The Effect of Polymer Concentration on Oil Recovery

by

Muhammad Faiz Bin Abdul Aziz

Dissertation submitted as partial fulfilment of

the requirements for the

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(Mr. Iskandar Bin Dzulkarnain)

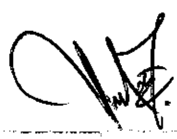
UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

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



MUHAMMAD FAIZ BIN ABDUL AZIZ

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ABSTRACT

Enhanced oil recovery consists of three major methods which are miscible method, thermal method and chemical method. Polymer flooding is considered as one of the chemical method which is inexpensive compared to other methods. The main objective of this project is to determine the optimum polymer concentration that will bring in the most recovery of oil in Angsi Field. Thus, the (1) polymer concentration, (2) polymer solution viscosity, and (3) polymer injection rate effects towards oil recovery are investigated. This investigation will solely base on the outcome from simulator. The principal difficulty in the recovery of oil is the viscosity of oil is higher than injection fluid viscosity, which makes displacement by a cheap fluid, such as water or gas, inefficient on account of the "unfavourable" mobility ratio (i.e. mobility of the injected fluid is greater than the mobility of the oil). Since improvement in the mobility ratio is the ultimate goal, viscosity of the injected fluid is increased by addition of soluble polymer. The polymer concentrations were varied so that different polymer solution viscosity can be injected into the model. Apart from improvement in the mobility ratio, average pressure of the reservoir will also be maintained for as long as possible, which would lead to an improvement in the oil recovery. In accordance to that, the injection rates of displacing fluid play an important role in maintaining average reservoir pressure and also the period of polymer flooding. The scope of study will mainly be focusing on the mobility relationship, but also will be revolving around capillary retention forces and reservoir heterogeneity. The research methodology used in this study is by varying polymer concentration, polymer solution viscosity, and the polymer injection rate. The resulting cumulative oil production and average reservoir pressure will be taken into consideration for each case.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Recently, there has been growing interest in this technique for heavy oil reservoirs. At the end of economical life of primary production, waterflooding is performed as a secondary recovery process. It is the most widely used secondary recovery technique. It involves injection of water into the reservoir to improve the recovery of oil. Several successful waterflooding projects in heavy oil reservoirs have been reported, and they show economical incremental oil recovery at high water cut. However, the range of reported recovery is large. Waterflood recoveries of 1% up to 20% original oil in place (OOIP) have been reported for these reservoirs [1]. Miller has discussed the condition of Canadian heavy oil waterflooding projects and has observed that insufficient literature related to this subject has been published. Miller states that the process of assessing performance of waterflooding generally is empirical rather than theoretical; meaning much of the understanding of waterflooding in heavy oil reservoirs is based on observation of the process in the field rather than understanding the fundamental processes involved [2]. Investigation of many waterflooding projects in Canadian heavy oil reservoirs has revealed that these waterfloods exhibit very poor sweep efficiency because of extreme adverse mobility ratio.

In order to improve the mobility ratio between the injected water and heavy oil, polymer flooding can be used to increase viscosity of water. High molecular weight water-soluble polymers in dilute concentrations (several hundred ppm) increase the water viscosity significantly. Conventionally, polymer flooding has been implemented in light to medium oil fields where it has led to economical improvements in incremental oil recovery beyond that of waterflooding. Hui et al. have reported on successful polymer flood in parts of Daqing oil field, China. The effective permeability of the reservoir was below 10-14 m^2 and the formation was as thin as 1 m. Therefore, waterflooding was not providing economical oil recovery, and polymer flooding was implemented where it led to 3-5% OOIP incremental recovery [3]. In another field trial in India, polymer flooding was conducted in Sanand field of India. Sanand was discovered in 1962 and commercial production started in 1969. Due to high mobility contrast and predicted recovery of around 15% of OOIP under depletion drive, polymer flooding was selected as an IOR process for improving oil recovery from this field. The field-scale implementation began from 1995, and it has led to oil recovery as high as 24% [4].

Applicability of polymer flooding for a given reservoir depends on various parameters, such as: oil viscosity, oil saturation, size of polymer molecules relative to pore size of the rock, stability of polymer molecules in reservoir environment, reservoir heterogeneity, well spacing and injection flow rates [5].

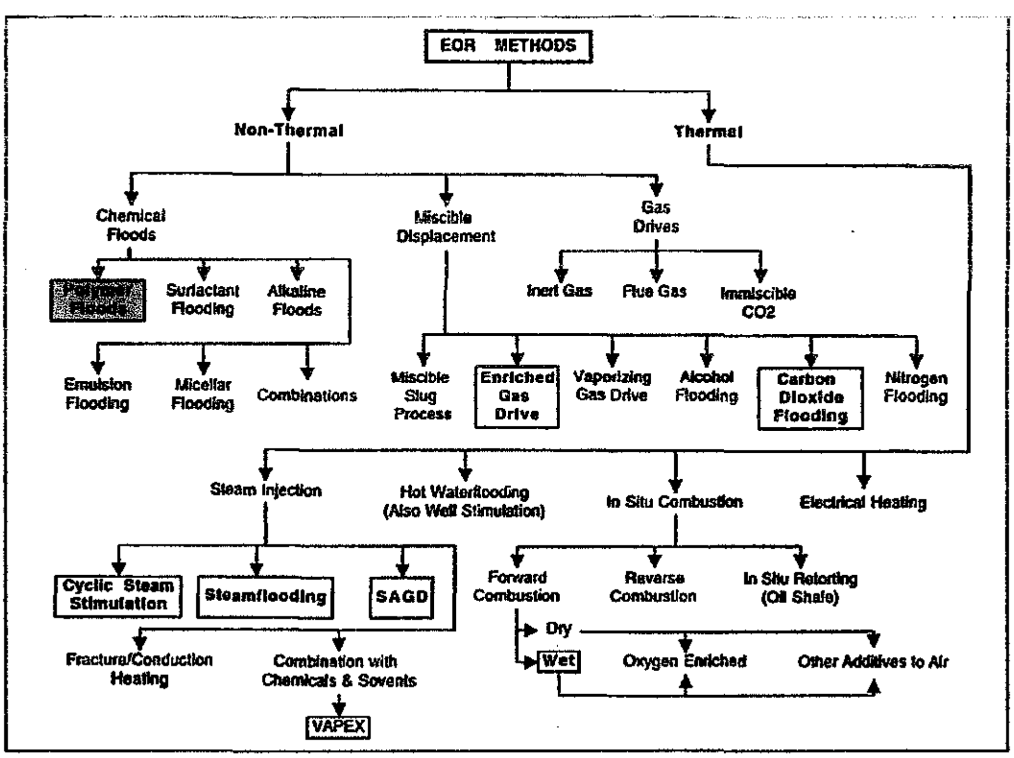

Figure 1: Classification of EOR methods [6]

1.2 Problem Statement

The principal difficulty in the recovery of oil is the viscosity of oil is higher than injection fluid viscosity, which makes displacement by a cheap fluid, such as water or gas, inefficient on account of the "unfavourable" mobility ratio (i.e. mobility of the injected fluid is greater than the mobility of the oil). Since improvement in the mobility ratio is the ultimate goal, it is either to lower the viscosity of the oil, or to increase the viscosity of the injected fluid. Apart from an improvement in the mobility ratio, improving the injection profile and improving the sweep efficiency will also lead to an improvement in recovery. The **choices** of the polymers and the **concentration** to be used are the crucial steps in design. A variety collection of polymers are available. These polymers include polysaccharides (e.g. Kelzan), polyacrylamides (e.g. Pusher), polyethylene oxides (e.g. Polyox), and hydroxyethylcellulose (e.g. Natrosol). However, the first two mentioned polymers are the most widely used (i.e. polysaccharides and polyacrylamides). In addition to that, the injection rates of displacing fluid also play an important role in waterflooding/polymer flooding. Unfortunately, there have been many failures due to improper design.

1.3 Objective

The main objective of this project is to determine the effectiveness and the design of polymer flood that will bring in the most recovery of oil. Thus, the (1) polymer concentration, (2) polymer solution viscosity, and (3) injection rate effects towards oil recovery are to be investigated.

1.4 Scope of Study

After primary production and possibly a waterflood - at least in the case of mobile oils - a certain amount of oil, often called "residual oil", remains unrecovered. Theoretically, in a water-wet rock, all oil could be displaced by the wetting phase, i.e. water, if the pressure gradient (velocity) is high enough. In practice, the amount displaced would depend on how much water has been injected and at what velocities, and also on the mobility ratio (even without considering viscous fingering). There are physical factors that must be considered to recover this residual oil. The principal considerations are (1) capillary retention forces, (2) mobility relationship, and (3) reservoir heterogeneity.

1.4.1 Capillary Retention Forces

There is a certain amount of oil is retained in the rock by the capillary retention forces that operate when oil and water is present in a porous rock system. The rock-wetting phase, usually water, traps the fluid contents of single pores and even isolates large fringes of the non-wetting phase oil. Oil is retained by the rock even if it is the rock-wetting phase.

Taber has simplified a Muscat formula to $\frac{\Delta P}{L\sigma} > X$; [4] the pressure drop per foot divided by the interfacial tension between oil and water. This function must be greater than some value X in order to move the oil in the reservoir. And Taber found that the value of X was most dependent on K, the permeability, and only slightly dependent upon viscosity. The value is also dependent upon the wettability of the rock.

1.4.2 Mobility Relationship

The mobility is denoted by M and the mobility relationship is shown by the following equation: $\frac{kw/\mu w}{ko/\mu o} = \frac{\lambda w}{\lambda o} = M \leq 1$

produced oil's cost becomes more than its real price in the market. Under normal conditions, oil production is halted and well is abandoned. Except for brief periods, which EOR becomes economical, there is no good reason for EOR operations.

Appreciable decline in the new reservoirs discovery and increase in the petroleum demands, has forced oil companies to develop EOR methods. Thermal, chemical and miscible gas flooding are three major EOR methods, which have been developed during the last years. Polymer flooding has found considerable increments during the last years.

This project will determine the design of the polymer flood that will bring in the most recovery of oil. This will be investigated by learning the polymer concentration effect on oil recovery, the effect of type of polymer on oil recovery as well as their economical, the effect of injection rate on the oil recovery, and also reservoir heterogeneity effects towards oil recovery.

1.6 Feasibility of Project

The project is planned and scheduled to be done in a period of at most 12 months. The approach that the author used is by using simulation to determine the oil recovery for each case and set of circumstances. The investigation involves around the improvement on mobility ratio by increasing the viscosity of displacing fluid, i.e. water, by addition of polymers, at an amount that are to be determined, and type of polymers, that are also yet to be determined. In addition, the injection rate of these polymers will also be determined to give the highest recovery of oil.

CHAPTER 2

LITERATURE REVIEW

2.1 Polymer Solution Viscosity

Polymer solution viscosity is one of the important parameters to improve the mobility ratio between oil and water. The effectiveness of polymer flooding increases as the injection viscosity increases. The viscosity can be affected by some factors. First, solution viscosity increases with the increase of polymer molecular weight. Second, increased polymer concentration leads to higher viscosity. Third, polymer solution viscosity decreases with increase of temperature. Fourth, increased salinity in the formation water decreases solution viscosity.

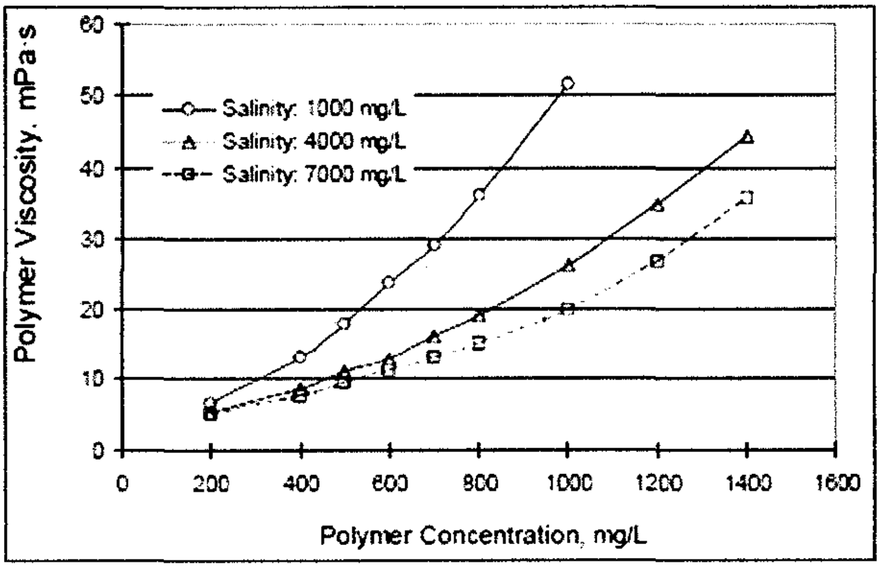

Figure 2: Viscosity vs. concentration for different salinities with medium Mw polymer [8]

2.2 Polymer Molecular Weight

The effectiveness of a polymer flood is affected significantly by the polymer molecular weight (Mw). Polymers with higher Mw provide greater viscosity. For many circumstances, larger polymer Mw will lead to improved oil recovery. This is confirmed by a laboratory test with a fixed volume of polymer solution injected, oil recovery increases with the increase of polymer Mw [9]. This is because for a given polymer concentration, solution viscosity and sweep efficiency increases as the polymer Mw increase. This means, less polymer is required using a high Mw polymer than a low Mw polymer to recover a given volume of oil.

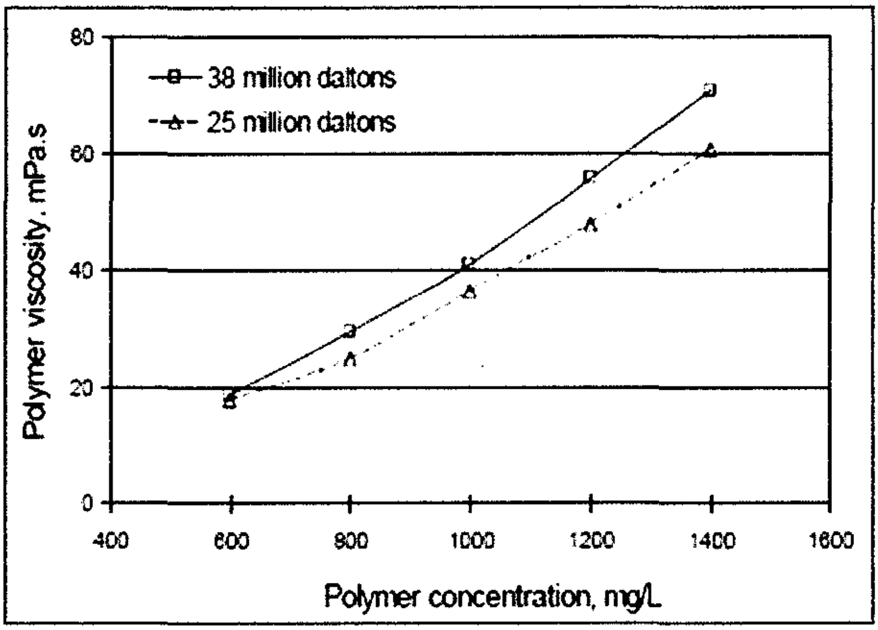

Figure 3: Viscosity versus concentration and Mw for polymers used in the central part of Xing 4-5 [10]

But the levels of mobility and permeability reduction (i.e. resistance factor and residual resistance factor) for polymer with a given Mw can increase with decreasing permeability [11]. This effect is highlighted as Mw increases. Mechanical entrapment can significantly hold back polymer propagation if the permeability and pore throat size are too small. So, depending on Mw and permeability differential, sweep efficiency may be reduced by this effect. Thus it is crucial to choose the highest Mw polymer that will not exhibit pore plugging or significant mechanical entrapment.

2.4 Polymer Injection Rate

Another important factor in the design of polymer flood project is the polymer injection rate. It determines the oil production rates. However, the magnitude of the injection rate has little effect on the final recovery and also on the fraction of injected polymer mass that is ultimately produced. But, the injection rate has a significant effect on the cumulative production time. Higher injection rate will lead to shorter production times. So, the injection rate shouldn't be too small during the polymer flood design.

Conversely, higher injection rates will cause a large disparity between injection and production. Injection rates must be controlled (i.e. not too high, kept below reservoir fracture pressure) so that the polymer flow out of the pattern (out of target zone) can be minimized. Fig. 4 shows the effect of injection rates towards oil production rate. Other than that, it also exhibit how the term of economic production varies injection rate.

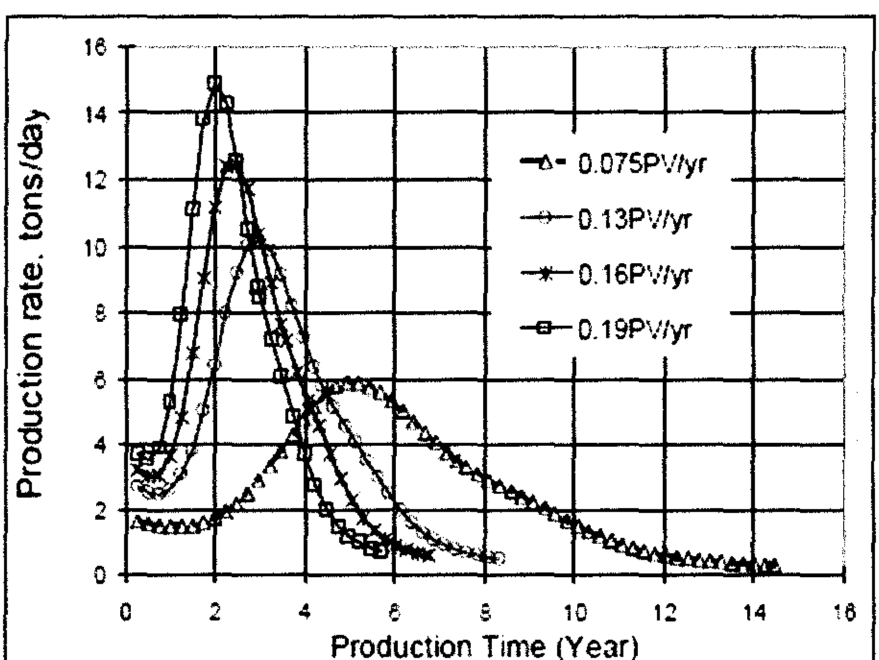

Figure 4: Changes in oil production rate vs. injection rate [13]

3.1.2 Polymer Solution Viscosity

Amount of polymer concentration will correspond to the polymer solution viscosity. Higher polymer concentration will give higher polymer solution viscosity. Polymer solution viscosity factor used in this study are as in table below.

Table 3: Polymer viscosity factor

Polymer Concentration (lb/ft^3)	**Viscosity Factor**
0.0	1.0
70.0	20.0

This polymer viscosity factor can be entered into ECLIPSE under the keyword "PLYVISC" in the "PROPS" section. Polymer viscosity factor used in this study is obtained from ECLIPSE Polymer Injection Tutorial, but the viscosity factor at polymer concentration of 70.0 lb/bbl was slightly changed from 10.0 to 20.0. This is because when the range is small, the resulting viscosity will be much closer to each other. This will not clearly show the effect of polymer solution viscosity on oil recovery. As to get clear results on the effect of polymer solution viscosity on oil recovery, the range had been slightly widened.

3.1.3 Injection Rate

Due to time constraint, polymer injection rate used in this study was the optimum rate. This is achieved by using pressure control mode "THP" in ECLIPSE. The injection rate will be adjusted automatically to maintain average reservoir pressure determined by user and as well as the well bottom-hole pressure. If the injection rate is to be varied, the rate control mode "RATE" should be used instead of pressure control mode "THP" in ECLIPSE. Then the required rate could be entered and the resulting oil recovery can be obtained. Not to forget, the average reservoir pressure and well bottom-hole pressure must be monitored closely, as the pressure is very likely to increase with increment in polymer injection rate.

3.1.4 Simple Model Polymer Injection

A simple model is also used to compare the results to the actual model. The 10×10×1 model obtained from ECLIPSE Polymer Injection Tutorial is used to conduct this study on them. The same polymer solution concentration and the same polymer solution viscosity are used in this model.

3.2 Project Activities

- Reading journals and papers published on the related topics.
- Search and survey the standard uses of polymers' concentration in industries.
- Search and survey the usual type of polymers and their properties/benefits.
- Review and study on the simulator manuals/tutorials.
- Obtain a base case model, generate all the results for base case model and use that as the reference in comparison of results.
- Carry out the experiment (with the use of simulators) to obtain the effectiveness of polymer flooding based on the polymer concentration, types of polymer and injection rate of polymer.
- Discuss on the results obtain with supervisors and senior lecturers/staffs, experts.
- Improve on the experiment (with the use of simulators) to get a better results, or to get a better outcome on the investigation.
- Discuss and organize all of the results in a presentable form to be presented.
- Compile all the methods, results, and discussion into a nicely organized report for future references.

3.3 Gantt Chart

DEPT.	PROJECT ACTIVITIES	WEEK													
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
PETROLEUM ENG	Conducting simulation							MIDTERM BREAK							
	Results Analysis														
	Progress Report														
	Poster Preparation														
	Work on Final Report														
	Technical Paper Writing														
	Oral Presentation Preparation														
	Work on Hardbound Copy														

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Model Description

4.1.1 Angsi Model

In this study, the actual model used is from Angsi Field. This model has a total of 16 wells, 4 wells are water injector wells (B-22A, B-06, B-08 and B-17), 6 wells are oil producer wells (B-02, B-04, B-09, B-14, B-15 and B-10), and 6 wells are initially oil producer wells, after reaching well economic limits, switched to water injector wells (B-01, B-03, B-05, B-07, B-13 and B-E1). The initial reservoir pressure for this model is 2369.7 psia. The stock tank oil initially in place (STOIIP) of this model is 231.14 MMSTB. The investigation period is 25 years.

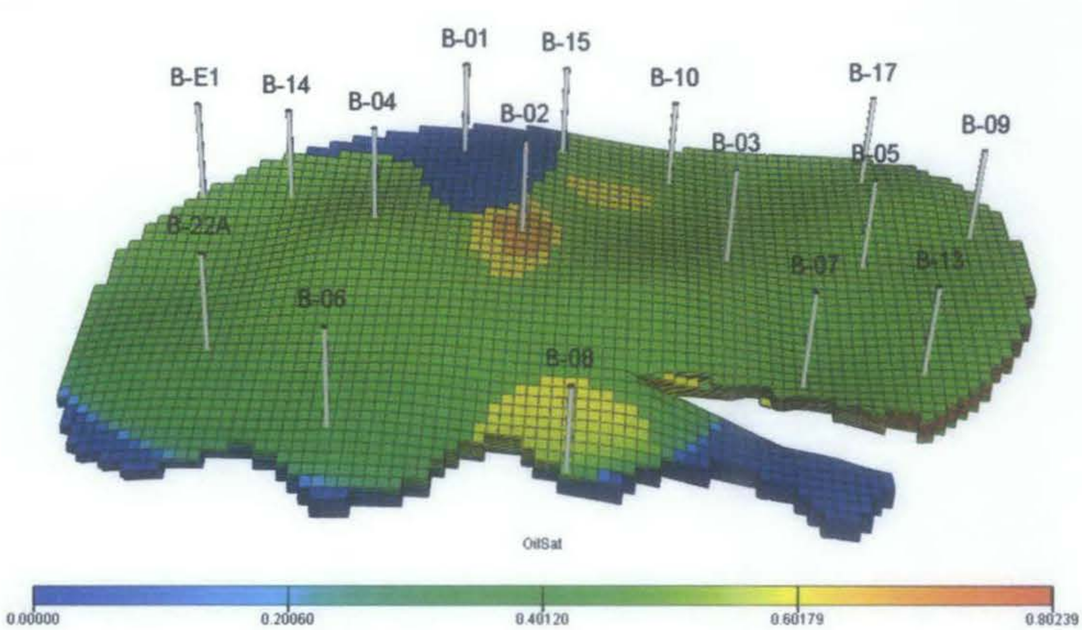

Figure 5: Angsi Field actual model at initial state

4.1.2 Simple Model

As a comparison to the actual model, the simple model was developed based on ECLIPSE Tutorial. The simple model has 1 injector well (I) and 1 producer well (P). The initial reservoir pressure for this simple model is 4005 psia. The stock tank oil initially in place (STOIIP) of this model is 470 472 STB. The period of investigation for this simple model is 1700 days (equivalent to 4.6 years). In this model, polymer was injected for the first 200 days and then injection was continued by using water.

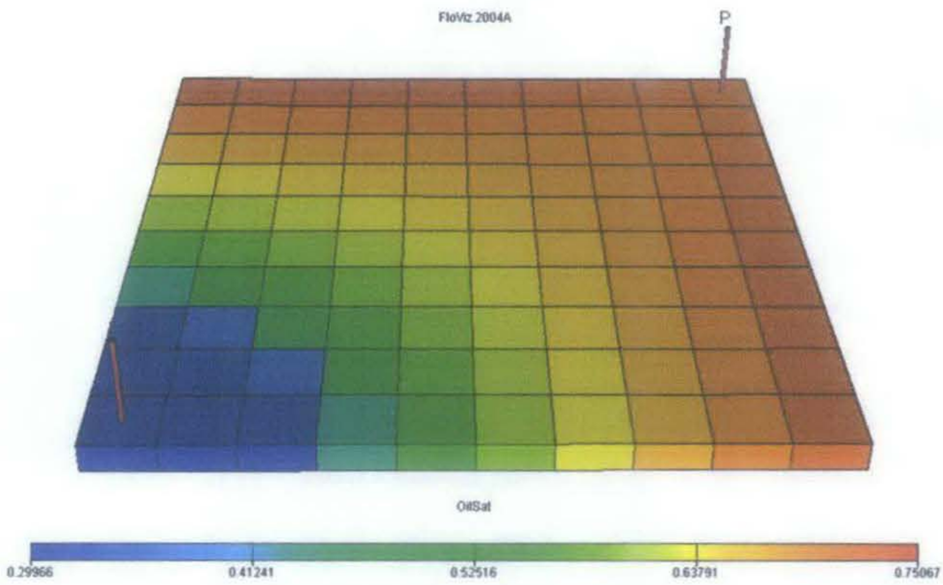

Figure 6: Simple model at day 200

4.2 Polymer Solution Concentration

There are a total of four cases run in this study concerning the polymer solution concentration. For Case 1, polymer concentration is set to 0.0 lb/bbl, which means there is no polymer concentration, only water is injected into the well. For Case 2, the polymer concentration is set to 20 lb/bbl. For Case 3, the polymer concentration is set to 50 lb/bbl, and for Case 4, the polymer concentration is set to 80 lb/bbl. The results for each case are shown in the table below.

Table 4: Results from the simulation concerning polymer solution concentration

Case	Polymer Concentration (lb/bbl)	Total Polymer Injected (10^6 lb)	Total Oil Production (MMSTB)	Recovery (%)
1	0.0	0.0	103.54	44.80
2	20.0	154.16	109.85	47.53
3	50.0	192.70	89.58	38.76
4	80.0	238.39	85.19	36.86

From the results above, it proves that the addition of polymer concentration can give additional recovery up to a certain level, before it decreases. From the results obtained (refer to figure 7 in the next page), it is significant that there is a limit for optimum polymer concentration. If the concentration is too high, polymer flooding will be ineffective. This is due to some reason.

The first reason is as polymer concentration increases, polymer solution viscosity will increase as well. So as polymer solution viscosity increases, it cannot navigate effectively through pores and it takes a longer time to sweep the oil. If the oil moving to producer well is faster than polymer moving from injection well, this will make polymer flooding not efficient.

The second reason is as polymer concentration increases, it will create higher well bottom-hole pressure that will restrict polymer injection rate. So to counter that problem, for each of these cases, polymer injection rate is different as to make sure well bottom-hole pressure does not exceed the reservoir fracture pressure (refer to figure 8 in the next page). Hence the average reservoir pressure cannot be well maintained when injecting with higher polymer concentration solution. This too will lead to unsuccessful polymer flooding.

4.2.1 Results from Angsi Model

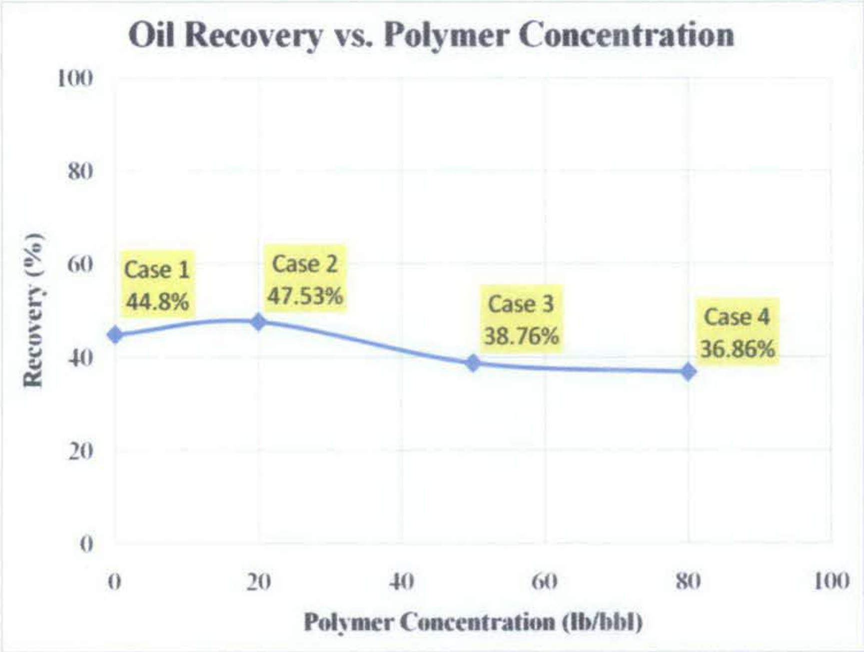

Figure 7: The effect of polymer concentration on oil recovery in actual model

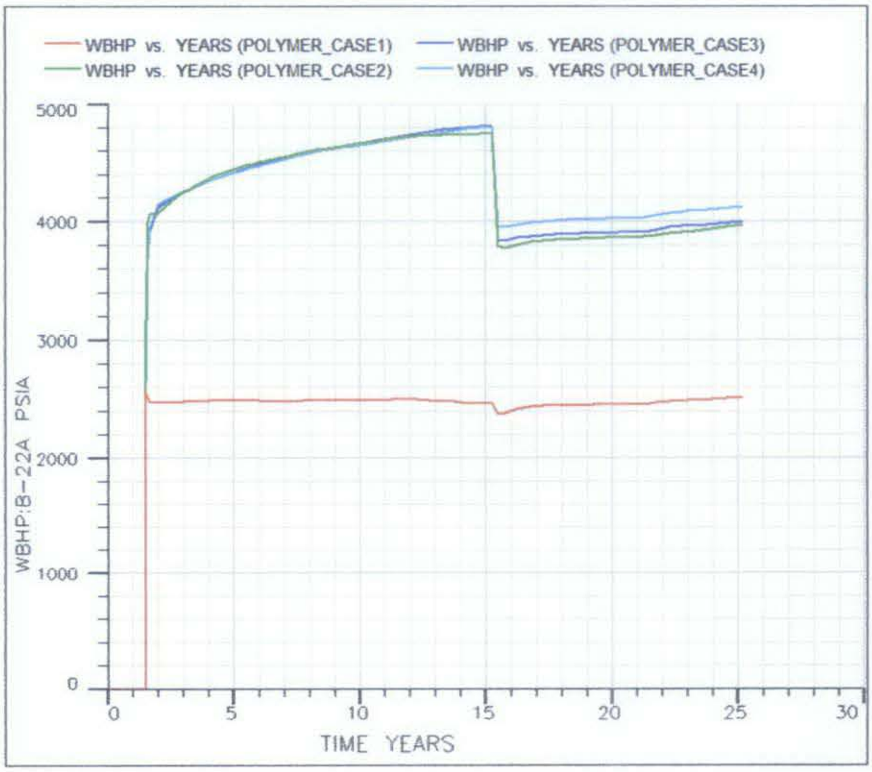

Figure 8: Maintained well bottom-hole pressure for Well B-22A in actual model by controlling the injection rate at each case

4.2.2 Results from Simple Model

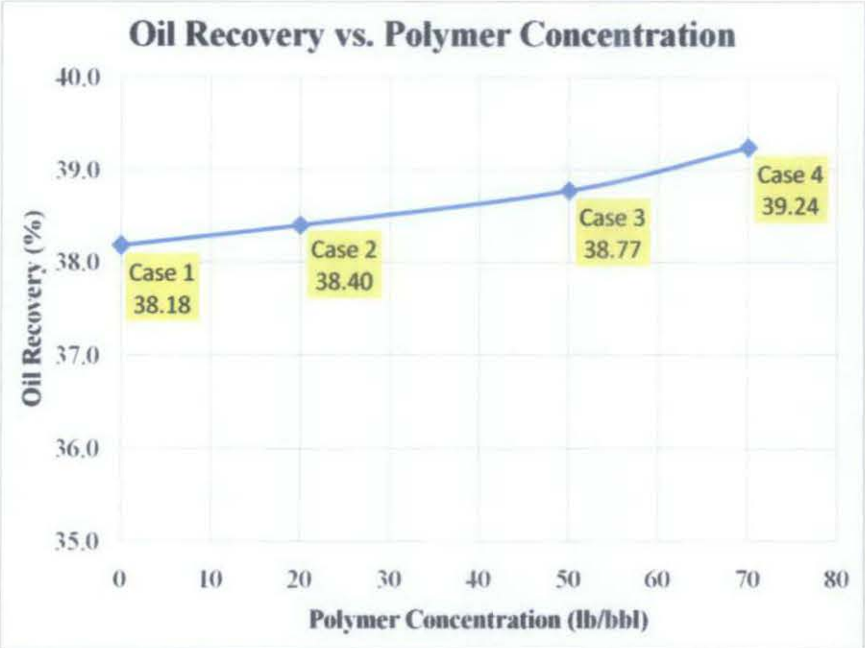

Figure 9: The effect of polymer concentration on oil recovery in simple model

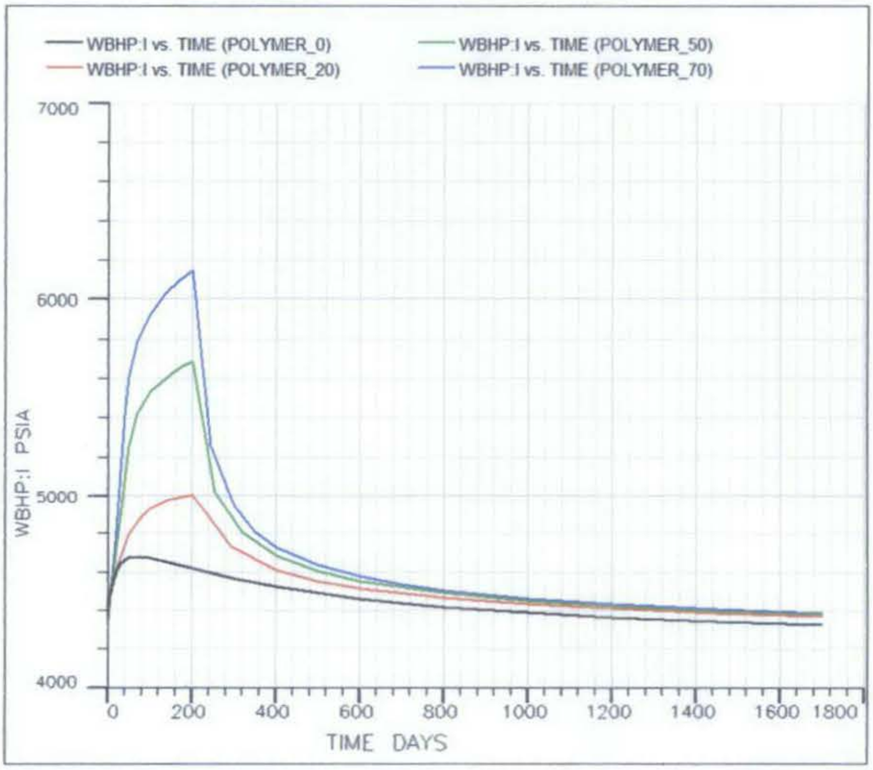

Figure 10: Well bottom-hole pressure for injector well in simple model by using the same injection rate at each case

The results from the simple model give the same attribute or trend. As the polymer solution concentration increases, the oil recovery increases. But in this simple model, there is no decrease in the oil recovery although the polymer concentration of 70.0 lb/bbl is used (refer to figure 9 in the previous page). This is may be due to the constant injection rate used in this simple model (rate control mode).

However, the well bottom-hole pressure showing an increasing trend as the polymer solution concentration increased (refer figure 10 in the next page). This agrees with the results in the actual field, which gives a lower oil recovery when polymer concentration higher than the optimum concentration is used. Restriction in the injection rate due to the well bottom-hole pressure in the actual field causes the injection rate to be lowered as the concentration increase. This is why the pressure maintenance when using higher polymer solution concentration is not good hence the lower oil recovery percentage.

4.3 Polymer Solution Viscosity

Due to time constraint, there is only one set of polymer viscosity is used in this study. This polymer viscosity factor is taken from ECLIPSE Tutorial and the viscosity factor at a concentration of 70 lb/bbl has been slightly changed from 10.0 to 20.0. This is to see the effect of polymer solution viscosity on oil recovery more clearly, as very close polymer viscosity factor will not give a clear result.

From the actual model, it shows that increment in polymer solution viscosity (increment in polymer solution concentration) increases the oil recovery, but when it exceeds its optimum point, oil recovery decreases (refer to figure 7). However, changes in polymer solution viscosity doesn't affect much on the total oil production, whereas changes in polymer solution viscosity will greatly affect the well bottom-hole pressure, as the higher viscosity solution needs more energy to move. In order to supply more energy for high viscosity solution to move, higher injection rate must be applied, and this will result in rapid increment of the well bottom-hole pressure.

4.3.1 Results from Simple Model

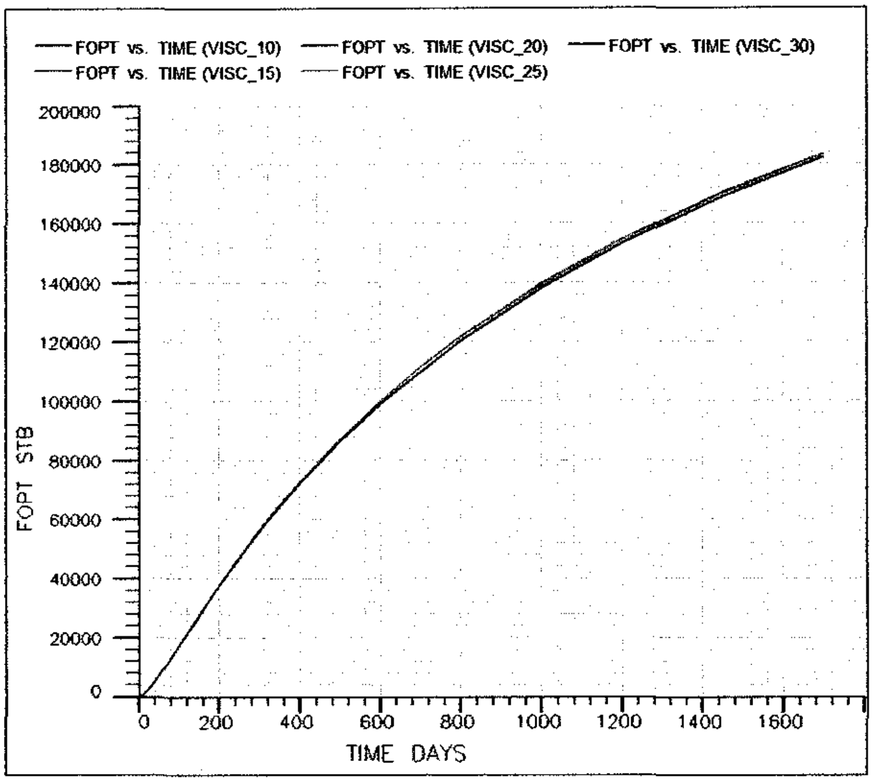

Figure 11: Cumulative oil production by using different polymer viscosity factors

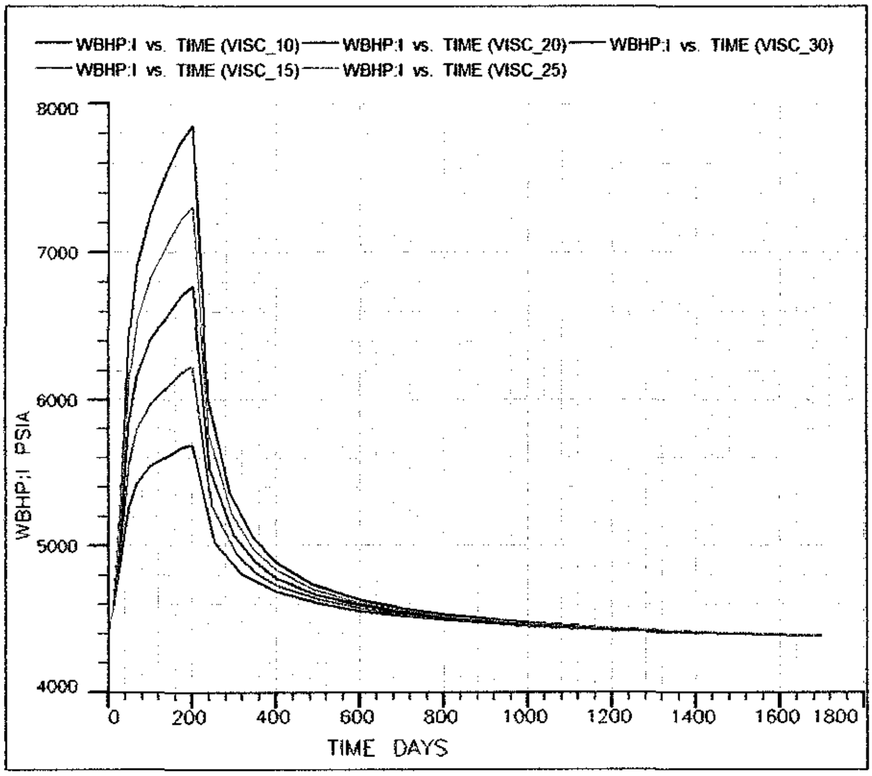

Figure 12: Well bottom-hole pressure for simple model using various viscosity factors

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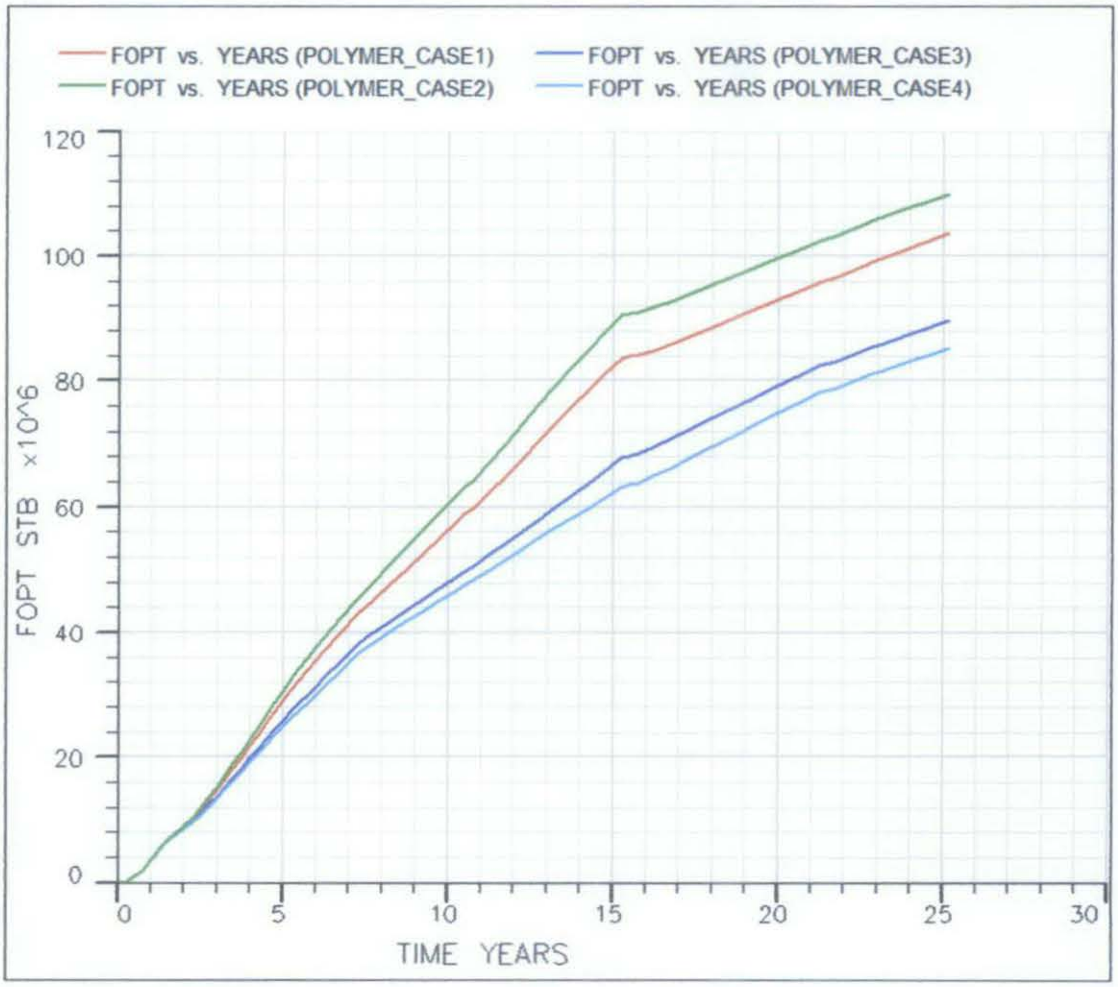
APPENDICES

Appendix 1

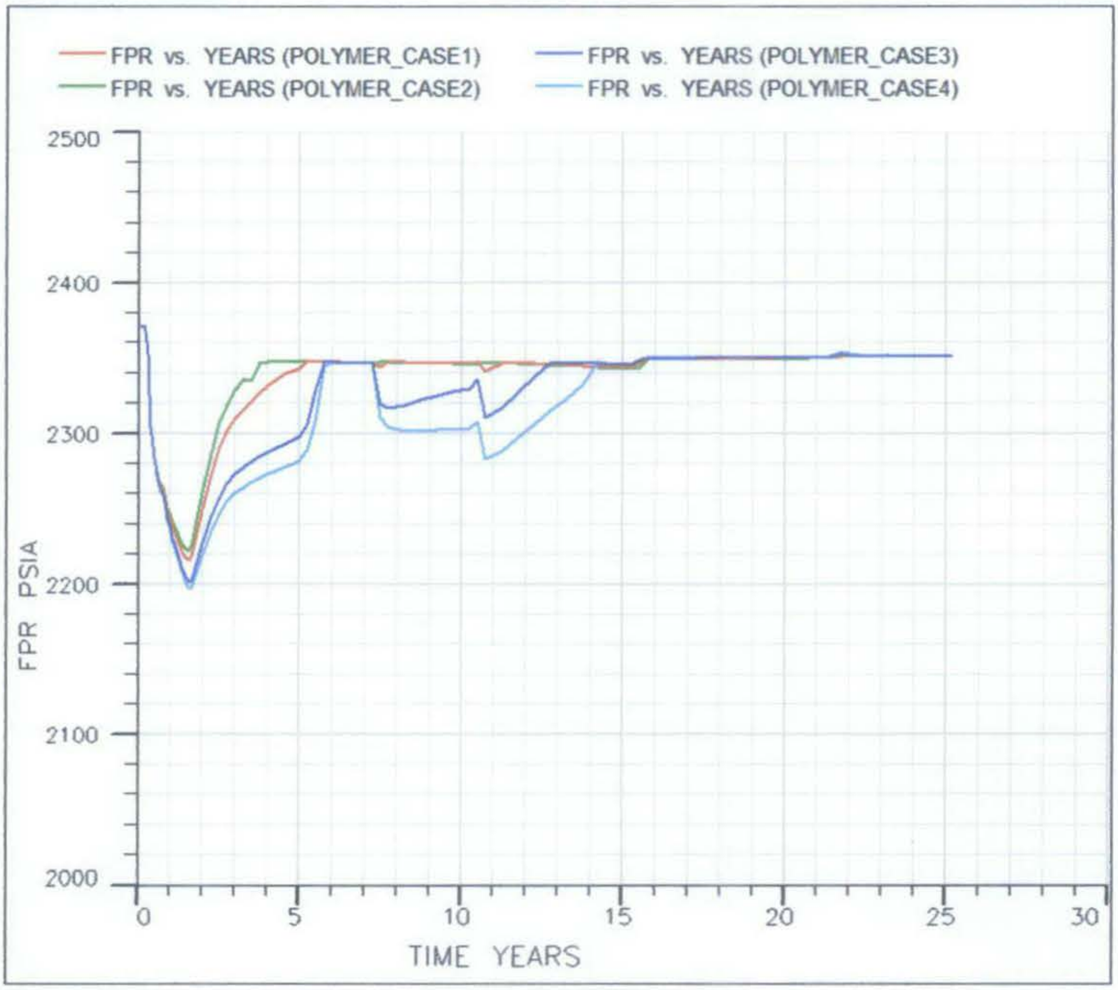
Cumulative oil production for Angsi Field



Case	Polymer Concentration (lb/bbl)	Cumulative Oil Production (MMSTB)
1	0.0	103.54
2	20.0	109.85
3	50.0	89.58
4	80.0	85.19

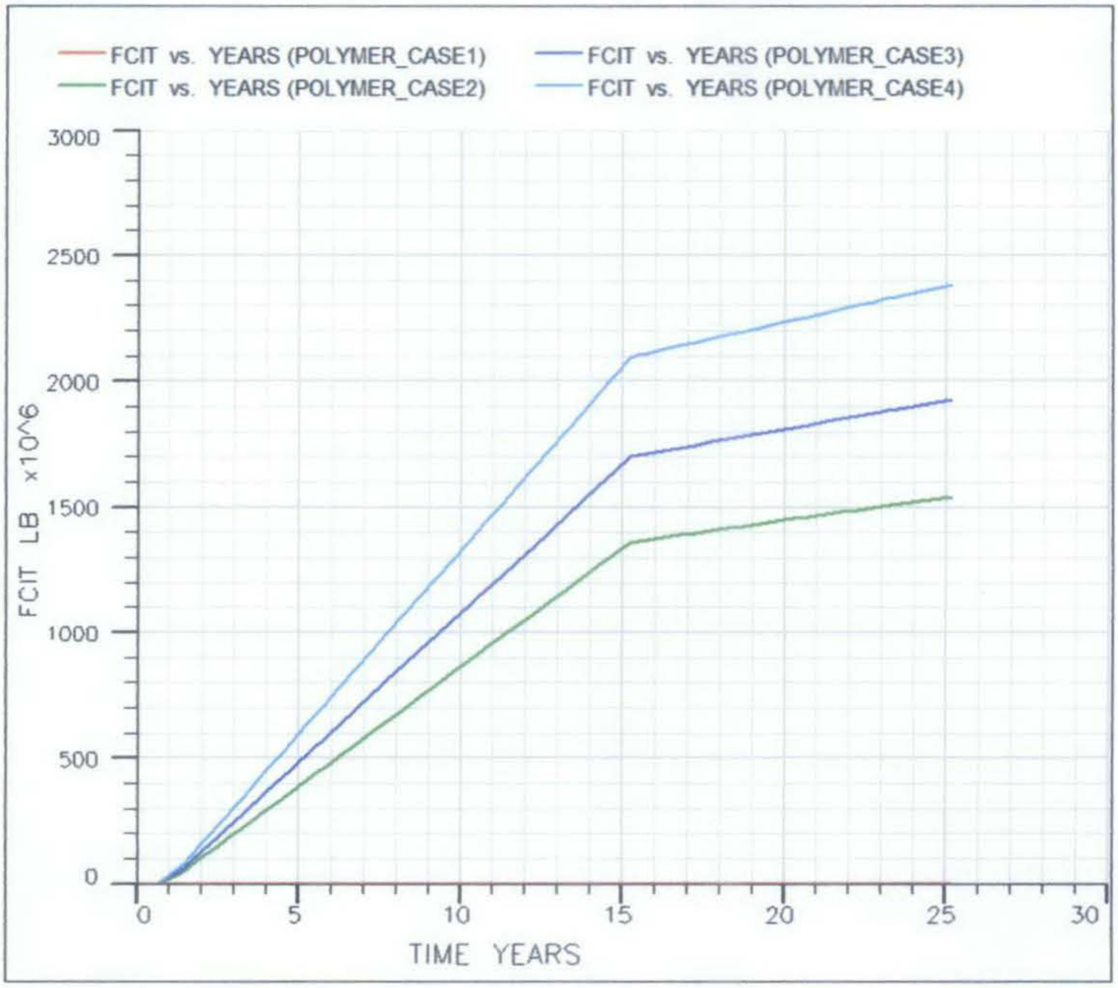
Appendix 2

Average Reservoir Pressure for Angsi Field



Appendix 3

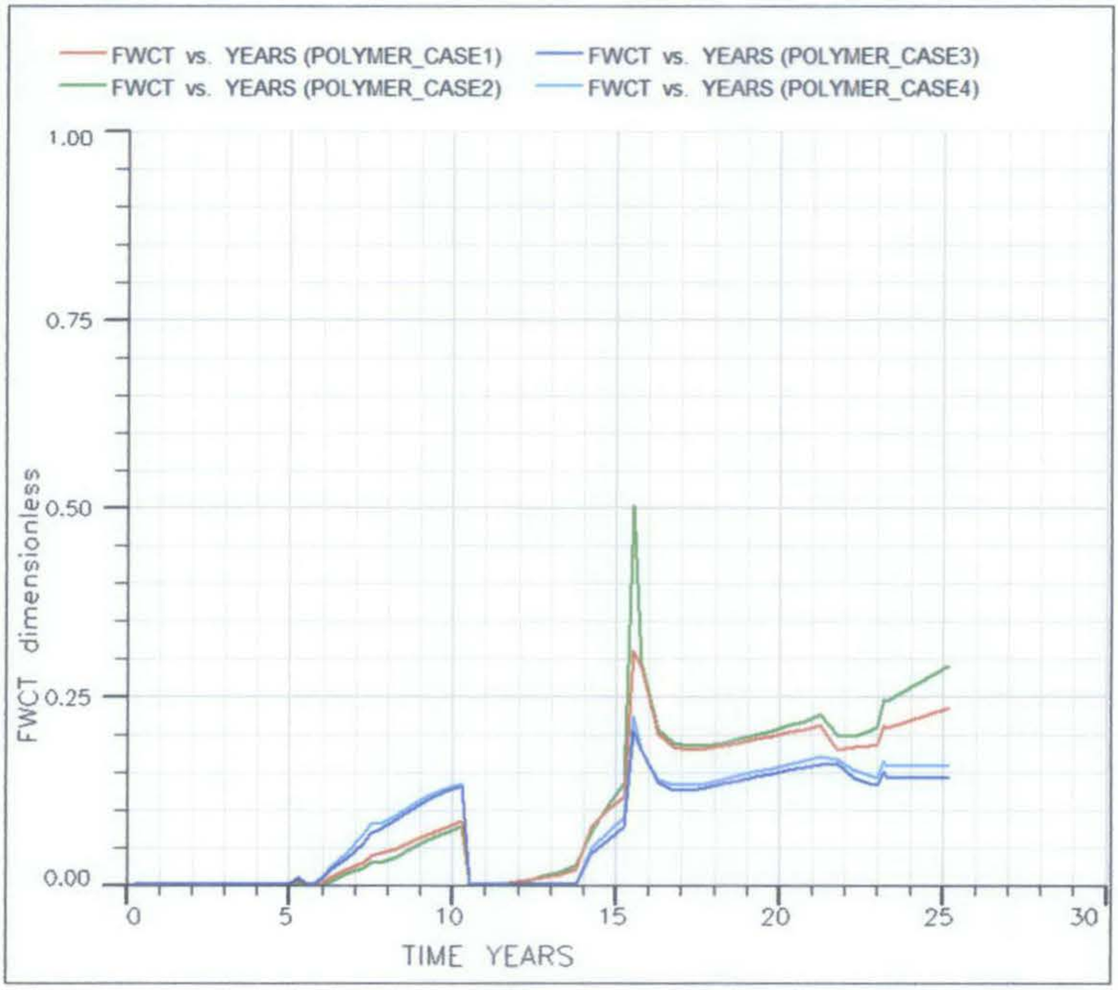
Total Polymer Injection for Angsi Field



Case	Polymer Concentration (lb/bbl)	Total Polymer Injected (10^6 lb)
1	0.0	0.0
2	20.0	154.16
3	50.0	192.70
4	80.0	238.39

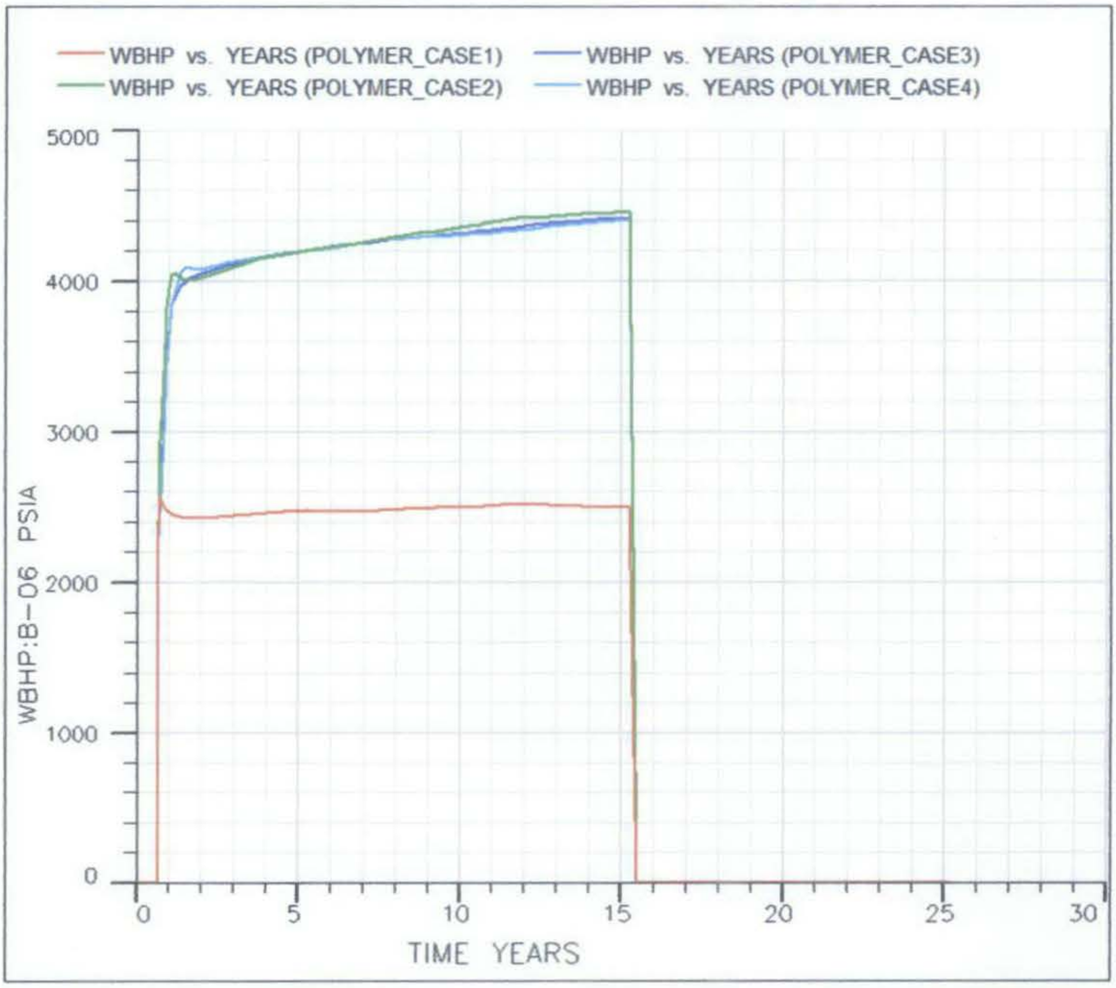
Appendix 4

Field Water Cut for Angsi Field



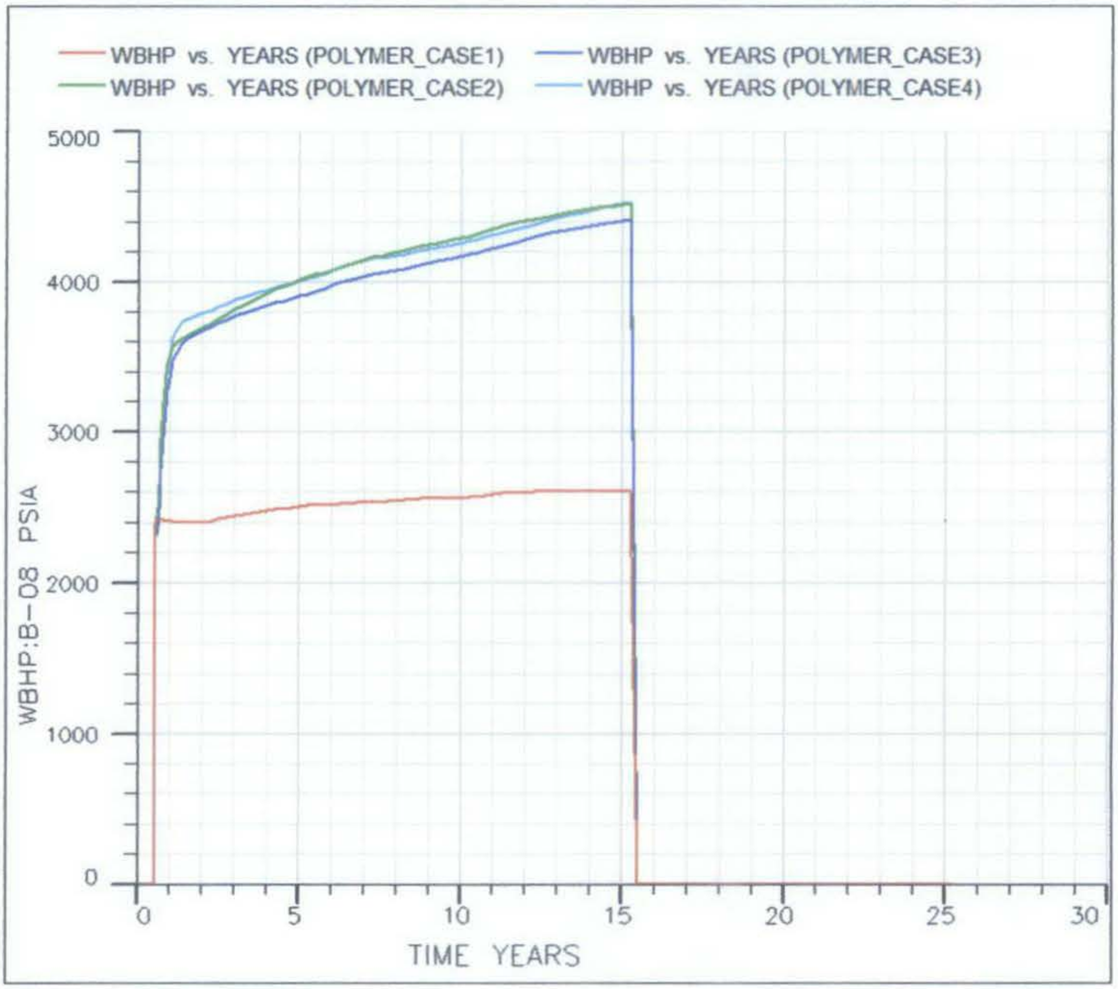
Appendix 5

Well Bottom-Hole Pressure for Well B-06 in Angsi Field



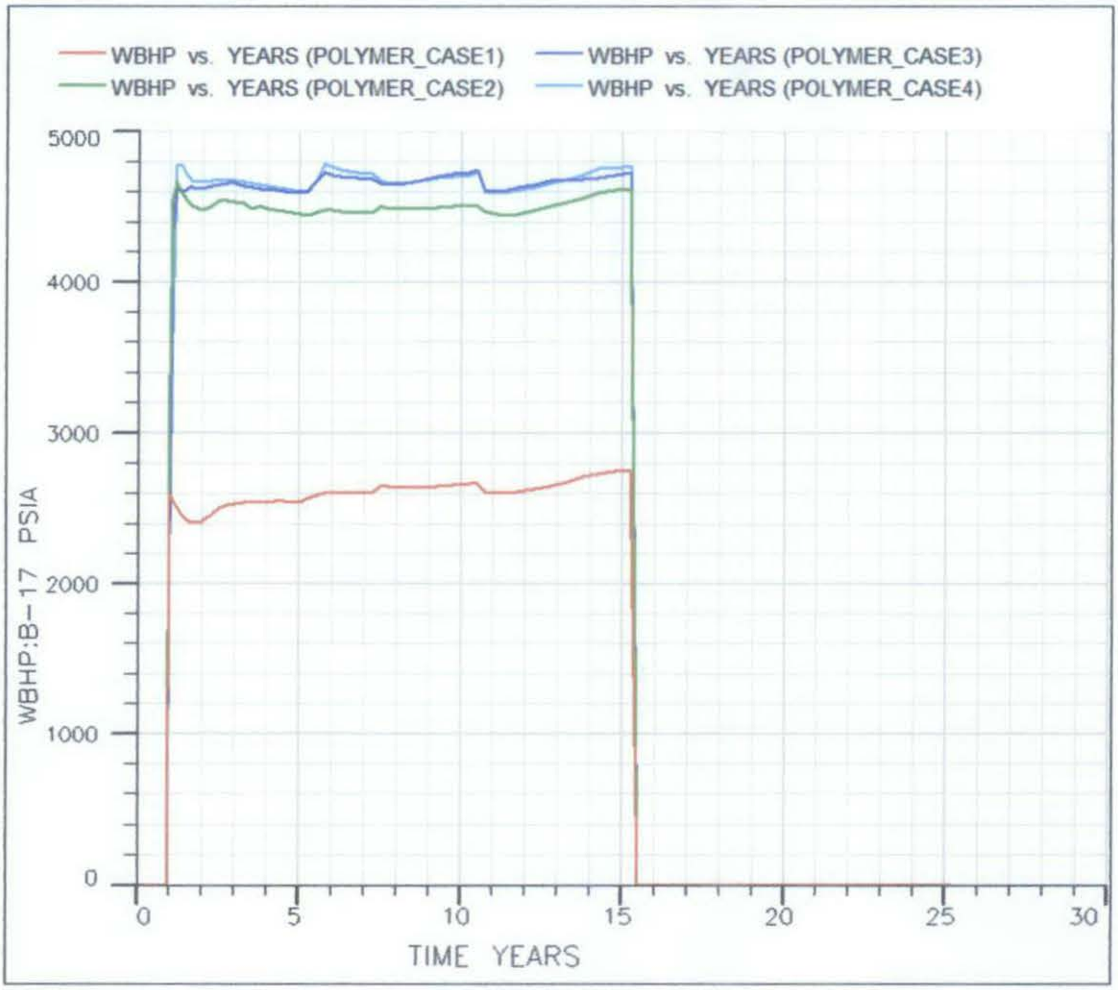
Appendix 6

Well Bottom-Hole Pressure for Well B-08 in Angsi Field



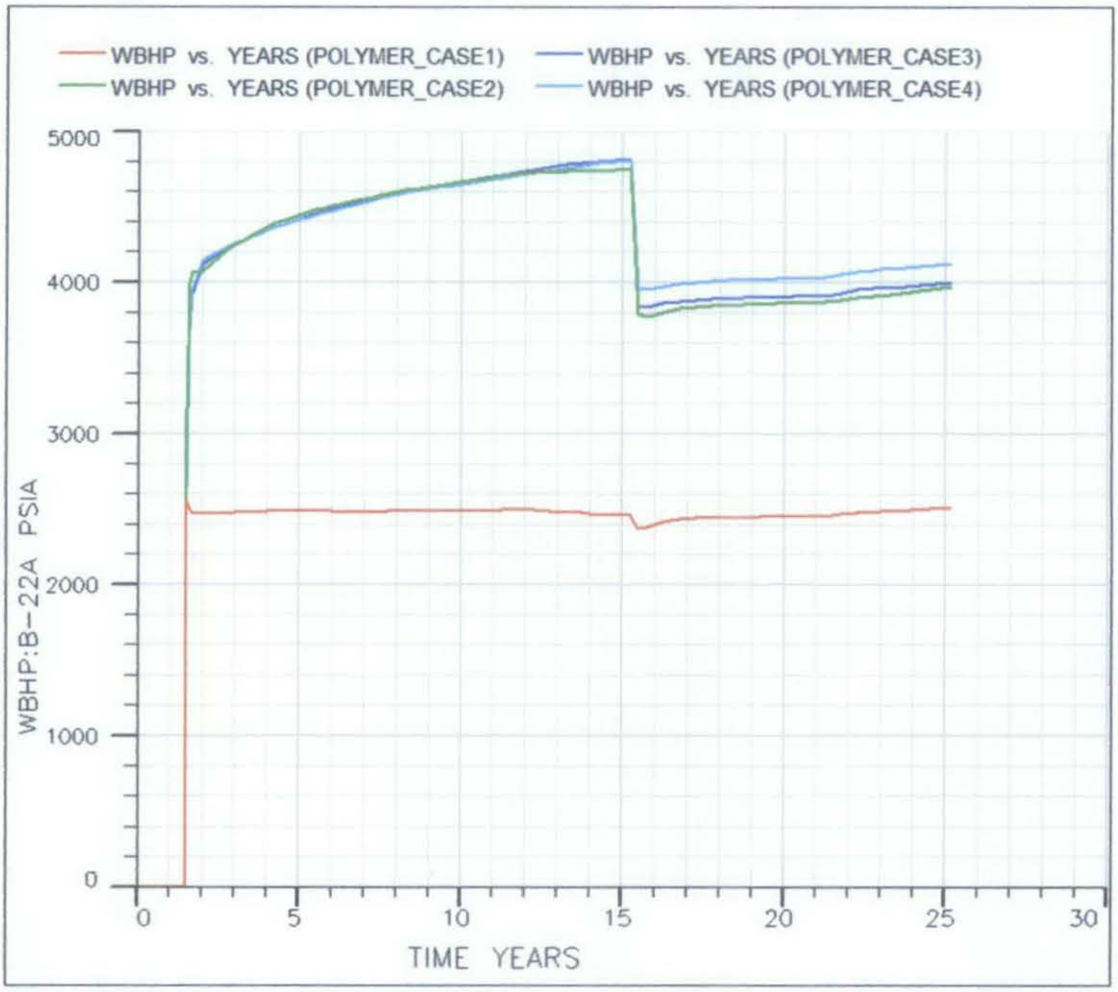
Appendix 7

Well Bottom-Hole Pressure for Well B-17 in Angsi Field



Appendix 8

Well Bottom-Hole Pressure for Well B-22A in Angsi Field



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'B*' 'WATER' 'SHUT' 'THP' 2* 3900 1500 1
1* /
/

GPMAINT
'PROD' 'PROD' 2 1* 2350 500 20 /
/

GPMAINT
'INJGP' 'WINJ' 2 1* 2350 500 20 /
/

GPMAINT
'INJ' 'WINS' 2 1* 5000 500 20 /
/

WLIFT
'B*' 1* 'OIL' 3* 0.1 4* /
/

WECON
'B*' 5* 'WELL' 'NO' 1* 'RATE' 1* 'NONE' 2*
/
/

GECON
'FIELD' 5* 'WELL' 'NO' 1* /
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DATES
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DATES
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'NONE' 2* /
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WCONPROD
'B-02' 'OPEN' 'BHP' 5* 2000.0 /
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WECON
'B-04' 2* 0.8 2* 'WELL' 'NO' 1* 'RATE' 1*
'NONE' 2* /
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WCONPROD
'B-04' 'OPEN' 'BHP' 5* 2000.0 /
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WCONPROD
'B-03' 'OPEN' 'BHP' 5* 2000.0 /
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DATES
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WCONPROD
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DATES
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WCONPROD
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DATES
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DATES
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DATES
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WCONINJE
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WCONPROD
'B-07' 'SHUT' 'BHP' 5* 2000.0 /
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WCONPROD
'B-09' 'OPEN' 'BHP' 5* 2000.0 /
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DATES
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DATES
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WCONPROD
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WCONINJE
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'B-14' 'OPEN' 'BHP' 5* 2000.0 /
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WCONINJE
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1500 1 1* /
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'B-13' 'WATER' 'SHUT' 'THP' 2* 5000 1500 1
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