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Evaluation of Different Wag Optimization and Secondary Recovery Techniques in a Stratified Reservoir

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Abstract

It is a general knowledge that considerable amount of oil is often left in a hydrocarbon reservoir after depletion of the primary energy. Therefore the need to develop an oil field is required through suitable recovery techniques such as water flooding, miscible gas injection and miscible WAG injection which are targeted towards recovering a considerable portion of the remaining oil. The world being an uncertain environment with an increasingly day to day demand for energy and uncertainty as to where the next oil field can be discovered are looking for means to maximally optimize the production of hydrocarbon from new and producing wells in the quickest possible time, ensuring pressure is maintained. The WAG injection scheme is varied with various WAG ratios. In this study, ultimate recovery was optimized using different WAG ratios which were compared with two secondary injection schemes, water injection and gas injection. The eclipse simulator was used to build a dynamic model where different development options, predictions and analysis was done on the reservoir model.

The evaluation of different schemes was considered to determine the highest ultimate recovery. Factors such as recovery factor, and field water cut were also analyzed to come up with an optimum recovery. From the results obtained, water flooding gave the highest ultimate recovery of 144 million barrels of oil though the FWCT was on the high side, while the MWAG (2:1) was second in ranking had an ultimate recovery of 120 million barrels of oil. Water flooding seems to be the best method to use amongst the five selected cases for the purpose of continual production by operators of field XYZ because it yielded the largest ultimate recovery.

From the results obtained, water flooding proves to be the most economical of all selected five cases discussed.

INTRODUCTION

THE NEED FOR RECOVERY MECHANISMS

Zeron (2012), with the advancement of technology worldwide, petroleum has become the largest source of non-renewable energy generation for the purpose of developing industrialized countries and the world at large. The demand for energy is developing radically which requires the provision and creation of efficient methods for tertiary recovery of the residual hydrocarbon after secondary recovery becomes uneconomical. These methods of recovery are done to ensure the maximum possible value of recovery of hydrocarbon before it reaches the stage of reservoir abandonment.

It is a general knowledge that considerable amount of oil is often left in a hydrocarbon reservoir after depletion of the primary energy. Therefore the need to develop an oil field is required through suitable recovery techniques such as water flooding, miscible gas injection and miscible WAG injection which are targeted towards recovering a considerable portion of the remaining oil. The world being an uncertain environment with an increasingly day to day demand for energy and uncertainty as to where the next oil field can be discovered are looking for means to maximally optimize the production of hydrocarbon from new and producing wells in the quickest possible time, ensuring pressure is maintained.

From definition, optimization is regarded as the act of obtaining the best achievable outcome under a specified circumstances or situation. The term 'optimum' means minimum and maximum. This research work seeks to achieve the maximum possible recovery attainable from a reservoir which is to be explored using 3 various recovery techniques.

OIL RECOVERY TECHNIQUE

Speight (2009), Oil recovery process is divided into 3 phases of its lifespan. They are primary recovery, secondary recovery, and tertiary recovery. The Primary recovery process usually occurs during the early life stages of the reservoir when the natural pressure of the reservoir is sufficient to flow the fluids from the reservoir to the surface. Primary recovery process is very responsive to the reservoir properties. The intermediate phase of oil recovery process is the Secondary recovery process and it involves the injection of water to displace or push the oil to the surface. Today, the EOR technique has become a supplementary method for raising crude oil to the surface through various methods by effectually making the primary and secondary methods assisted after the former two processes have become uneconomical for production. The enhanced oil recovery method which can be otherwise referred to as the supplementary methods can help to increase the recovery of crude oil. This can only be done at an additional cost which is to be incurred by the operators of a particular field. In most cases, the EOR method usually has a target of nearly 2/3 of the Initial oil in place which is about 66.7 percent. The residual oil after primary and secondary recovery processes becomes uneconomical is always the motivating factor for companies to commence on an EOR project. There are 3 main groups of the EOR process. They include the thermal process, the miscible gas injection process and the chemical process.

This research paper focuses on a comparative approach of ultimate recovery using various recovery techniques. To optimize NPV, this study seek to provide various strategies to Optimize sweep efficiency of the injector and producer wells using the results from analysis of miscible WAG, water flooding and miscible gas injection. The results will be compared to check the various effects they have on the outcome of production. Most often, water is a good choice of injectant because they help in providing pressure maintenance through the replacement of the produced fluid. They also provide assistance to pushing out the oil into the producers. When considering under ride of oil by water in most reservoirs, it is necessary to consider the fact that Water is heavier than oil. Gravity is usually responsible for the under ride of water by oil. Some other factors such as reservoir heterogeneity, well spacing and thickness of the reservoir can also be causes to how intense or marginal this under ride can be when considering the density of water to oil.

Gas flooding is the other secondary flooding that is to be used in this research work. This can either be miscible or immiscible. Emphasis on this research is centred on using a miscible gas. When considering miscible gas injection, the depth and pressure of the reservoir are variables in which gas flooding depends on. Miscibility occurs when two phase fluids forms a single fluid phase. To attain miscibility is always difficult in real gases. Ideally, when there is an increase in gas mobility the resultant is usually an increased injectivity and this often results in the wells becoming rate-limited. Scenarios where decline in injectivity occurs often results to a drastic reduced reservoir pressure during production. Gas tends to override the oil in the reservoir because they have a lower density and this may result in a significant volume of the reservoir to be left unswept thereby leading to early breakthrough. Early breakthrough is a situation in which the reservoir starts producing water at a very immature stage. This can be ensuring the injection cycles are done properly. Miscible gas flooding helps to reduce the interfacial tension between oil and water. During an immiscible flood heterogeneities cause worse fingering and bypassing of oil than water. This problem gets worse as the mobility ratio becomes larger. Worse fingering and bypassing of oil are problems that occur from immiscible flood heterogeneity.

Incorporating the use of water and gas is named Water Alternating Gas or WAG. This process can be described as "An enhanced oil recovery method whereby water and gas are injected in alternating cycles for time duration so as to provide better sweep efficiency. The benefits of water injection and gas injection are usually combined in a WAG process. Typically, a protracted water flood and gas flood is executed until the field is no longer economical for production. This process involves alternating slugs of gas and water into the reservoir with an injection period having phases that tends to extend for about one to six months.

WAG injection engages drainage and imbibition occurring simultaneously in the reservoir (Nezhad S, 2006). Due to mixture of mass transfer, drainage and imbibition cycles, the residual oil saturation becomes typically lower than in water flooding which is also like gas flooding. The concept behind this process known as "WAG" is a blend of two secondary recovery processes of water flooding and gas injection. This process was targeted for an ideal or perfect system such that microscopic and macroscopic sweep efficiency are perfected concurrently. A scenario where the reservoir is being flooded with water, oil droplets will be trapped inside the pore spaces of the water flooded region.

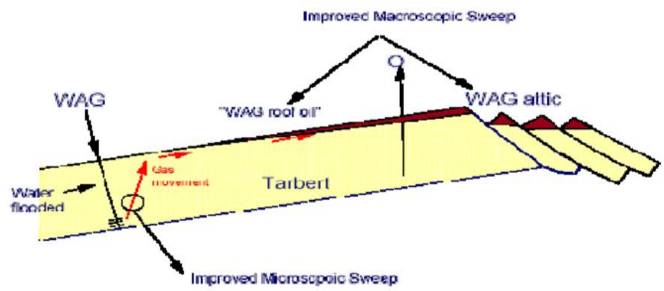

Figure 1: WAG process (accessibility of WAG to difficult to reach oil) (Esmaiel, 2005).

There are numerous publications on the use of slug as secondary recovery technique to reduce residual oil saturation, where effective macroscopic and microscopic sweep efficiencies is of interest as shown in fig.1. Stenby et al, (2001) reported the first WAG injection that was carried out in the North Pembina oil field in Alberta, Canada in 1957. 59 WAG field cases both miscible and immiscible were reviewed, an increased oil recovery of 5% to 10% was recorded from majority of the 59 fields investigated but oil recovery increase of 20% was recorded in some other fields. Esmaiel (2005) carried out an initial screening of various properties of the reservoir to attain sensitivity of the Net present value to the WAG process using a proxy model developed. His work involves the use of reservoir simulation model for computation of oil recovery done at duration of 5years and 10years. This was done mainly to increase the ultimate recovery of the flood pattern. The output from his base model before optimization was carried out gave an average recovery of 15.5% having a standard deviation rating of 1.25% for time duration of 10years.

METHODOLOGY

This paper throws light on the art of producing research methodology ranging from the gathering of data to the implementation of software approach. A major tool to be used in this project is the schlumberger eclipse simulator. This research seeks to compare three various injection schemes to account for which method produces a better recovery. Sensitivity analysis will also be done using the simulator by increasing and decreasing certain parameters to yield a good ultimate recovery. The WAG injection scheme is varied with various WAG ratios. This is then compared with two secondary injection schemes water injection and gas injection to account for which method gives a better recovery. The eclipse simulator will be used to build a dynamic model where predictions and analysis will be done on the reservoir models. The models are imported using the Floviz in the eclipse prior to building of the reservoir model. The research methodology is as shown in fig. 2

WELL MODELLING

The well modeled for the mechanisms to be compared are built using a dynamic reservoir model. The numerical simulation is built using the eclipse 300. The reservoir built comprises of 2injectors and 2 producer wells. The location and no of injectors and producer wells play a great role as to how the oil can be recovered from the reservoir pores. This factors can either increase of reduce the total amount of oil recovered from the reservoir pores when comparing various schemes. It consists of a coarse to upper medium sandstone characterized by non-inclined strata or trough sedimentary structure. The well penetrates the 7 layers of the reservoir.

The injector rate used for simulation are shown below

WCONINJE

I1 GAS OPEN RATE 2000
I2 GAS OPEN RATE 2000

WELTARG

I1 WRATE 2000
I2 WRATE 2000

Where WCONINJ and WELTARG are commands in the eclipse simulator to assign injector rates to water and gas during a WAG cycle.

Building the model entails looking at the type/dimension of the grid blocks from the X, Y and Z direction. Pressure-volume-temperature, viscosity, formation volume factor, relative permeability of water, relative permeability of oil, compressibility factor of the rock, fluid density, oil water contact depth, datum depth, datum pressure, gas oil contact depth and gas oil saturation function data are all provided to build the reservoir model. Water injection or gas injections were performed using the same reservoir parameters for comparison. This simulation is done by employing the schlumberger eclipse simulator to test result derived. The recovery of the oil versus time is plotted on a graph for a better understanding of the oil recovery trend.

Data required in building the model includes a reservoir discretized into a 15 by 15 by 7 in the XYZ direction respectively.

Basically 5 cases are to be considered in this study. These five cases includes the following outlined below

CASE 1: Miscible WAG injection scheme using ratio 1 to 1.

CASE 2: Miscible WAG injection scheme using ratios 2 to 1.

CASE 3: Miscible WAG injection scheme using ratios 1 to 2

CASE 4: Miscible gas injection scheme.

CASE 5: Water flooding injection scheme.

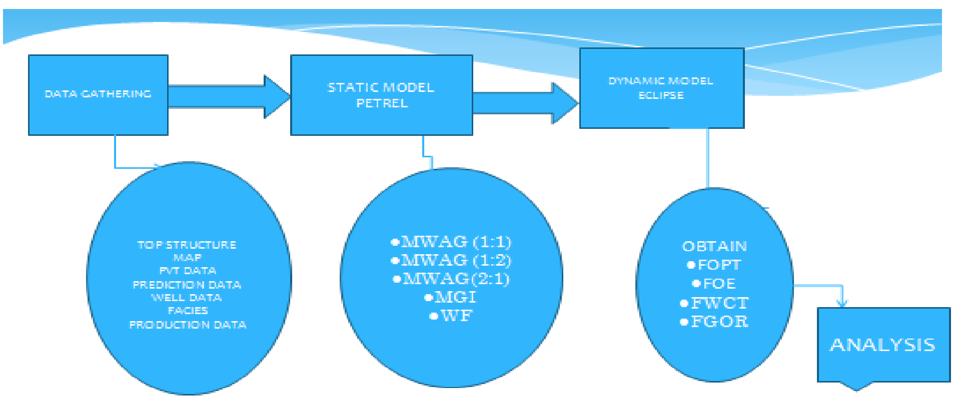

Figure 2: Research Workflow/Methodology

RESULT AND DISCUSSION

The results are tabulated and analyzed in this study. The tabulated values from the simulations done are provided in the later part of this research. The results obtained from the simulation are the Recovery factors, the Ultimate recovery, Field water cut and the Field gas-oil ratio from various injection schemes.

ANALYSIS OF MISCIBLE WATER ALTERNATING GAS SCHEME RATIO (1:1)

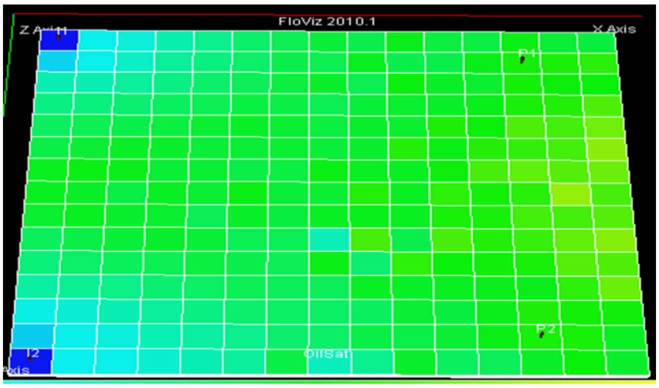

Figure 3: Showing grid after simulation during WAG (1:1)

CASE 1 ANALYSIS:

The simulation done was subject to WAG (1:1) scheme; water and gas were injected through two injector wells as presented in the model from fig. 3. Water and gas were alternated throughout the entire simulation process in an equal 1 to 1 ratio. The injection of water took place for 100days and alternated with gas for the next 100 days. This cycle was repeated throughout the entire simulation process. Various plots were generated and analysis of each plot is discussed extensively.

Field oil efficiency versus time after the reservoir was subjected to MWAG (1:1) yielded a recovery factor of 0.37 after production occurred for 77 years from fig. 4. 33years of simulation using the MWAG mechanism yielded an insignificant recovery as the project life span remained actively productive for only 77years. The ultimate recovery from this injection scheme yielded about 101million barrels of recovered hydrocarbons after 77years. This analysis is derived from the plots of FOE and FOPT against time. The simulation process using MWAG yielded an ultimate recovery of 112 million barrels of oil after 110years

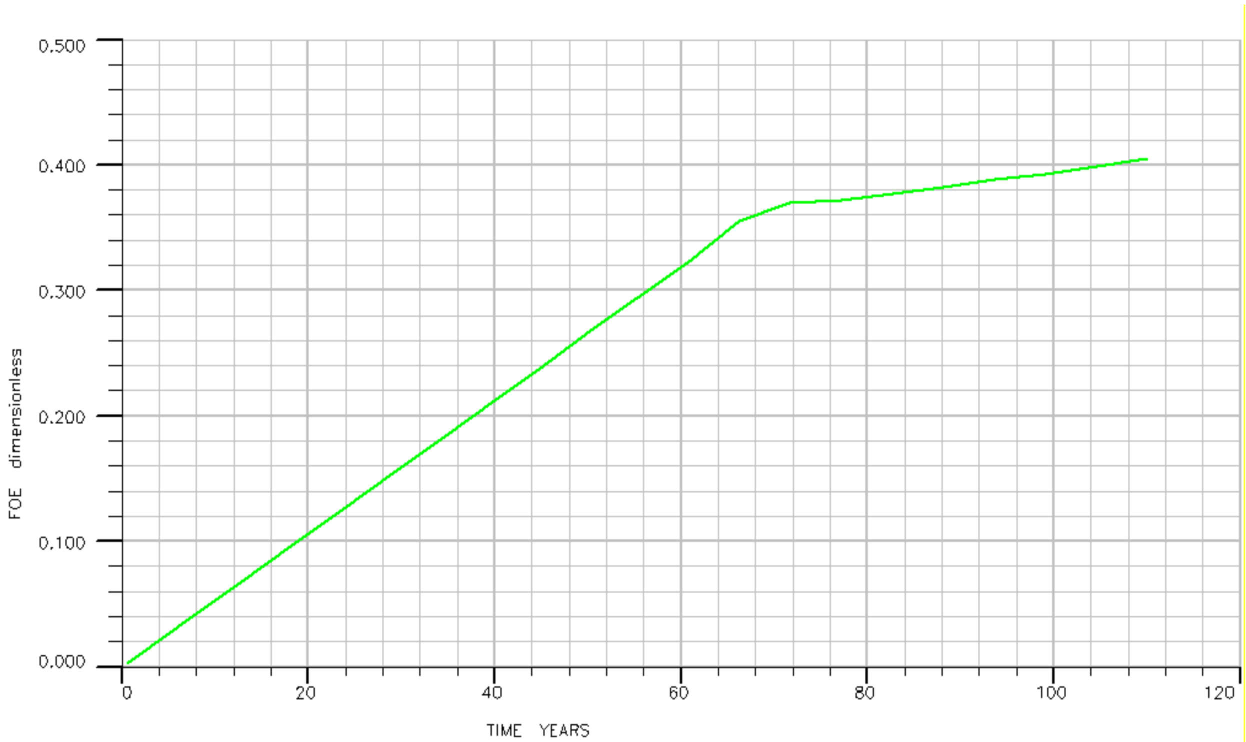

Figure 4: Plot of FOE vs. time

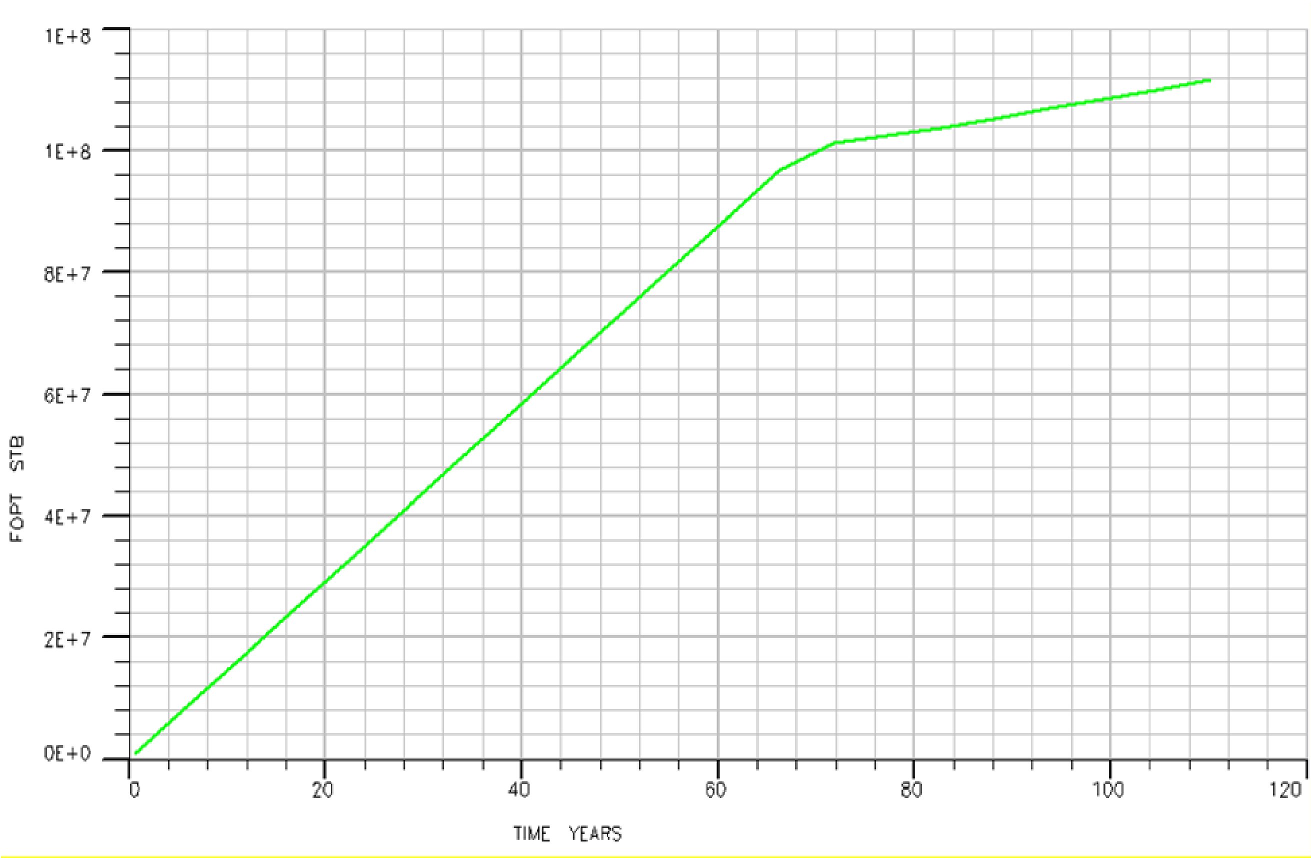

Figure 5: Plot of FOPT vs TIME

Field oil efficiency versus time using water alternating gas (1:1) gave a productive recovery factor of 0.405 over a period of 110years with an ultimate recovery of 112million barrels of oil recovered from fig. 5. The project showed active productivity up until 93 years of production, thereafter the recovery became insignificant. 93 years of production yielded a recovery factor of 0.5 with an ultimate recovery of 136.8 million barrels of oil recovery over 93 years.

ANALYSIS OF MISCIBLE WATER ALTERNATING GAS SCHEME RATIO 2:1

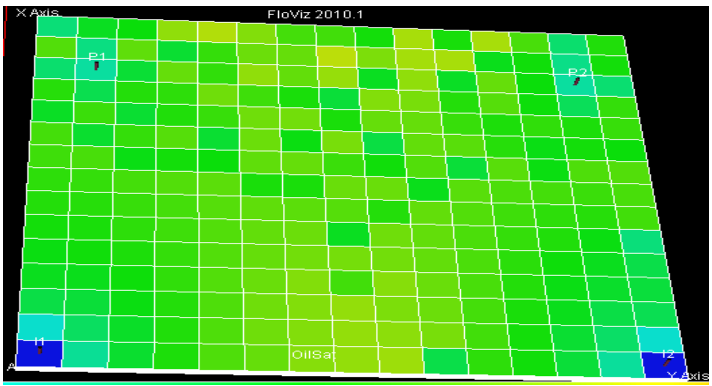

Figure 6: Showing model after simulation for MWAG (2:1)

CASE 2 ANALYSIS:

The simulation done was subject to miscible gas injection with a ratio of 2:1. Miscible WAG injection scheme (2:1) was investigated; water was injected through two injector wells for 200 days and alternated with gas which is injected for 100 days as presented in the model from fig. 6. The production rate was set at 2000 barrels per day for each producer well.

Field oil efficiency versus time using water alternating gas gave a recovery factor of 0.439 over a period of 110years with an ultimate recovery of 120.5million barrels of oil recovered from fig. 7. The scheme showed active productivity up until the 77th year of production thereafter the recovery mechanism became insignificant. Production span for 77years yielded a recovery factor of 0.407 with an ultimate recovery of 111.4 million barrels of oil recovery over 77 years. This mechanism showed that it was advisable to foster production at the 77th year because the remaining 33 years lead to an insignificant recovery. This is due to the marginal extra 9.1million barrels that was produced during the remaining 33 years

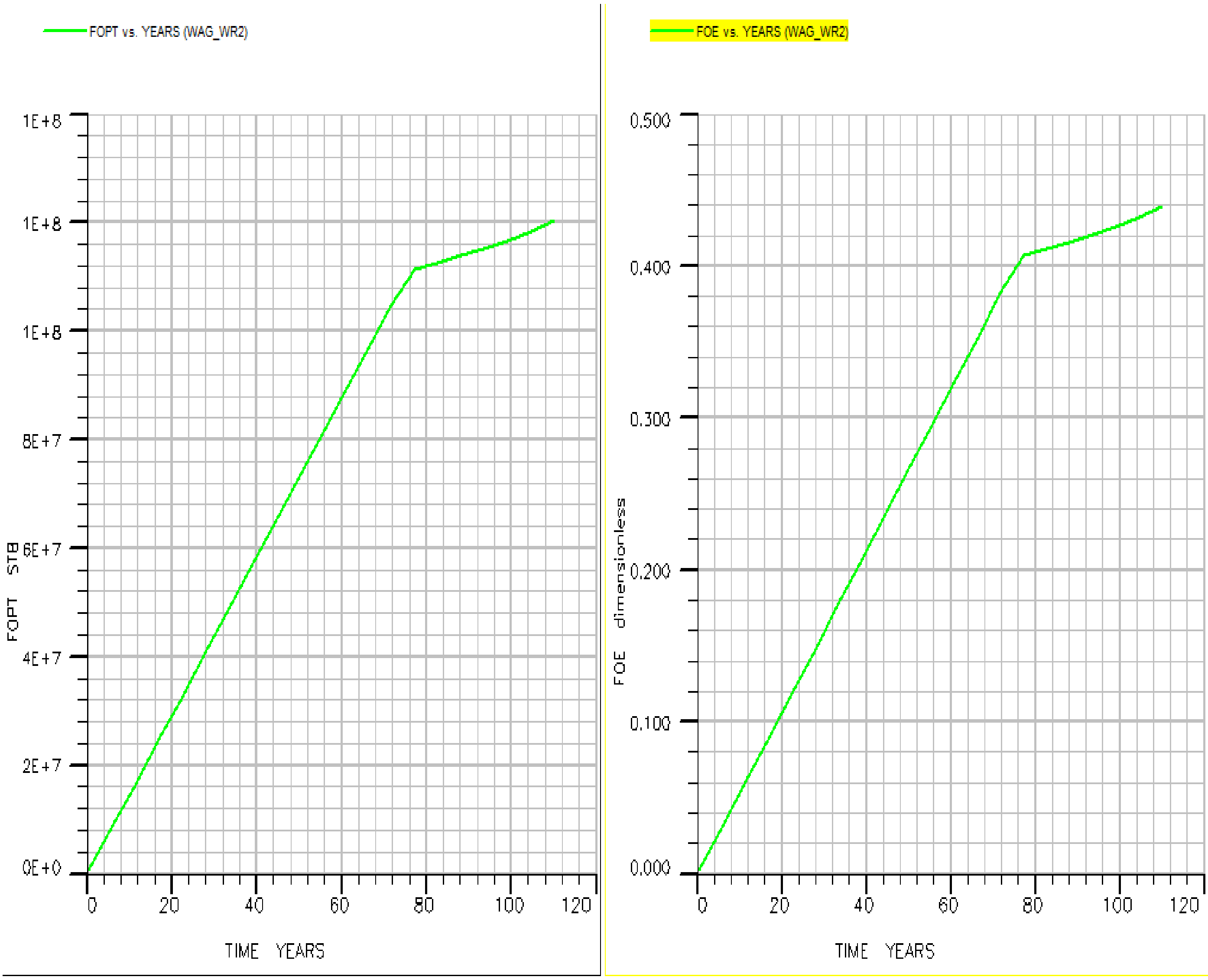

Figure 7: Plots FOPT, FOE VS time using MWAG (2:1)

ANALYSIS OF MICIBLE WATER ALTERNATING GAS SCHEME RATIO 1:2

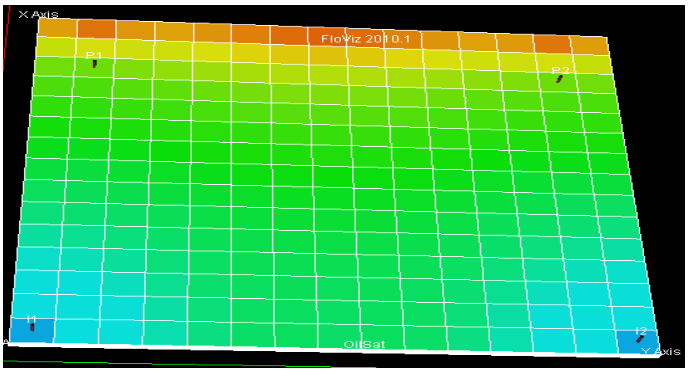

Figure 8: Showing model after simulation for MWAG (1:2)

CASE 3 ANALYSIS:

The simulation done was subject to miscible wag injection with a ratio of 2:1. Miscible WAG injection scheme (1:2) was investigated with water injected through two injector wells for 100 days and alternated with gas which is injected for 200 days as presented in the model from fig.8. The production rate was set at 2000 barrels per day for each producer well.

Field oil efficiency vs time using water flooding gave a productive recovery factor which was highest at the 66th year of production with an ultimate recovery of 92.5 million barrels beyond the 66th year of production as shown in fig. 9, the recovery mechanism became uneconomical without further emergence of oil at the producers. As shown in fig. 10, plots of FOPT versus TIME shows that no further production was achieved after the 66th year as a constant production was achieved up until the production time limit set at 110 years.

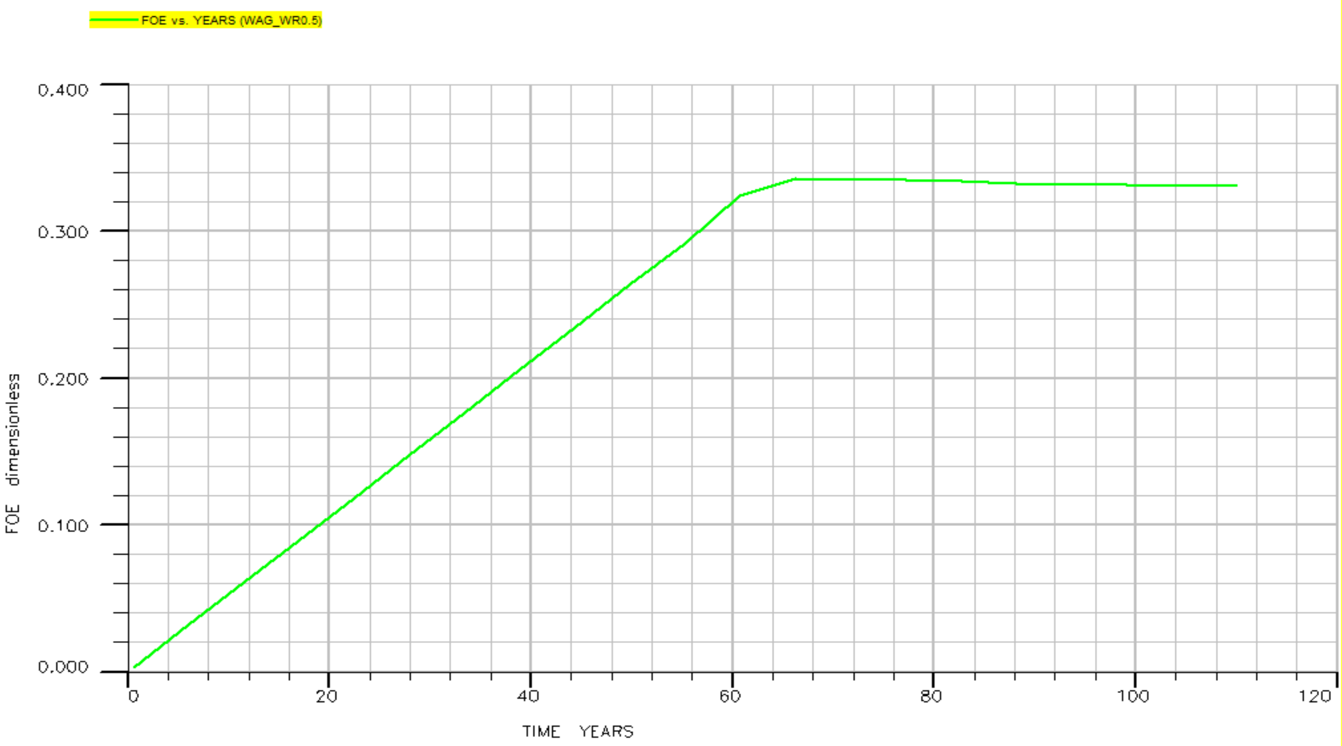

Figure 9: Plots of FOE VS time using MWAG (1:2)

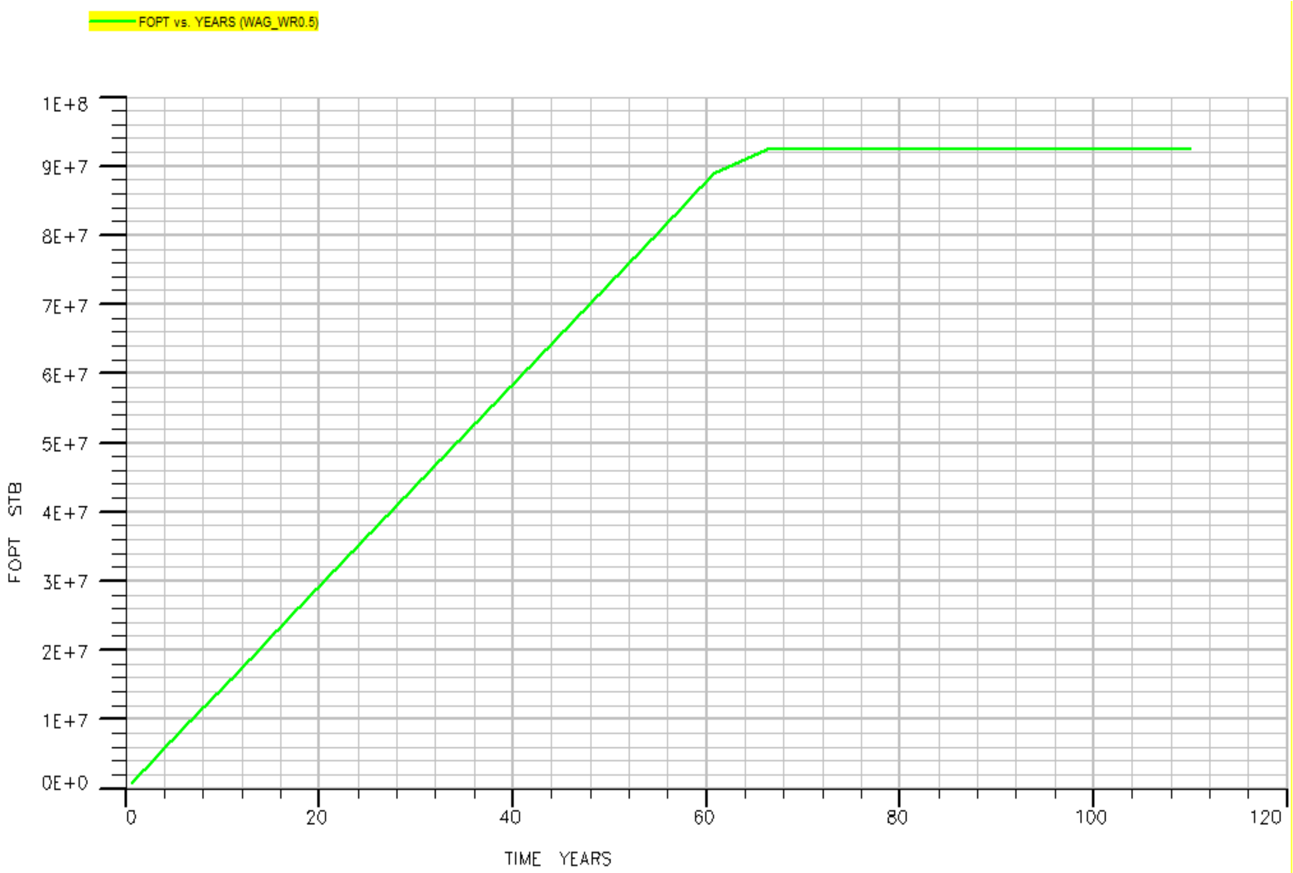

Figure 10: Showing FOPT VS time using MWAG (1:2)

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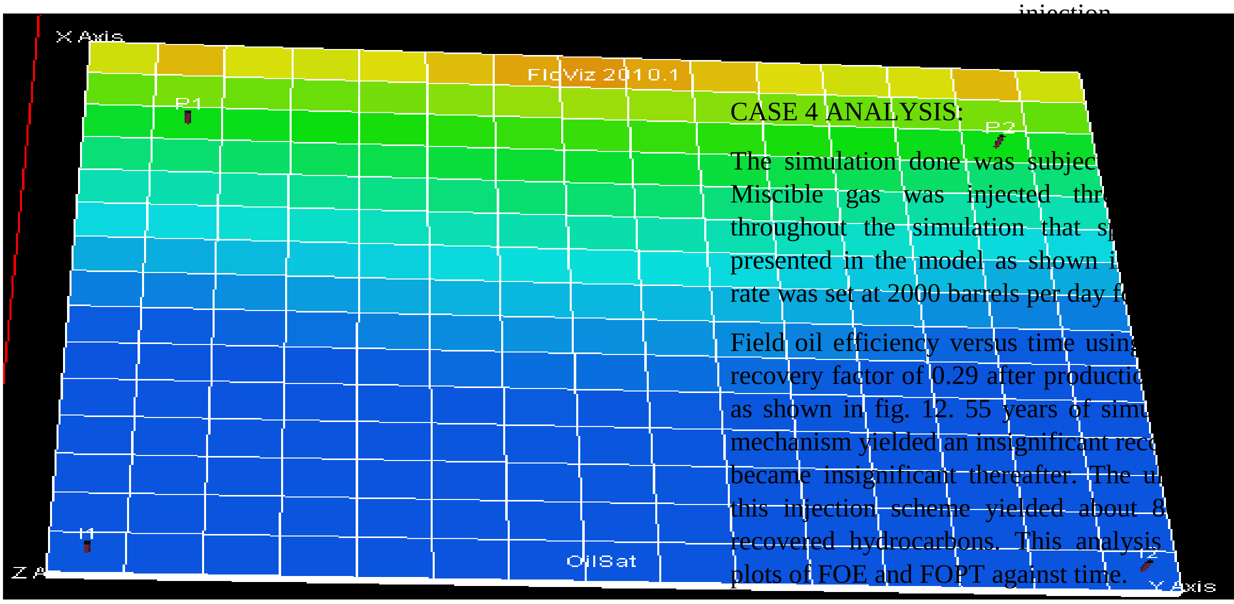
ANALYSIS OF MISIBLE GAS INJECTION

Figure 11: Showing model after simulation for miscible gas injection



CASE 4 ANALYSIS:

The simulation done was subjec… gas injection. Miscible gas was injected thr… injector wells throughout the simulation that sp… 110 years as presented in the model as shown i… The production rate was set at 2000 barrels per day f… oducer well.

Field oil efficiency versus time usin… e gas yielded a recovery factor of 0.29 after productio… ed for 55 years as shown in fig. 12. 55 years of simu… sing the WAG mechanism yielded an insignificant reco… the production became insignificant thereafter. The u… recovery from this injection scheme yielded about 8… lion barrels of recovered hydrocarbons. This analysis … rived from the plots of FOE and FOPT against time.

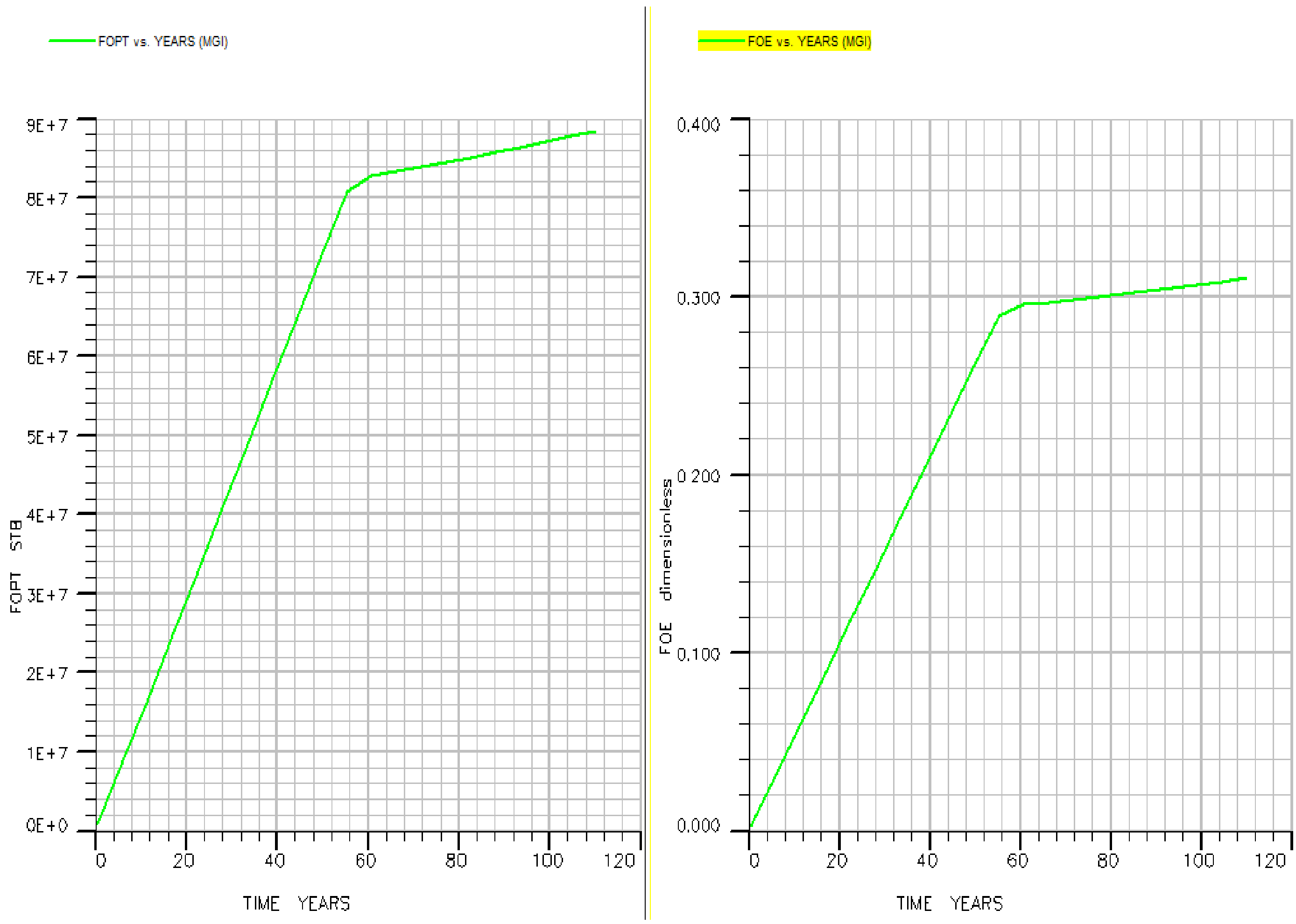


Figure 12: Showing FOPT, FOE versus TIME using MGI.

ANALYSIS OF WATER FLOODING

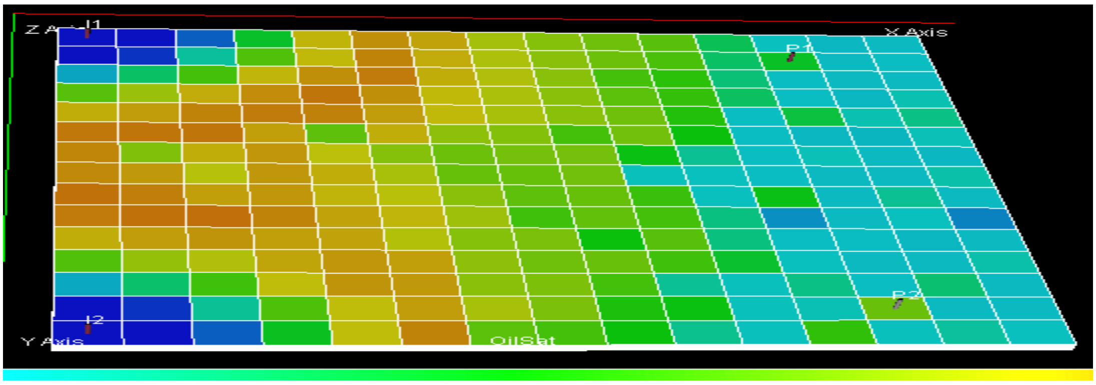


Figure 13: Showing model after simulation for water flooding

CASE 5 ANALYSIS:

The simulation done was subject to water flooding. Water was injected through two injector wells throughout the simulation that spanned for 110 years as presented in the model as shown in fig. 13. The production rate was set at 2000 barrels per day for each producer well.

Field oil recovery efficiency versus time using water flooding gave a productive recovery factor of 0.526 over a period of 110years with an ultimate recovery of 144million barrels of oil recovered. The project showed active productivity up until the 93rd year of production. Thereafter the recovery became insignificant. 93 years of production yielded a recovery factor of 0.5 with an ultimate recovery of 136.8 million barrels of oil recovery over 93 years.

The ultimate recovery was gotten from plots of FOPT against time from fig. 14. The plot of FOE vs Time from fig. 17 shows a 53% recovery factor.

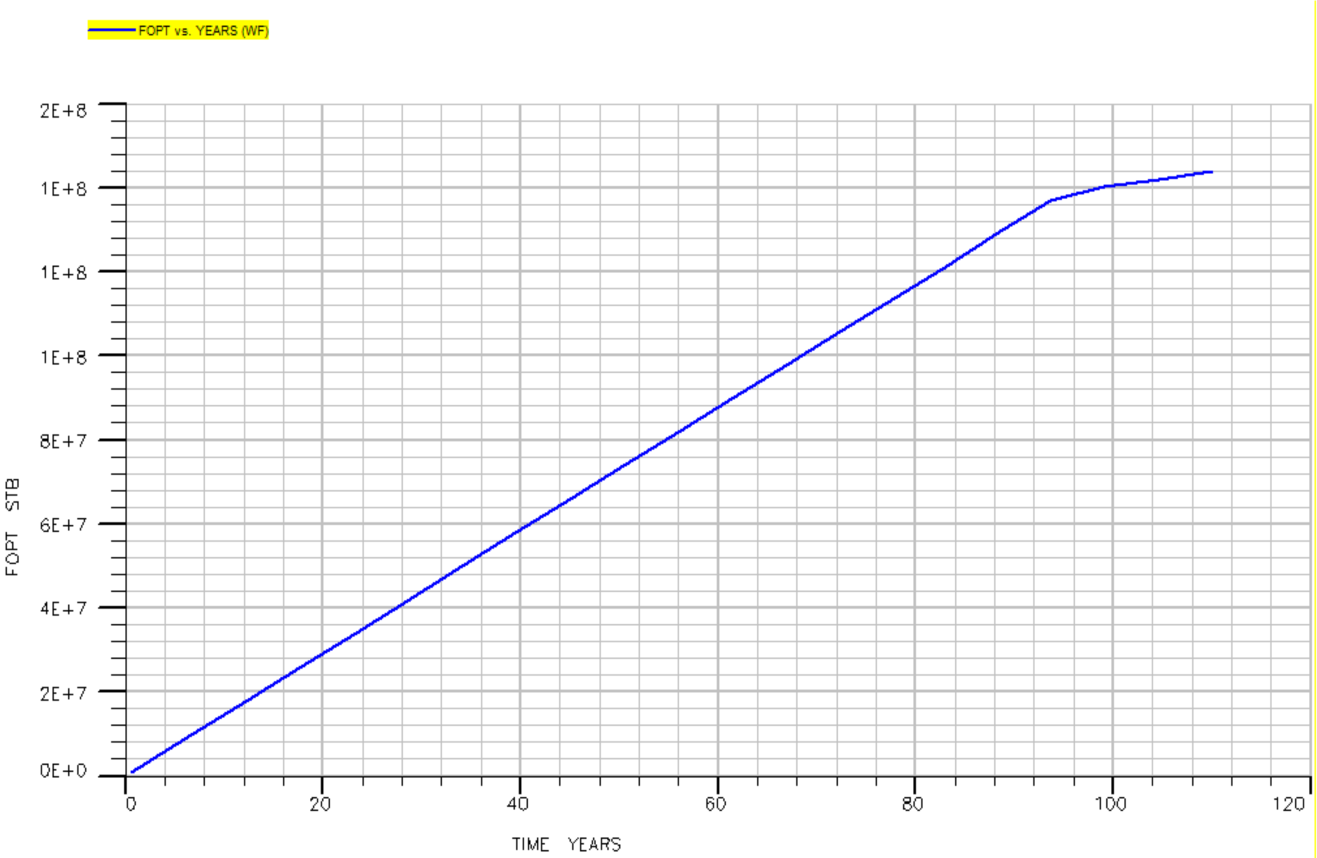


Figure 14: Plot of FOPT VS time using water flooding

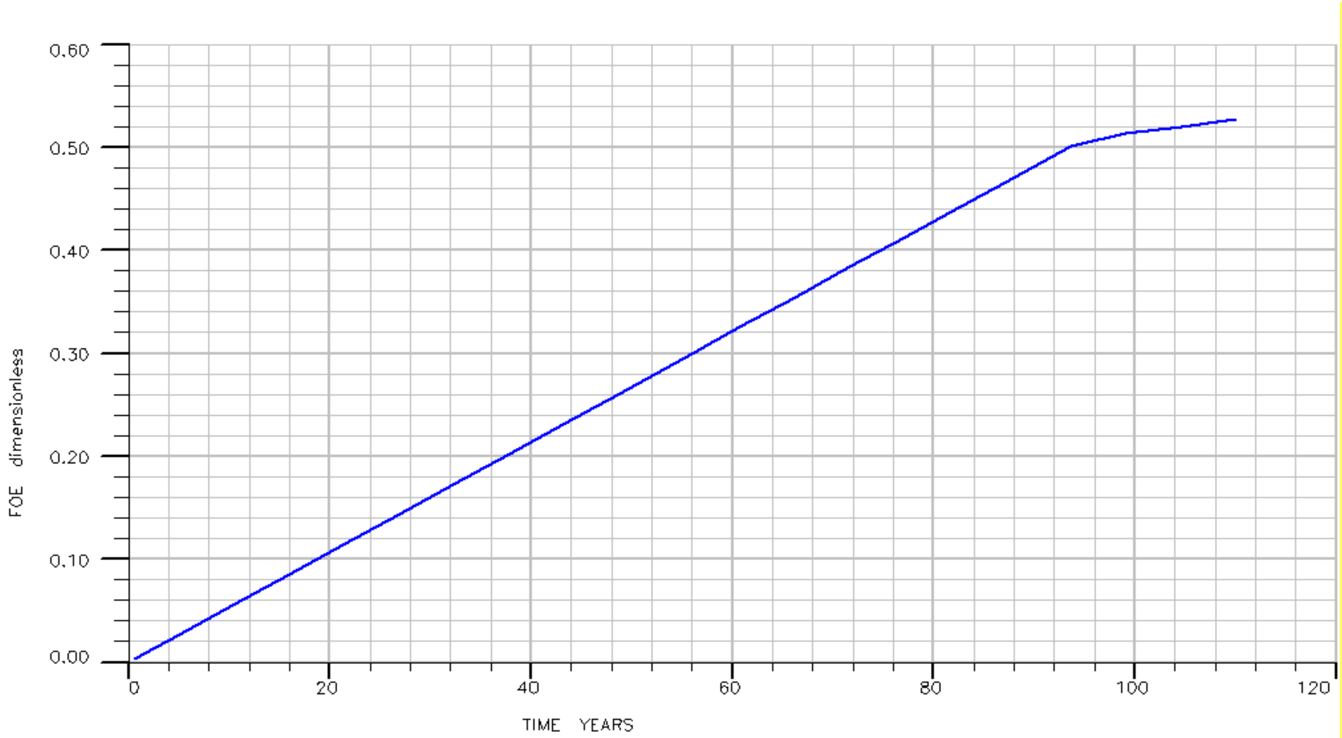


Figure 15: Plots of FOE VS time using water flooding

Table 1: Showing tabulated values of Recovery factor and Ultimate recovery

EOR Method	Ultimate Recovery Factor After 110 years of simulation (Dimensionless)	Ultimate Recovery (million Barrels) after 110 years of simulation
MWAG(1:1)	0.405	112
MWAG(2:1)	0.431	120.5
MWAG(1:2)	0.33	92.5
MGI	0.310	88.43
WF	0.527	144

Table 2: Showing tabulated values of FWCT and FGOR

EOR Method	Field water cut	Field gas-oil ratio(MSCF/STB) Maximum production
MWAG(1:1)	0.00099	4.640
MWAG(2:1)	0.0120	3.783
MWAG(1:2)	0.00048	4.71
MGI	0.00052	11.472
WF	0.089	2.48

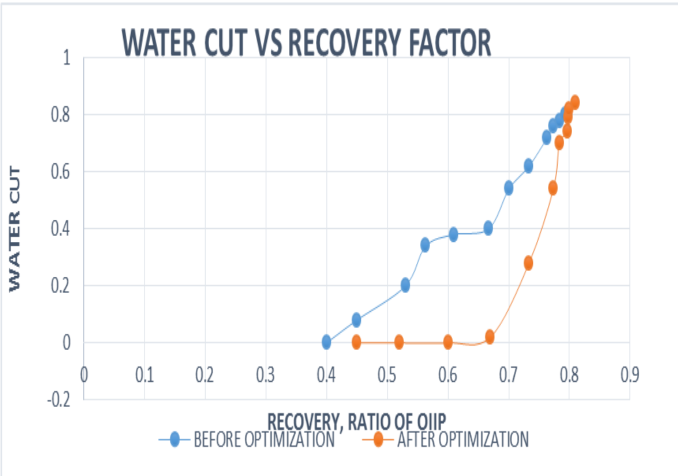


Figure 16: Plots showing WATER CUT VS RECOVERY FACTOR before and after optimization

CONCLUSION AND RECOMMENDATION

Inferring from the analysis derived from this study, the following remarks are drawn:

Water Flooding is the best method to use amongst the five selected cases for the purpose of continual production by operators of field XYZ because it yielded the largest ultimate recovery for this study

Based on analysis, water flooding proves to be the most economical of all selected five cases discussed earlier because of the cheap nature and availability of the resource.

MWAG (1:2) may have been the best technique to control the water breakthrough as the total field water cut was estimated at yield of 0.00048 as compared to MWAG (1:1) values at 0.00099, MWAG (2:1) values at 0.0120, MGI values at 00052 and WF at 0.089

Ultimate recovery was optimized using water alternating gas by comparing 3 different MWAG ratios. The results derived from MWAG (1:1), MWAG (2:1) and MWAG (1:2) are 112, 120.5 and 92.5 million barrels of oil respectively which shows that MWAG (2:1) has the highest ultimate recovery

RECOMMENDATION

Various scenarios of recovery techniques should be analysed critically before oil companies embark on project solely to attain the best mechanism that suits the reservoir as factors such as heterogeneity varies in different fields.

The recommendation for the acquisition of accurate data should be provided in EOR projects because this can either make or break the results attained and misinterpretation of data could lead to making wrong decisions which could cause a reduction in the ultimate recovery after embarking on the EOR techniques.

An economic analysis should be followed up after the predictions of Ultimate recovery from various scenarios performed as this will give a better insight as to which technique would prove to be the cheapest and economical technique in developing the field.

NOMENCLATURE

EOR: Enhanced oil recovery

FWCT: Field water cut

FOE: Field oil recovery efficiency

FOPT: Field oil production cumulative total

FGOR: Field gas oil ratio

HCPV: Hydrocarbon pore volume

IDE: Integrated development environment

IFT: Interfacial tension

IWAG: Immiscible water alternating gas

MMP: Minimum miscibility pressure

MWAG: Miscible water alternating gas

MGI: Miscible gas injection

NPV: Net present value

OOIP: Original oil in place

PV: Pore volume

RF: Recovery factor

WF: Water flooding

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