Research Studies on Water Coning, Preventive and Remedial Action That Can Be Taken.

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the requirements for the
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CERTIFICATION OF APPROVAL

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Petroleum Engineering Programme

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In partial fulfillment of the requirement for the

BACHELOR OF (HONS) PETROLEUM ENGINEERING

Approved by,

(DR REZA ETTEHADI OSGOUEI)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JAN 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own accept as the specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(FARIDZUL RUSYIDEE BIN IBRAHIM)

ABSTRACT

This document discusses on the study of water coning and its preventive and remedial action that can be taken. The objective of this study is to identify preventive action that can be taken to prevent water coning from happening and identify remedial action that can be taken after water coning is formed. The purpose of this study is also to model the calculated critical rate and to model the breakthrough time taken for the water cone. A reservoir that has strong water support in Sarawak offshore is chosen to be modeled and preventive action (gellant treatment) is modeled to find out whether it is a good solution to the water coning problem.

ACKNOWLEDGEMENT

Firstly, I would like to express my gratitude and appreciation to my zealous supervisor, Dr Reza Ettehadi Osgouei for his full commitment in assisting me and giving a valuable advises. His willingness to teach and guide me along the period of this project greatly inspired me to successfully complete the project even though he is in tight and fixed schedule.

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Furthermore, I would like to dedicate my gratitude to my late mother and father who always loved me with full of their heart and continuously give priceless supports that cannot be compared by anyone else and you are my number one. Lastly, to all my family members and to who contribute directly and indirectly thank you very much.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDIES

The problem of water coning has plagued the petroleum industry for decades. Both gas and oil wells are assailed by this phenomenon which, in almost every

case, results in eventual shut in of the well and substantial loss in revenue. The problem occurs in every quadrant of the globe and engineers view its resolution as a technical "holy grail".

When the oil is drained from the reservoir by a drilled oil well, the pressure gradient generated will cause the oil-water interface to rise; the distortion of the oil-water interface is counterbalanced by gravity forces due to density differences. Depending on the magnitude of the forces, the oil-water interface may reach a stable shape below the well, or reach the well, causing the undesirable product of pumping a mixture of oil and water to the surface. This rising and possible breakthrough to the well of the water layer is known as "water coning" in an oil reservoir.

Water coning can adversely affect oil production in oil reservoirs. In oil reservoirs, a large oil rate can cause upward coning of water into the well perforations. Once water is produced, the oil rate decreases and the cost of water handling is increased. It is a common industry practice to reduce water coning in oil reservoirs by perforating vertical wells as far above the oil water contact (OWC) as possible and to produce the wells at or below the critical oil rate. The benefits of this practice which are mixed in that limited perforations may increase the pressure gradient (the drawdown) near the well, which can exacerbate coning.

The change in oil-water contact or gas-oil contact profiles as a result of drawdown pressures during production. Coning occurs in vertical or slightly deviated wells and is affected by the characteristics of the fluids involved and the ratio of horizontal to vertical permeability. The research that being introduced in this project is based on real possible water coning in B field (Sarawak).

By using data from the field, the conceptual reservoir and well model generated to be tested to analyse the sensitivities. Based on the well model and reservoir model, Wellflo and Eclipse software are used to match it with current production in order to model the coning problem and find the remedial and preventive action for water coning:

1.2 PROBLEM STATEMENT

Water production in oil and gas wells has been a problem for many years. Commonly, reservoirs have an aquifer beneath the zone of hydrocarbon. If the aquifer is large it may act as a constant-pressure lower boundary. In such cases, this bottom-water boundary condition constitutes an infinite aquifer. This results in excellent production support replacing all voidage induced by the production of the hydrocarbon. However, the study regarding the water coning causes and how to prevent it need to be done.

Eventhough solution introduced based on the theory; artificial lift, bean control can significantly improve the oil recovery, but certain well problem can be prevented by controlling the production rate. This project will determine how water cut can be introduced early in different reservoir characteristic.

However significant the benefit of a strong water drive, if the water drive dominates and fills the near well-bore region with water (literally a cone of water in the region of the producer – thus the name of water coning) then hydrocarbon production suffers and in some cases the well may become uneconomic. Depending on the variables of the reservoir, in-situ fluids, production protocol and completion interval, the well may exhibit more or less serious coning problems.

The productive life of a well completed over an active aquifer is strongly affected by water coning. The evolution of the water cone is driven by non-uniform drawdown pressure near the wellbore. The irreversibility of water coning mandates its early detection, modelling and control before and/or during water breakthrough. Recent development in technologies for in situ monitoring using pressure and temperature distributed sensors allow acquisition of real-time production data that carry valuable information about reservoir properties and the water coning process in the vicinity of the well. The acquired data can be used to maximize oil-water ratio through model based dynamic optimal control of pressure drawdown along a production well and/or inflow allocation among the wells draining the same reservoir.

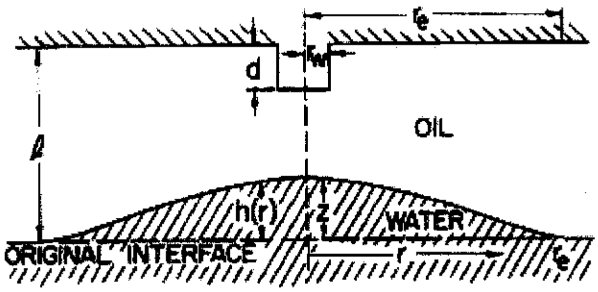


FIG. 1—WATER CONE IN VICINITY OF OIL WELL.

1.3 OBJECTIVES

The objective of this study is :

- To study the causes of water coning in oil reservoir
- To study any measurement that can be taken:
  - Before water coning happen (preventive)
  - After water coning happen (remedial)

1.4 SCOPE OF STUDY

1.4.1 The scope of study in this project is more towards:

- <u>Water coning causes study</u>

  Determine the causes of water coning problem

- <u>Different reservoir simulation, preventive and remedial study</u>

  Reservoir simulation and using software and preventive and remedial study on how to prevent water coning before it happen.

1.5 SIGNIFICANCE OF THE PROJECT

1.5.1 Water Treatment cost

As stated earlier, the presence of water in produced hydrocarbon will result in extra cost in separating and treating them. In this case, it is important to study the reservoir characteristics and do modeling which will indicate the possibilities of water coning to happen and how to prevent or cure it.

1.5.2 Water coning can be prevented

As calculated the water coning can be prevented when the reservoir itself producing within a critical flow rate or if it is produced beyond the critical rate, the calculated breakthrough time will tell how long the time for the water cone is formed.

1.5.3 Early control of water coning can stop the problem from getting worse.

Early control of water coning can save a lot of money since water production needs extra cost to be treated and reduce production of oil significantly. Once the cone is formed, the water cannot be reduced because water is more mobile than oil.

1.6 FEASIBILITY OF THE PROJECT WITHIN SCOPE AND TIME FRAME

Due to time constraint, this project needs to be done as soon as possible. It requires a lot effort and understanding on both modeling phase and reservoir knowledge. However it is not impossible to complete this project within the given period. There are three essentials elements to make this project possible:-

i. **Information from previous study**

   There must be some information on the reservoir from the past studies. With the data, further studies and researches can be done. With the data also we can compare the changes occur in the reservoir for more understanding of the reservoir in the modelling part.

ii. **Application of theories and concepts**

Theories and concepts related to water coning and reservoir rocks must be known. It is crucial to have this knowledge for modelling interpretation and analysis works.

iii. **Data availability**

For modeling works, strong water driven reservoir is chosen. A model from one of the reservoir in Sarawak is chosen Miri Field to model water coning problem. From the field, the model will be fine tuned to start water coning problem. In this project, data will be gathered from the model itself. Basic reservoir data get from reports and production data.

For further explanations regarding the time frame, please refer to Appendix for the Project Milestone.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

2.1 Introduction

Water coning is primarily the result of movement of reservoir fluids in the direction of least resistance, balanced by a tendency of the fluids to maintain gravity equilibrium. Production from the wells in a reservoir would create pressure gradients that tend to elevate the water-oil contact in the immediate vicinity of the well. Counterbalancing these flow gradients is the tendency of the water to remain below the oil zone because of its higher density. These counterbalancing forces tend to deform water-oil contacts into a bell shape.

Capillary forces usually have negligible effect on water coning and will be neglected. Gravity forces are directed in the vertical direction and arise from fluid density differences. The term viscous force refers to the pressure gradients associated fluid flow through the reservoir as described by Darcy's Law. Therefore, at any given time, there is a balance between gravitational and viscous forces at points on and away from the well completion interval. When the dynamic (viscous) forces at the wellbore exceed gravitational forces, a "cone" will ultimately break into the well.

We can expand on the above basic visualization of coning by introducing the concepts of:

- Stable cone
- Unstable cone
- Critical production rate

If a well is produced at a constant rate and the pressure gradients in the drainage system have become constant, a steady-state condition is reached. If at this condition the dynamic (viscous) forces at the well are less than the gravity forces, then the water or gas cone that has formed will not extend to the well. Moreover, the cone will neither advance nor recede, thus establishing what is known as a stable cone. Conversely, if the pressure in the system is an unsteady-state condition, then an unstable cone will continue to advance until steady-state conditions prevail.

If the flowing pressure drop at the well is sufficient to overcome the gravity forces, the unstable cone will grow and ultimately break into the well. It is important to note that in a realistic sense, stable system cones may only be "pseudo-stable" because the drainage system and pressure distributions generally change. For example, with reservoir depletion, the water-oil contact may advance toward the completion interval, thereby increasing chances for coning. As another example, reduced productivity due to well damage requires a corresponding increase in the flowing pressure drop to maintain a given production rate. This increase in pressure drop may force an otherwise stable cone into a well. The critical production rate is the rate above which the flowing pressure gradient at the well causes water (or gas) to cone into the well. It is, therefore, the maximum rate of oil production without concurrent production of the displacing phase by coning. At the critical rate, the built- up cone is stable but is at a position of incipient breakthrough.

2.2 Water coning by equation

The Darcy equation is very useful in describing the phenomenon of water coning. Equations 1 and 2 define this simple relation for the case of oil and water flow.

$$V_{OIL} = \frac{K_{ABS} K_{RO}}{\mu_o} \frac{\partial P_o}{\partial R} \quad (1)$$

$$V_{WATER} = \frac{K_{ABS} K_{RW}}{\mu_w} \frac{\partial P_w}{\partial R} \quad (2)$$

Darcy stated that the velocity of the fluid is inversely proportional to the viscosity of the phase and proportional to the absolute permeability, the relative permeability and the pressure gradient of that phase. As the pressure gradient increases, the more mobile phase begins to dominate production. Typically, water is more mobile and, therefore, water production increases relative to the rate of oil production.

$$\frac{V_W}{V_O} = \frac{\mu_{OIL}}{\mu_{WATER}} \frac{K_{RW}}{K_{RO}} = \text{Mobility} = M \quad (3)$$

$$f_W - \frac{1}{1+1/M} \quad (4)$$

Dividing Equation 2 by Equation 1 shows the ratio of water velocity to oil velocity very clearly as Equation 3(neglecting capillary pressure), which is the common mobility ratio. This ratio expresses the tendency for water cut when viewed in the context of the fractional flow equation (Equation 4). As M increases the tendency to flow water preferentially increases. With operators desiring more and more output from each well, if M is large, then water cut is going to be a problem. Another reason for water production increasing quickly relative to oil production is due to the aspect ratio.

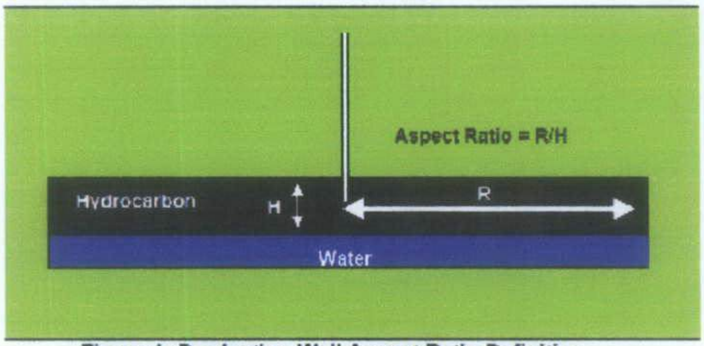


Figure 1: Production Well Aspect Ratio Definition

Figure 1 presents the geometry of a standard production well. The aspect ratio is defined as the ratio of Radius to Thickness (H); the thinner the formation (H becoming smaller), the greater the aspect ratio. Since there is a common boundary condition at the well bore(constant pressure for example), the pressure gradients in the axial direction will be greater than the pressure gradient in the radial direction to the extent to which the thickness is less than the radial extent of the imposed pressure drop.

2.3 Porosity

Porosity is the pore spaces in the rocks which act as the storage for the fluids. Porosity is the ratio of the pore spaces volume with the bulk volume. Porosity can be reduced and increased by either physical or chemical alteration towards the rock. It is also can be altered naturally or artificially. In terms of heterogeneity, the porosity is inconsistent within a reservoir rock. It is due to the sediments fabric and sorting which gives different sizes of pores within the rock. There are two types of porosity which are effective porosity and cul de sac or closed pores. The producible fluid comes from effective porosity but not from closed pores except fracturing or fissure through the closed pores occur.

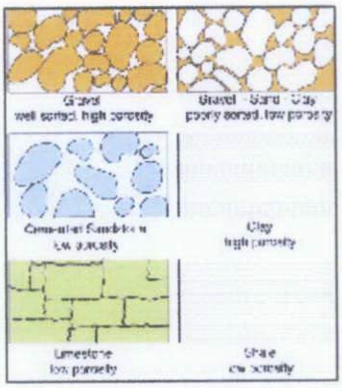


Figure 9 : Porosity

2.4 Permeability

Permeability is very much related with porosity. It is related with the flow of the fluid through it and defined by Darcy's Law as

$$Q = \frac{-kA}{\mu}\frac{(P_b - P_a)}{L}$$

Where Q is the flowrate, k is the permeability, A is the area, μ is the viscosity. L is the length and (Pb-Pa) is the pressure difference between point a and b. Permeability is measured in Darcy or mili Darcy (mD).The connected pores in the rock creates links which allows fluid to travel out of the rocks. It is also called effective permeability. Similar with porosity, it can be altered naturally of artificially. Permeability is not applicable if the pore spaces is isolated excepted there are fracture or fissure. When there are more than one fluid exist within the rock, the flowing fluid is said to be having relative permeability. It is a complex relation with the fluid types and their properties such as wettability and viscosity.

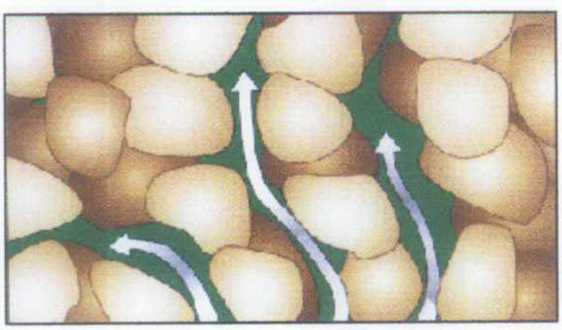


Figure 10 : Permeability

2.5 Upscaling

Upscaling is the process used in reservoir modeling. It simplifies the reservoir to make it easier for calculation and also save time. In reservoir modeling the model is upscaled using several methods. In terms of reservoir heterogeneity, the upscaled reservoir model is simplifying the heterogeneity, from the microscopic level to the macroscopic level[2]. The relevancy of simplifying the reservoir is due to complex calculations and long time required to solve the equations, even with the computers. Even though, the upscaling of the reservoir increases more uncertainty of that reservoir. So, in case of enhanced oil recovery (EOR) consideration, heterogeneity characteristic must be identified to determine the most effective method to recover the hydrocarbon, economically.

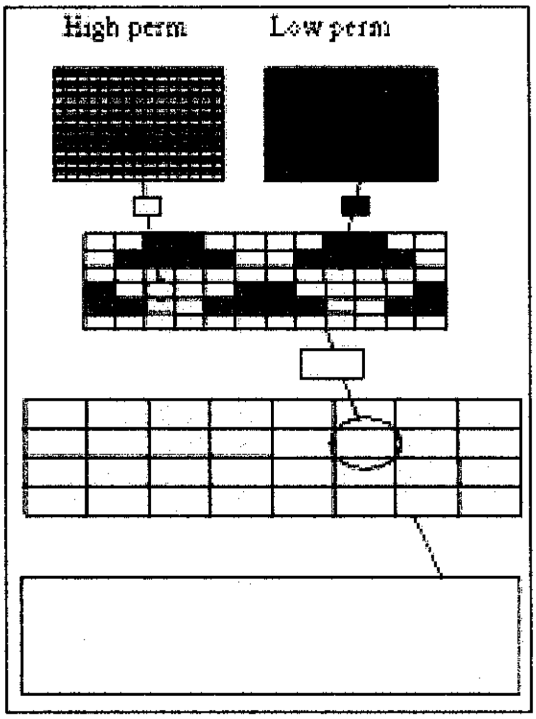


Figure 11 : Upscaled reservoir model[32]

CHAPTER 3

RESEARCH METHODOLOGY

To make sure this project runs smoothly, proper methods will be used. There are several stages needed to be done till the end of the project completion.

3.1 Planning phase

The planning for the project is the most crucial part. Tasks are divided into sections within the period of time. The tasks should comprise all the essential works needed to achieve the project objectives. In planning phase, Gant Chart and milestones are constructed at this stage as a guide for the rest of the project.

3.2 Research and Data collection

For research and data collection, several methods will be used:

- **Books**

  Reading books relating to well technology which closely related with water coning. From the books, theories and concepts of the water coning are extracted and interpreted to obtain sufficient knowledge about the topics. By understanding the theories, any misinterpretation can be prevented during the analysis in the later part.

- **Modelling**

  Modelling will helps to understand more about what had been read earlier. The application of theories can be seen from the model itself. The model needs to be fine tune with the data I get from my internship.

- **Paper and journals**

  There are a lot of studies and researches in form of journals relating water coning. The journals are usually describing case studies or researches on particular topics. From the journals, relations between the reservoir properties and calculations are explained to aid futher studies on water coning. There are old and new journals available and by studying both of them, the development preventive and remedial steps of water coning study will be visible.

- **Websites**

A lot of informative websites containing information on water coning are available on the internet. Although, some of the websites are not reliable as there is no valid sources stated. Plus, the websites belongs to different parties which have different interpretation on the interested subject. With that, comparing the informations between the websites will be good as the additional to the books and journals read as the references.

3.3 Data interpretation and modelling

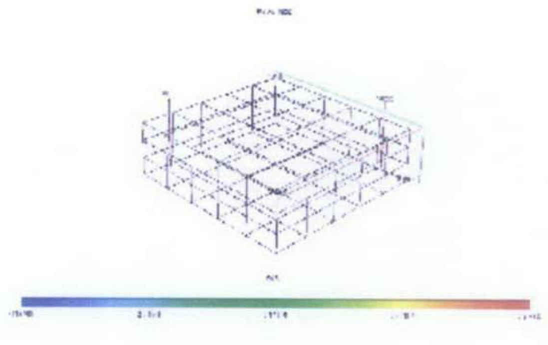
With the data available, reservoir model can be done to identify the reservoir characteristics. In this phase, reservoir model are generated. With reservoir model, the characteristics of the sand that leads to water coning problem will be identified which will lead to preventive and remedial solution later on.

3.4 Project Activities

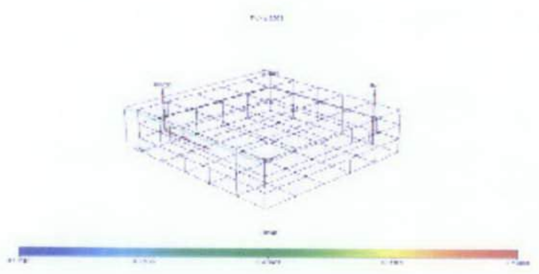
- Study and researches on reservoir characteristics
- Get data and put into software (Eclipse & Wellflo)
- Execute the modeling of the reservoir and the water coning
- Study the preventive and remedial solution with the model

3.5 Software Specification

- Windows operating system
- Eclipse 100
- Wellflo

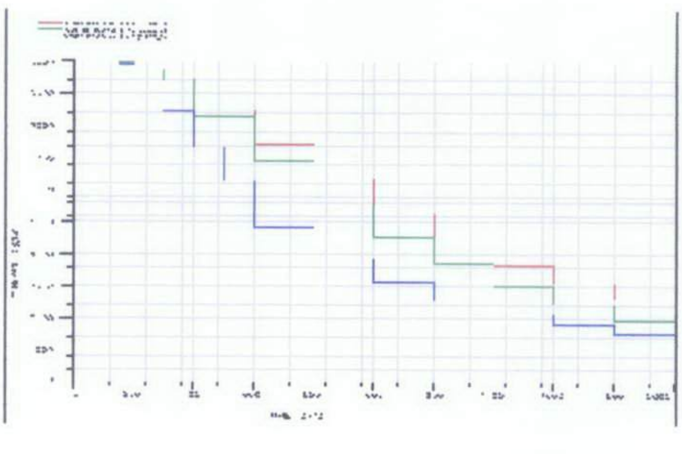


Vertical Production Well model from reservoir

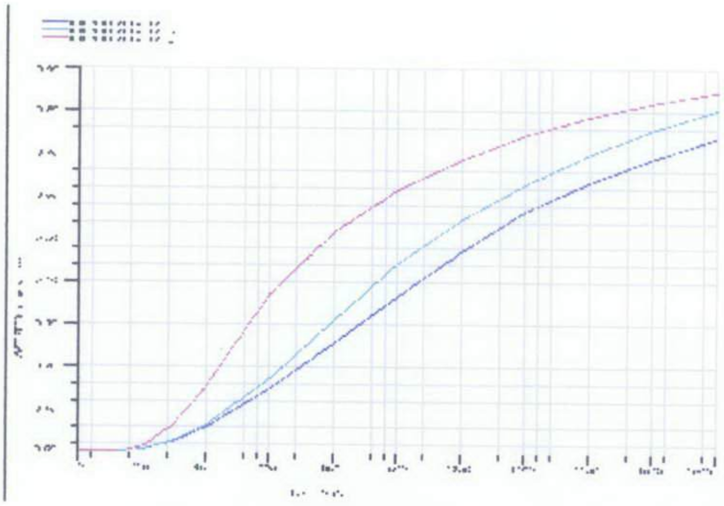


Horizontal Production Well model from reservoir

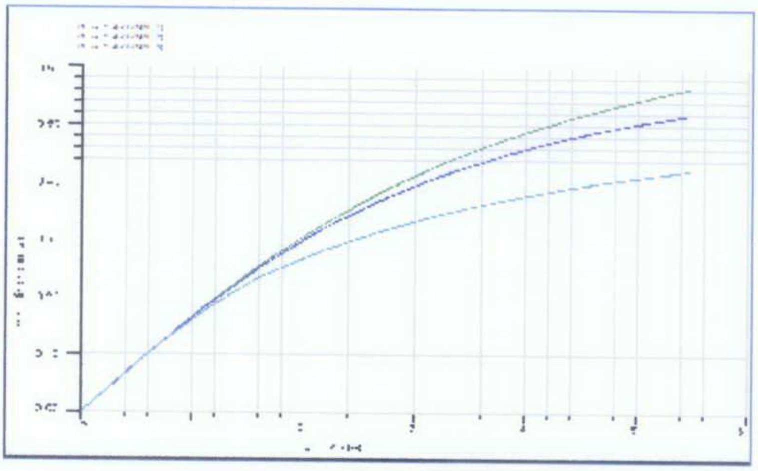
Permeability Distribution Fine tuning



Production Rate vs. Time (Permeability Distribution



Well Water Cut vs. Time (Permeability Distribution)

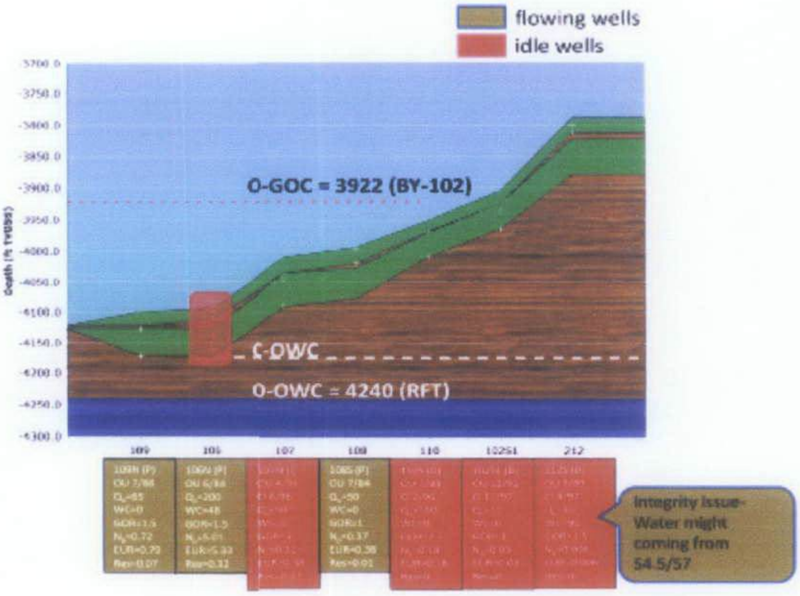


Field Recovery Factor vs. Time (Permeability Distribution)

CHAPTER 4

RESULTS

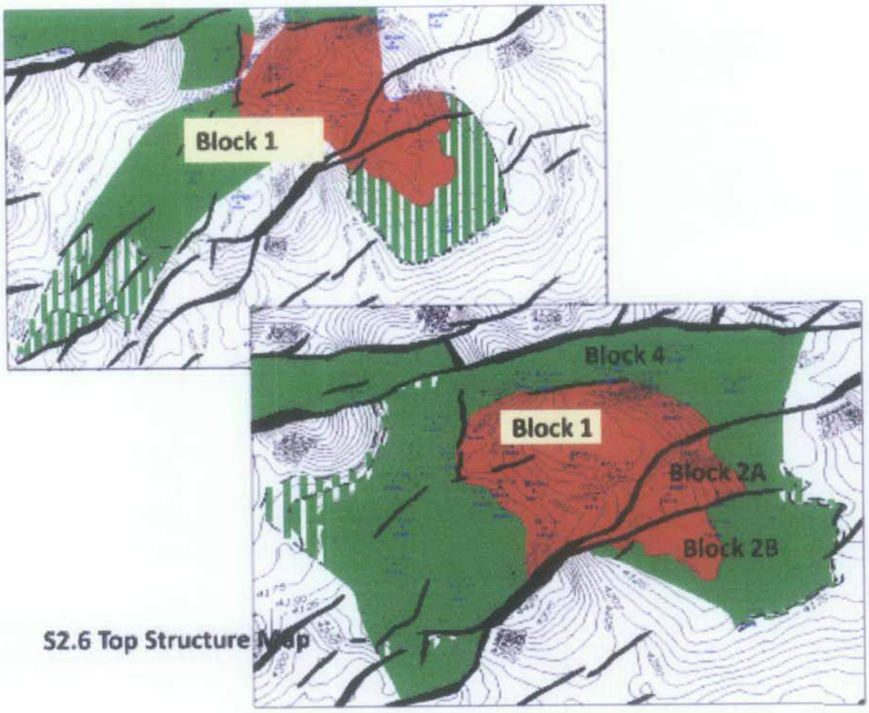
4.1 INTRODUCTION



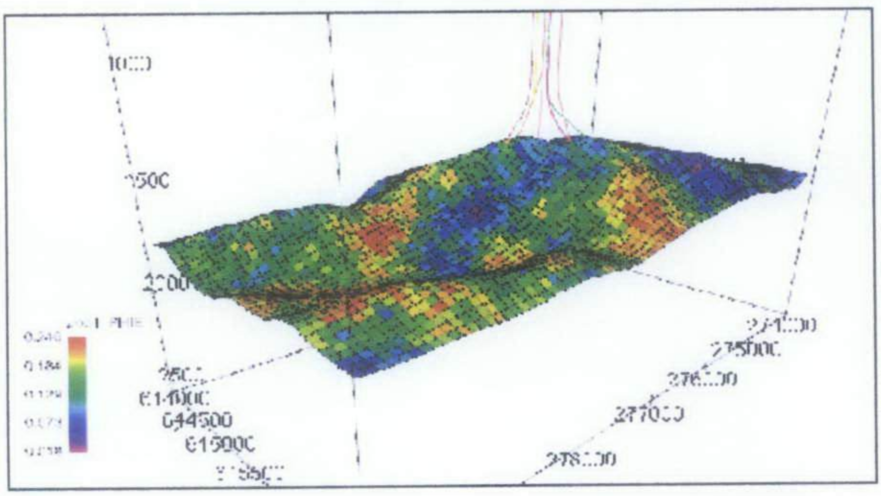
Well B-106 was perforated at sand S2.2/S2.6. As shown in Figure 3.10, B-106 is the most down-dip well at the flank area. The high water cut issue (90%) is probably caused by the water coning at all the sands it was perforated.

4.1.1 Reservoir 1-S2.2/S2.6Drive Mechanism

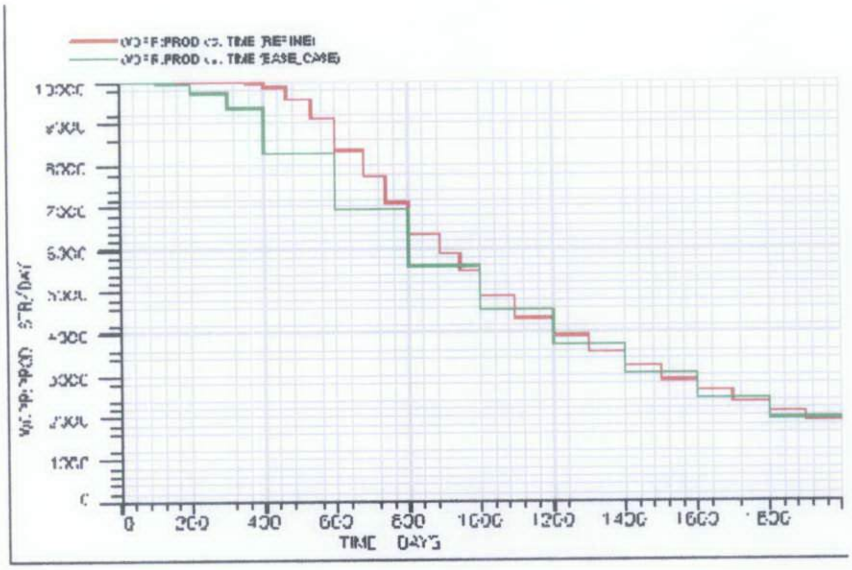
Reservoir 1-S2.2/S2/6 performance is in line with strong water drive characteristic which is based on the performance showed gradual increase in water cut that indicate water support from aquifer and also GOR trend is maintained at 400 scf/stb throughout the production period


Block 1
Block 4
Block 1
Block 2A
Block 2B
S2.6 Top Structure Map

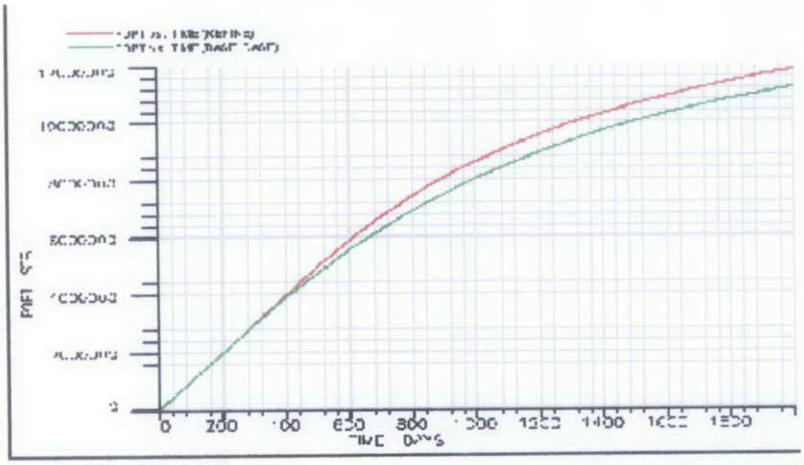
4.2 Results



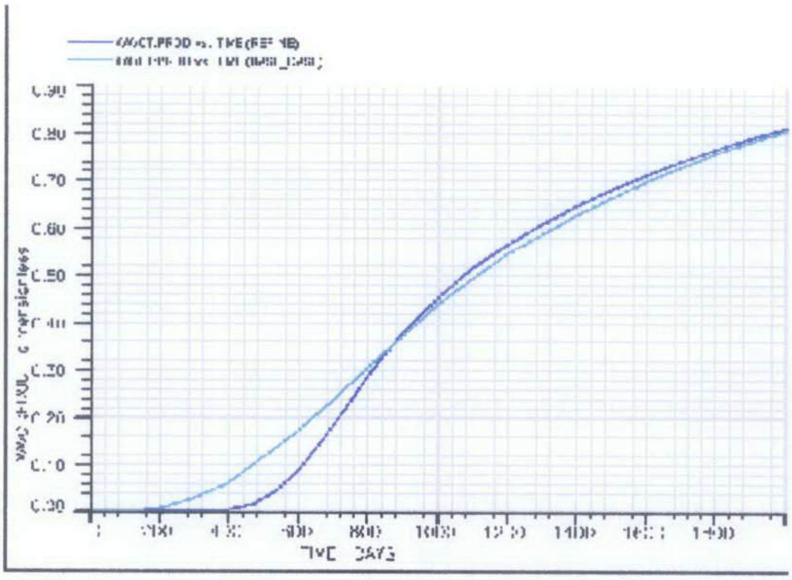
4.2.1 Fine Tuning Model by Refining Grid Cells



Well Oil Production Rate vs. Time (Refine Data)

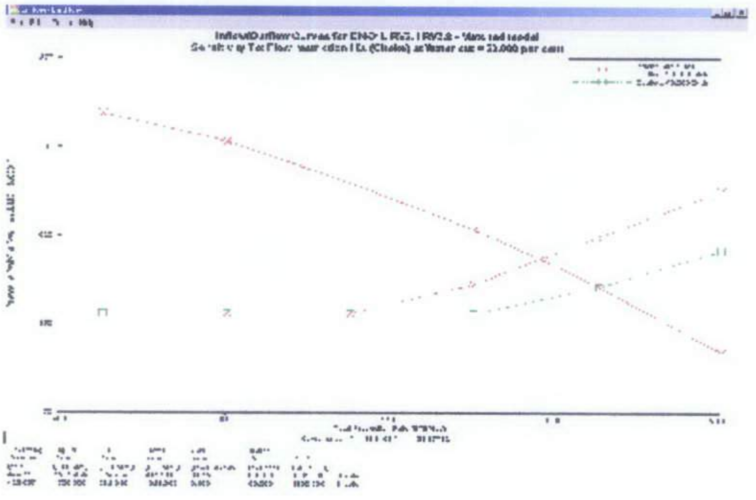


Field Oil Production Total vs. Time (Refine Data)

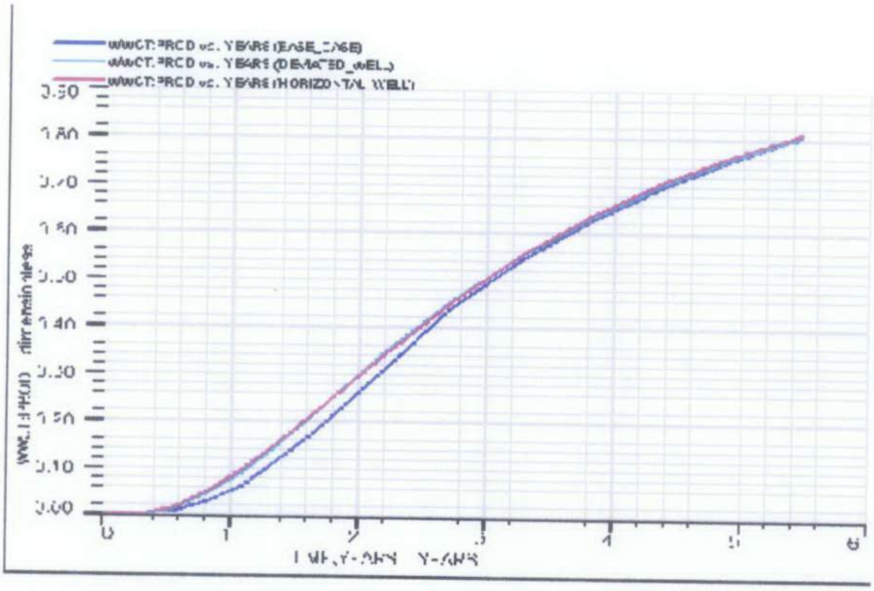


Well Water Cut vs. Time (Refine Data)

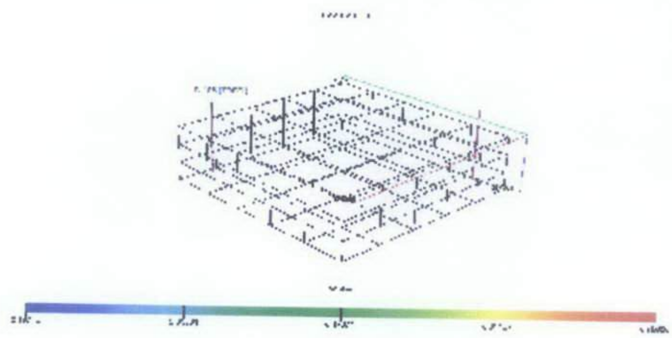
4.2.2 Sensitivity Analysis



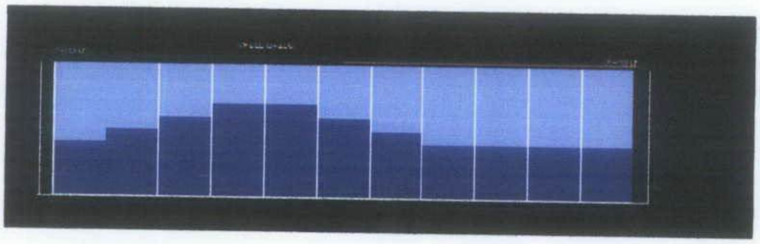
Critical Rate analysis



Water cut vs well orientation (horizontal/vertical)



Reservoir model for B-106 producer



Water movement for B-106 (coning)

CHAPTER 5

DISCUSSION

5.1 Introduction

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

In the research study, things regarding theory and problem of different wells and reservoir on water coning are studied. Besides that, all the data are gathered throughout this phases which includes the reservoir characteristic, reservoir data and production data. After that is conducting simulation where in this phases, I will start to generate the reservoir model in the simulation software and start to play around with the water coning problem in the simulation.

The last phase is evaluating result. In this phase, all results from the research will be compiled and evaluated. It is important to compare the results from different reservoir water coning problem and do preventive study.

5.2 Critical Rate

Critical rate is defined as the maximum allowable oil flow rate that can be imposed on the well to avoid a cone breakthrough Here is an example of relationships for determining the critical oil flow rate in horizontal wells:

Efros (1963) [10]	$q_c = \dfrac{4.888 \times 10^{-4} k_h \Delta\rho h^2 L}{\mu_o B_o [2y_e +]\sqrt{2y_e + (h^2/3)}}$
Kraeher (1986) [11]	$q_c = 4.888 \times 10^{-4} \left[\dfrac{k_h}{\mu_o B_o}\right]\left[\dfrac{\Delta\rho h^2}{2y_e}\right]\left[1 - (1/6)\left(\dfrac{h}{2y_e}\right)^2\right] L$
Joshi (1991) [12]	$q_{c,v} = \dfrac{1.535 \times 10^{-1}(\rho_o - \rho_g) k_h [h^2 - (h - l_v)^2]}{B_o \ln r_e / r_w}$
	$\dfrac{q_{ch}}{q_{cv}} = \dfrac{[h^2 - (h - l_p)^2] \ln(r_e/r_w)}{[h^2 - (h - l_p)^2] \ln(r_e/r_w')}$ Where q_{cv} is the critical rate for vertical wells & q_{ch} is the critical rate for horizontal wells.

Where:

For oil water system:

$$q_{oc} = 0.0246 \times 10^{-3} \frac{(\rho_w - \rho_o) k_o \left[h^2 - (h - D_b)^2 \right]}{\mu_o B_o \ln(r_e / r'_w)}$$

$$r'_w = \frac{\left[r_{eh} \frac{L}{2a} \right]}{\left[1 + \sqrt{1 - \left[L/(2a) \right]^2} \right] \left[h/(2r_w) \right]^{h/L}}$$

$$r_{eh} = \sqrt{\frac{43560A}{\pi}}$$

$$Q_{oc} = 0.246 \times 10^{-4} \left(\frac{\rho_o - \rho_g}{\ln\left(\frac{r_e}{r_w}\right)} \right) \left(\frac{K_o}{\mu_o \times B_o} \right) (h^2 - h_p^2)$$

Q_{oc} = Critical Oil Flow Rate
ρ_o = Oil Density
ρ_g = Gas Density
r_e = Drainage Radius of Well
r_w = Well Bore Radius
K_o = Effective Oil Permeability
μ_o = Oil Viscosity
B_o = Oil Formation Volume Factor
h_p = Perforated Interval
h = Oil Column Thickness

This is an example for gas-oil system

5.3 Breakthrough Time

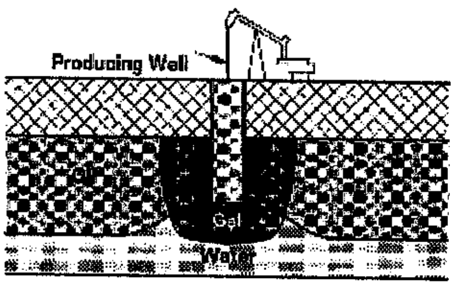
Critical flow rate calculations frequently show low rates that, for economic reasons, cannot be imposed on production wells. Therefore, if a well produces above its critical rate, the cone will break through after a given time period. This time is called time for the water cone to breakthrough.

$$t_{bt} = \frac{(N_p)_{bt}}{q_t}.$$

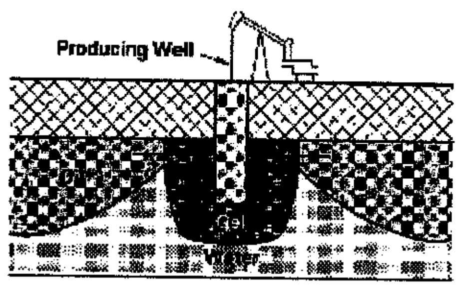
where

$$(N_p)_{bt} = A\varphi(1 - s_{wc} - s_{or})(h - h_{wb} - h_{ap} - h_p).$$

5.4 Gel Treatment



The correct placement of gel



High cone height restrict oil flow

It it shown that in the research gel treatment need to be applied in early stage of water coning as the water cone height is low and will not restrict oil flow. Its effectiveness in early stage of water coning can stop water cone height from increasing and can reduce produced water.

5.5 Errors and Uncertainty

There are maybe errors and uncertainties in the project work such as in the modeling part where the fine tuning and upscalling might lead to imprecise and makes the model react differently to the sensitivity analysis.

There are also possibilities that the software itself did not give the best model because of difference in data that been put in the software to model thus, will lead to weak model and different result with the calculated result.

The error can be solved by using different software to model the well and reservoir. The reservoir can be model using Irap RMS software and the well model can be modeled using Prosper.

CHAPTER 6

CONCLUSION

. Water coning can be explained by using Darcy's by utilizing both equation for water and oil we could get mobility ratio which will show water is more mobile than oil. The main things being discussed in this project is more towards the water coning causes and preventive steps that can be taken.

Three things should be determined is water coning which are:

- The maximum oil production rate at which a well can be produced without coning any water (also called Critical Rate).
- To see if the well produces above the critical rate and the breakthrough time
- The watercut performance after breakthrough.
-

Discussion for model and research

1. The models are fine tuned and history matching are done using production data. The setting of the grid sizes, reservoir poro-perm data give big impact on water coming in to the reservoir. By calculating the critical rate, the safe rate for the reservoir is known and if the reservoir is producing above the critical rate, the water breakthrough time estimation can be made. So the time taken for water to enter the wellbore will be known and we can prevent it from happening. It is proven when the producible hydrocarbon is far from the estimated production. Thus, studies on B Field reservoir should be continued in order to find any possible chances for enhanced oil recovery.

2. The gel treatment are best used in early stage of water coning, this is because the higher the height of the water cone, the harder the oil to move into the wellbore as if ther are "bottleneck" nearby the reservoir.

3. The critical rate calculation is always uneconomical for production. That is why the breakthrough time is calculated to estimate how long the water will take to form a cone near the wellbore if the reservoir and the well are produced above the critical rate.

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Activities	Week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Data acquisition	■															
Data preparation		■														
FYP 2 briefing			■													
Modelling preparation			■	■												
Modelling fine tuning and analysis				■	■	■	■	■								
Progress report							■	■								
Final report preparation									■	■						
Poster										■						
Pre-EDX											■					
FYP 2 final report submission											■					
Oral presentation												■	■			
Finalizing final report														■		
Hardbound service															■	
Submission of hardbound																■