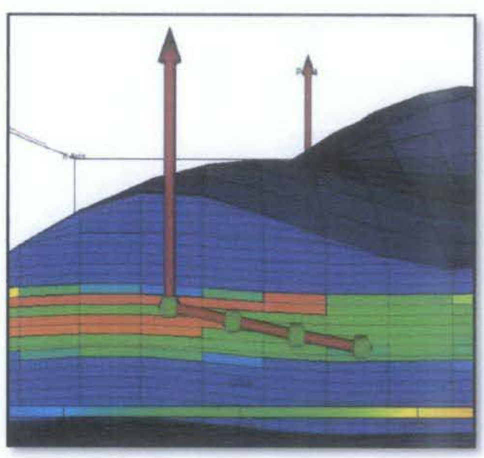

Figure 4.12: Deviated well placement

On the other hand, the vertical well placement does not provide an expected productivity because the vertical well could provide excellent productivity in the formations with moderate mobility only. And for the deviated well (slanted well), it can produce a marginal increase in the productivity over a vertical well but still lower productivity than the horizontal well placement. Thus, choosing an appropriate type of well which need to be drilled is still strongly depend on the type of reservoir characteristics. As shown in Figure 4.13, horizontal well placement seems to contribute to the highest well oil production total (WOPT). Thus, horizontal well placement can be used in the optimization of the well productivity for the Gelama Merah field reservoir.

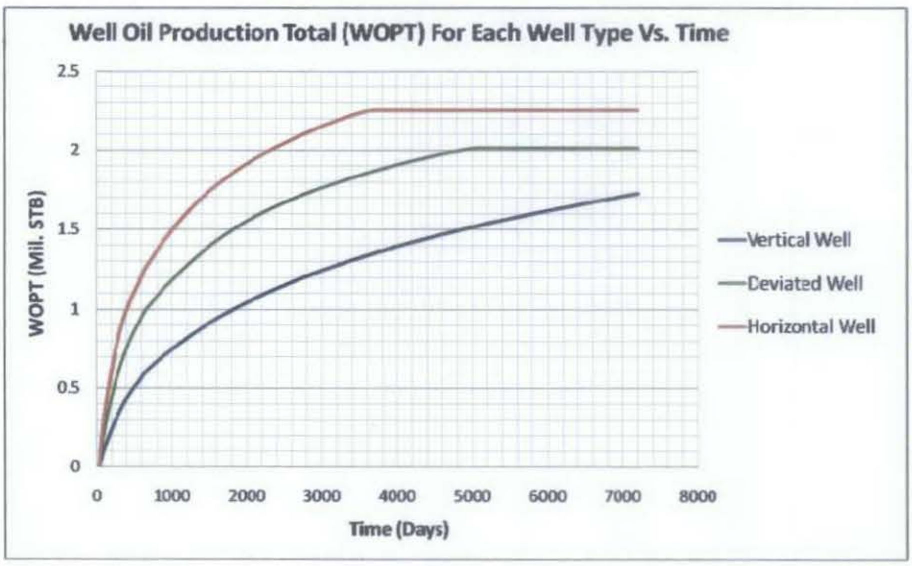

Figure 4.13: The graph of the well oil production total (WOPT) for each type of well vs. time

4.2.4 Effect Of Well Spacing

During the field development, determination of the optimum number of production wells is very vital as the spacing between the wells will highly affect the well oil production rate (WOPR) and well oil production total (WOPT) for each well. Several well spacing configurations are set in order to evaluate the well production duration (days) for each different number of production wells with respect to the variation in the well spacing. From the settings, the WOPT of the well with purple in color in which it is located normally at the center from each of other wells will be evaluated by varying the location of the wells with white color away from the well in purple color as shown in Figure 4.14 below.

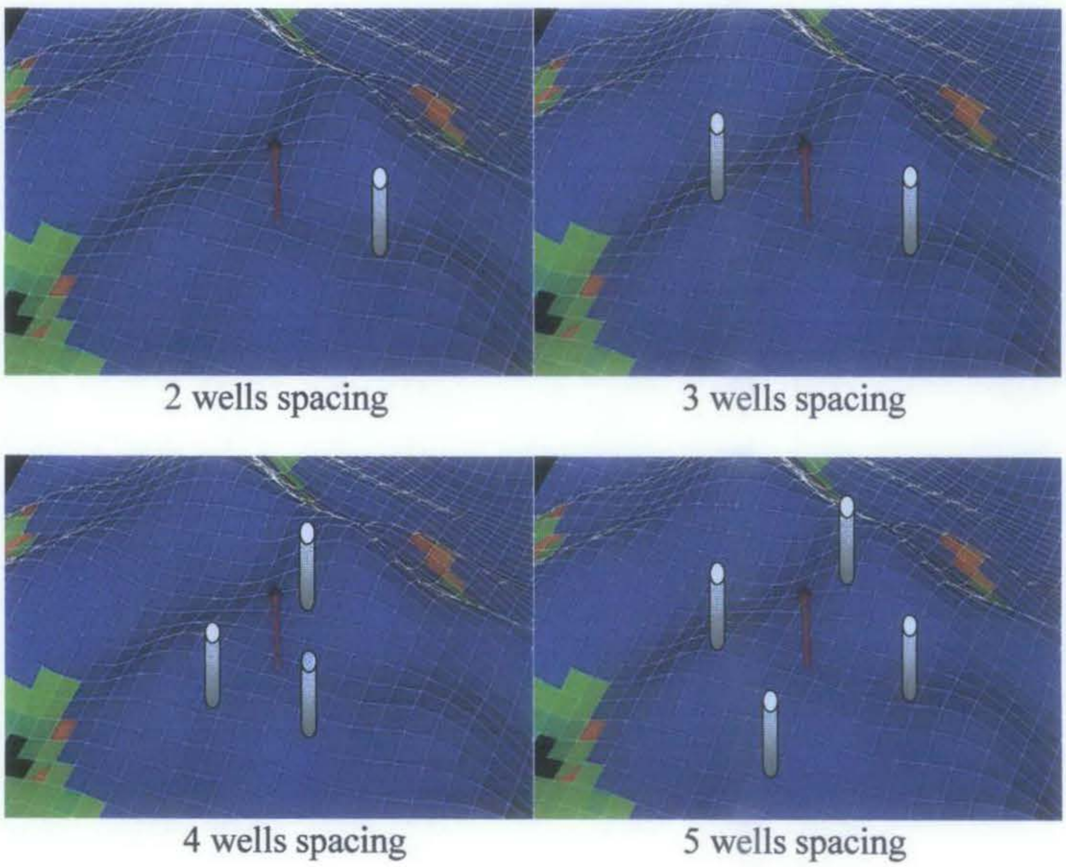

Figure 4.14: The well spacing configurations

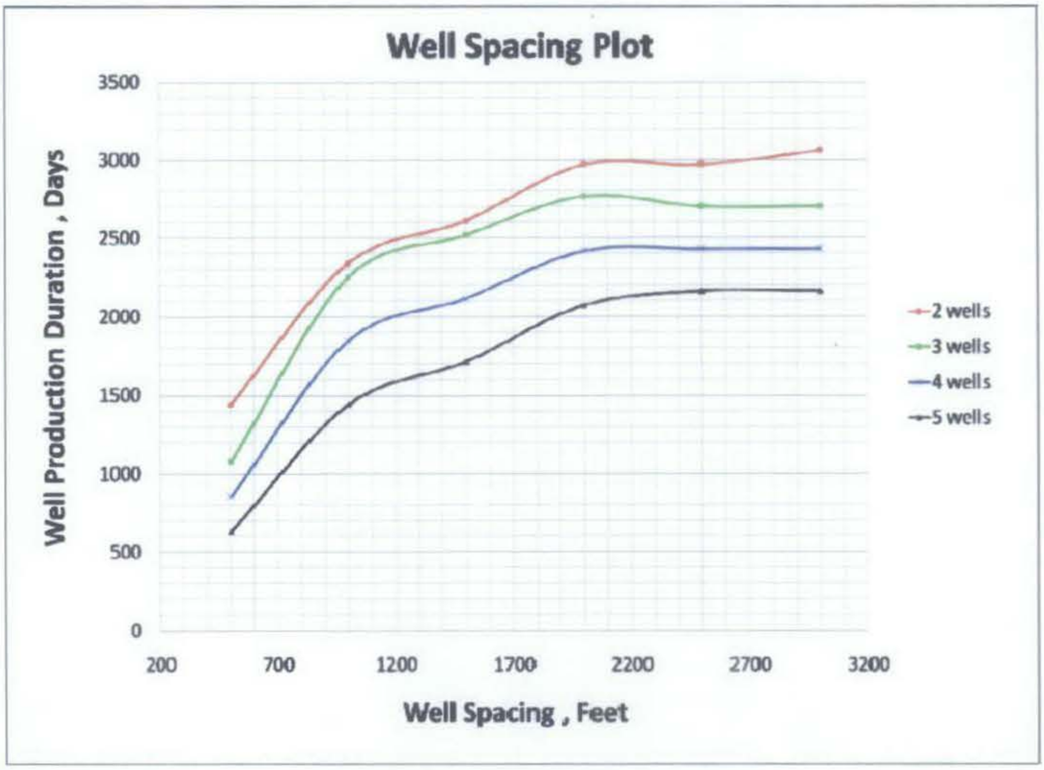

Figure 4.15: The well spacing plot (*WOPR of 200 bbl/ day)

After running all the reservoir simulations using Eclipse 100 simulator suite, all the data for the well production duration for each different number of production well with respect to each different well spacing is recorded and compiled. Then, all the data are used to plot the graph as shown in Figure 4.15 above.

From the plotted graph, at the well oil production rate (WOPR) of 200 bbl/ day, 2 wells configuration seems to result in a higher well production duration with respect to each different of well spacing. Thus, the number of production well drilled is inversely proportional to the well production duration. On the other hand, the well production duration will increase with the increase of the well spacing and the oil production of the well will achieve the same well production duration after certain degree of well spacing.

The correlation is being done by converting the plotted graph into logarithmic pattern as shown in Figure 4.16 below. From each of the logarithmic equation, the relationship for each number of production well with different well spacing with respect to the well production duration has established.

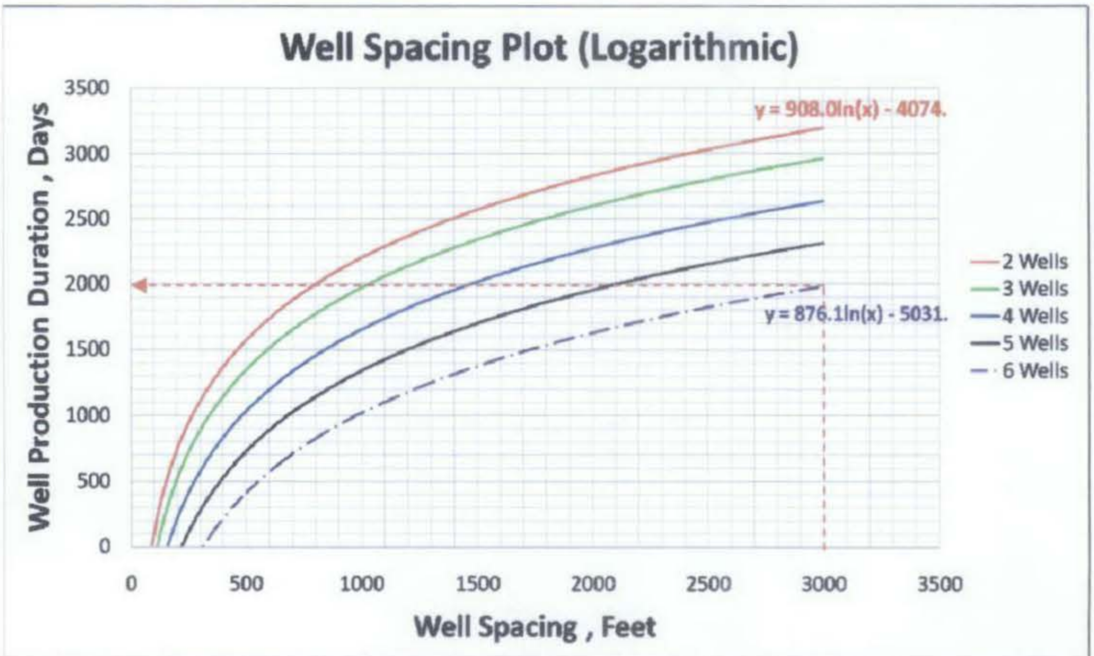

Figure 4.16: The well spacing plot in logarithmic pattern (*WOPR of 200 bbl/ day)

Well Spacing Calculation Steps:

$y = m\,ln(x) - c$; y: well production duration, days

$x = e^{\frac{y+c}{m}}$ m: well production duration per well spacing, days/ ft

x: well spacing, ft

c: constant

1. Specify the number of wells needed to be drilled, n.
2. Determine the slope, m_o from the 2 wells spacing graph in the well spacing plot.

   **Note: 2 wells data must be established first before any estimation is done. Use the slope of the 2 wells equation as an initial reference, m_o*

3. Calculate the slope, $m = m_o - [8(n - 2)]$
4. With the m value, obtain the c value from the correlation graph shown in Figure 4.17.
5. By knowing the desired well spacing, the well production duration can be estimated.

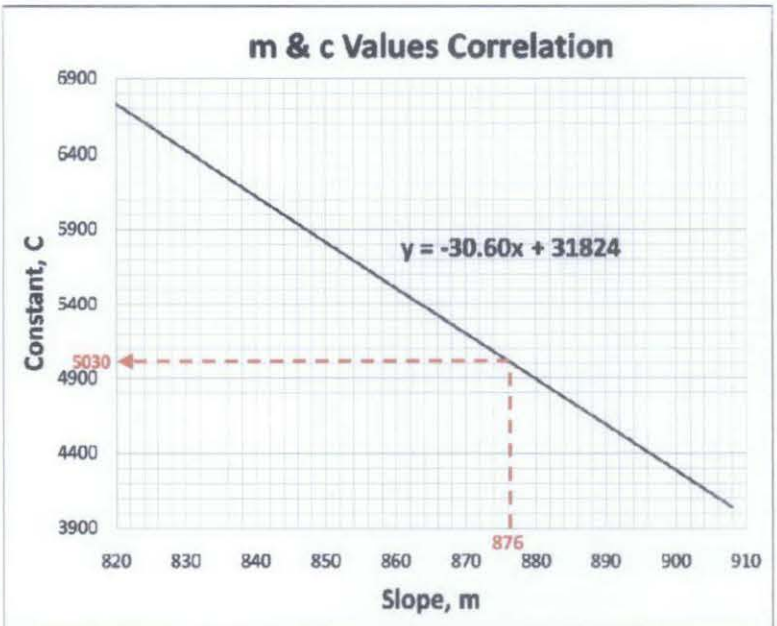

Figure 4.17: The graph of the slope correlation with respect to the constant values

Example of the well spacing calculation:

1. Number of production wells needed to be drilled, n = 6
2. From Figure 4.16, the slope of the 2 wells spacing graph, $m_o = 908$
3. Insert n and m_o values into the equation, $m = m_o - [8(n - 2)]$

$$m = 908 - 8(6-2)$$

$$m = 876$$

4. From Figure 4.17, when m = 876, c = 5030

   Insert m and c values into the equation, $y = m\ln(x) - c$

$$y = 876\ln(x) - 5030$$

5. If the desired well production spacing x is 3000 ft,

$$y = 876\ln(3000) - 5030$$

$$y = 7013.58 - 5030$$

$$y = 1983.58$$

$y \approx 2000$ days (Proven as shown in Figure 4.16)

**Note:* *Negative value obtained is undesirable. The calculation only applicable for the number of well ≤ 12.*

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the studies and the research that has been done so far, understanding of the structure of the subsurface reservoir at the specific geographical locations is very crucial in gaining a clear overview before any new well is to be placed for the recovery activities of the hydrocarbon recourses. A basic understanding of a conceptual reservoir model should be gained and it is a very crucial understanding process before the actual reservoir model is used as further studies.

5.1.1 THE BASIC CONCEPTUAL 3D RESERVOIR MODEL STUDIES

From the understanding of the wells location optimization studies, as the distance between the producers and the injectors are closer to each other, the recovery factor for the oil production will not be optimized. Besides that, the locations between the injectors has to be closed to each other if possible in order to get a more evenly water injections flows towards the producers in recovering the optimum hydrocarbon from the reservoir.

By utilizing the injecting water through the injection wells in the oil reservoir, it can recover high volume of hydrocarbon. And in this homogeneous basic conceptual 3D reservoir model, the water flood is highly efficient as compared to the heterogeneous reservoir model, in which the water flood method might not be so efficient. Besides that, both the injection and the producing wells must penetrate at the same element of sand body in order to have a more optimized oil recovery.

From the 3D reservoir simulation studies, the injected water flows fastest through the most permeable zones (thief zones) and reach the production well. The water is heavier than oil, so the injection rate should not be too high as it tends to flow furthest along the bottom of the reservoir, hence it will be less efficient with less oil recovered.

On the other hand, by the used of the conceptual reservoir model for the studies, the optimized wells location of the reservoir has been determined and hence, proper study of the optimization of the wells placement at the specific geographical areas on the actual reservoir model can be carried out and determined in a more effective approach.

5.1.2 THE ACTUAL 3D RESERVOIR MODEL STUDIES– GELAMA MERAH

5.1.2.1 Determination Of High Oil Production Area

By sub-dividing the field into an several sections equally, the determination of the zones from where the oil production is expected to be the highest can be done easily Thus, the attempts and possibilities to place the wells at low oil production zone in such a reservoir is reduced to a minimum.

5.1.2.2 The Sensitivity Analysis

An alternative approach which focusing on the parameters such as the permeability (k), porosity (ø), and the oil saturation (S_o) has been used for the identification of the well location process by conducting a sensitivity analysis. And this analysis has significantly allow the well optimization to be utilized on a much larger scale. The crucial parameter which is the oil saturation (S_o) has become one of the basis in order to determine the best well placement. Thus, placing a new well at high oil saturation area does gives best to the high oil recovery factor.

Hence, by studying the properties of the reservoir, proper placement of the wells can be determined more efficiently. As a result, the parameters are ranked in the decrease of priority which are:

1. Oil saturation (S_o)
2. Porosity (ø)
3. Permeability (k)

5.1.2.3 Effect Of Different Well Orientation

Besides that, the type of well also can affects the productivity of the well and from the studies that have been made, horizontal well placement is an excellent type of well used in order to obtain a high well productivity and it is followed by deviated well and vertical well. On the other hand, it is still important to take into consideration of the proposed approach which may not lead to the ultimate results because the engineering analysis is still an important tool to define the best strategy in order to obtain the best outcome as expected.

5.1.2.4 Effect Of Well Spacing

From the analysis and evaluation that have been done, the well spacing does highly affect the well production duration with the changing in the number of production wells with respect to each of the well spacing.

Low number of wells configuration seems to result in a higher well production duration with respect to each different of well spacing. Thus, the number of production well drilled is inversely proportional to the well production duration. Consequently, the well production duration will increase with the increase of the well spacing and the oil production of the well will achieve the same well production duration after certain degree of well spacing.

The relationship between the number of wells configuration with respect to the different in well spacing towards the well production duration is established. Hence, calculation can be done in estimating the well production duration and with proper number of production wells when the desired well spacing is known by using the formulation and graphs established.

5.2 RECOMMENDATIONS

Considering the vast areas to be assessed and the uncertainty of the different type of fields, forecasting an optimum subsurface location in order to place the new wells is very crucial. These tasks are often complex and consist of a set of time consuming challenges in the well placement problem. Hence, apart from the project works done, there are several recommendations made in order to improve and rectify the results obtained:

1. The effect of well spacing analysis can be further studied and investigated by using different well oil production rate (WOPR) in order to establish the relationship between the WOPR with respect to the well oil production duration.
2. Different well orientation such as deviated well and horizontal well can be used for further analysis.
3. Different type of 3D reservoir field should be used in rectifying the results reliability obtained currently.
4. More sensitivity analysis can be done for future reference in order to ease the optimum well placement.
5. Injectors can be utilized in order to observe the effect on the optimum well placement.

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