

Intermittent Carbon Dioxide (CO₂) Injection in a Sandstone Reservoir in Sabah Basin

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Abstract— The intermittent carbon dioxide (CO₂) injection is another alternative method which actually had already been used for a several cases such as heavy oil reservoir and also for the low permeability but none of this technique had been found to be used for light and intermediate oil types of reservoir. Most common problems faced for the carbon dioxide injection is the carbon dioxide breakthrough in the hydrocarbon resulting in the production of carbon dioxide higher than oil. For this simulation, the designated sandstone reservoir is located at Sabah Basin. The simulation of the intermittent of carbon dioxide injection using Petrel 2015 and Eclipse 300 has showed positive results of oil recovered and also avoiding the drawback of carbon dioxide breakthrough during injection. The results have showed that, for intermittent injection rates of 10000 MScf/day can recover for about 8.75% of oil.. Although the continuous injection have shown a higher oil recovered percentage which is 14.15% for 10000 MScf/day injection rates, however, the drawback of continuous injection is, an increase in gas injected produce back to the surface. Therefore, it can be conclude that, intermittent injection method is more efficient compare to the continuous injection, since it improve the oil recovery while avoiding the drawback of carbon dioxide breakthrough.

Keywords— Carbon Dioxide (CO₂), Carbon Dioxide (CO₂) Breakthrough, Continuous Injection, Intermittent Injection.

I. INTRODUCTION

In general, the production of hydrocarbon from the underground reservoir involves in whether chemical or mechanical process that reduce the reservoir pressure thus, it could lead to the decreased production. Therefore, the oil recovery methods were introduced in order to increase the production of the hydrocarbon in the reservoir. The oil recovery methods could be divided into three categories which is, primary, secondary and tertiary. In primary recovery methods, the oil production is usually by using the existing natural pressure in the, the method were known as, solution-gas drive, rock expansion, water drive process and gas-cap expansion. The primary recovery is known to recover an average of 5 – 10% of original oil in place [1].

Although with primary recovery methods, as the oil initial in place decrease with the production, the reservoir pressure decline, thus, the insufficient pressure in the underground would not tolerate to force the oil out to the surface. Therefore, it is deficient to rely on the natural pressure of the reservoir to increase the production. However, there is a secondary method to recover the hydrocarbon in the reservoir. The secondary method is performed by the water or gas injection into the reservoir which later replaced the hydrocarbon for production and also to maintain the pressure in the reservoir. Usually, to minimize the cost for the secondary

recovery method, some of the production wells were designated to be compatible injection wells, in order to maintain the reservoir pressure. Primary and secondary recovery method were known to recover for about 20 – 50% of the oil original in place depending on the oil and the reservoir properties [1]

Thus Enhanced Oil Recovery (Tertiary Recovery) were introduced to recover the remaining probable reserve in the reservoir which have been exhausted of energy during the primary and secondary recovery methods. The (EOR) process and other methods such as water alternating gas flooding (WAG), water flooding and simultaneous water alternating recovery. The Enhanced Oil Recovery (EOR) techniques could offer a prospect of producing in a range of 30 to 60 percent (30% - 60%) or more of the reservoir's original oil in place [4].

The miscible flooding recovery is one of the enhanced oil recovery method which indicates that, the displacing fluid is miscible with the reservoir oil either at first or several contacts. A thin transition zone (known as mixing zone) develops between the displacing fluid and the reservoir oil, which inducing like a piston-like displacement [3].

Therefore, in this study, a new carbon dioxide (CO₂) injection strategy which is carbon dioxide (CO₂) is injected in an intermittent fashion that cycle between period of injection and period of halt. The research is conducted experimentally and below is the procedure and results of the experiment [2]. The Sabah Basin reservoir characteristics were given as shown in the Table 1 below.

Table 1: General Reservoir Characteristics

Property	Value
Reservoir Type	Sandstone
Reservoir Depth, ft	4908
Porosity	0.206 – 0.425
Relative Permeability, k (mD)	50.1 – 1100
Oil Gravity, ° API	23.6 – 23.7
Initial Reservoir Temp. ° F	154
Initial Reservoir Pressure, psi	1753

II. METHODOLOGY

A. Upscaling Reservoir Model

The upscaling is a necessary method for any reservoir model from

the geologist, since the total number of cell for the static data, usually more than >1,000,000 cells, which later affect the time consume during the simulation. Therefore, the first step before simulating the reservoir is, to upscale the grid size, from 2012400 to 556800 number of cell and also cut-off the outer layer that consist only water, in order to reduce the time taken for the simulation to complete. Figure 1 shows the static model before upscaled and Figure 2 shows the upscaled static model with reduce block.

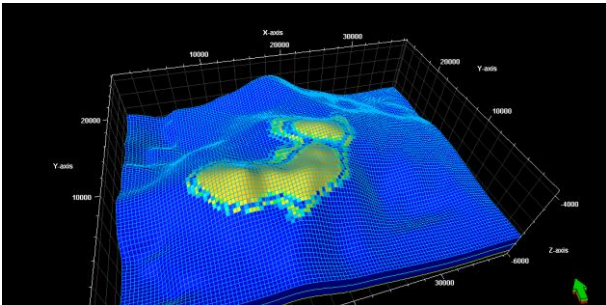


Figure 1: Static Model of Gelama Utara before Upscaled

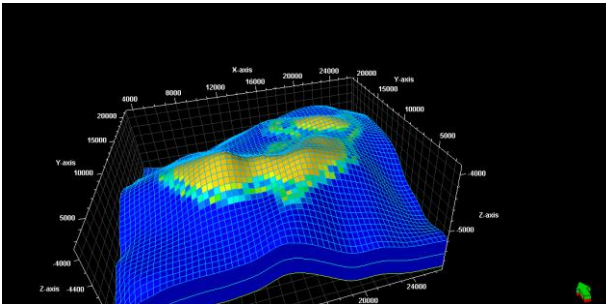


Figure 2: Static Model of Gelama Utara after Upscaled

Next, after upscaling the grid size of the model, reducing the layer between the surface and bottom of the unit sand are vital in order to further reduce the number of cell for faster simulation. However, reducing the layer is slightly different compare to reducing the grid size, since, the properties of the reservoir need to be averaged as well. By using the Petrel scale up properties option, the reservoir properties such as porosity, permeability, net-to-gross and water saturation can be average according to targeted layer. Figure 3 shows the method of averaging the reservoir properties. For porosity, water saturation and net-to-gross, this properties can be averaged by using volume-weighted method, meanwhile for, permeability, the averaging method are the directional averaging, since, the values of permeability in horizontal and vertical direction are not equal. Therefore, after averaging all the required properties, the total number of cell is reduced from 556800 to 139200 after layering the model.

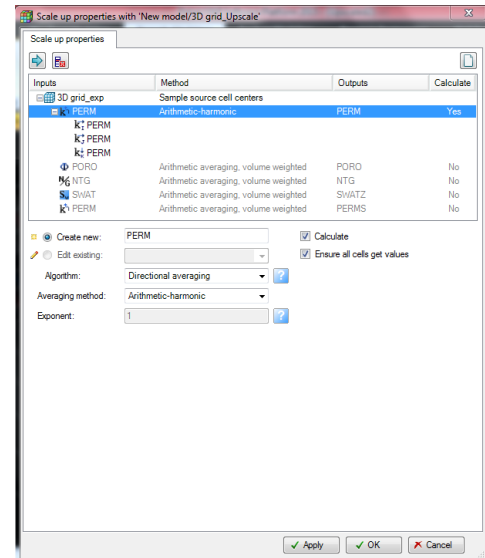


Figure 3: Method of Averaging the Reservoir Properties

B. Development Strategies

For development strategies, seven (7) numbers of production well were created in order to observe the oil productivity without any injection for a duration of 20 years. Next, for injection strategies, seven (7) numbers of injection well were created in order to observe the productivity of oil. The injection were approximately to start 9-10 years after the production, since it is estimated that, the production of oil will reduced by then, due to the pressure reduction after the production.

The parameter for oil production is set to 1000 STB/day for each well, with limitation of 800 psi of bottomhole pressure. The limitation is to ensure that, the well will shut-off after exceeding the bottomhole pressure. For injection well, the injection were varies from 2000 MScf/day, 4000MScf/day, 6000MScf/day, 8000MScf/day and 10000MScf/day. In order to observe the oil productivity, the injection well is set-up to 2 different strategies, which is, intermittent injection and continuous injection throughout the years. For continuous injection strategies, the carbon dioxide is injected without any interval set in between years. However, for intermittent injection, the carbon dioxide is set-up to be injected with interval in between the years, where the injection well will be closed after 1-year of injection activity, and the next year onward, the injection well will be open to resume the injection activities. This strategy is repeated until the end of the targeted production date.

III. RESULTS AND DISCUSSION

A. Base Case for Oil Productivity for 7 Production Well

The Oil production were set to 1000 STB/day in order to investigate at which year the productivity of oil is starting to reduce. Figure 4 shows the oil production cumulative and Figure 5 shows the oil production rates. Based on both figure, it was observe that, the oil production begins to drop after 9-10 years of production and the production rates start to drop until it approximately reach 0 STB/day/

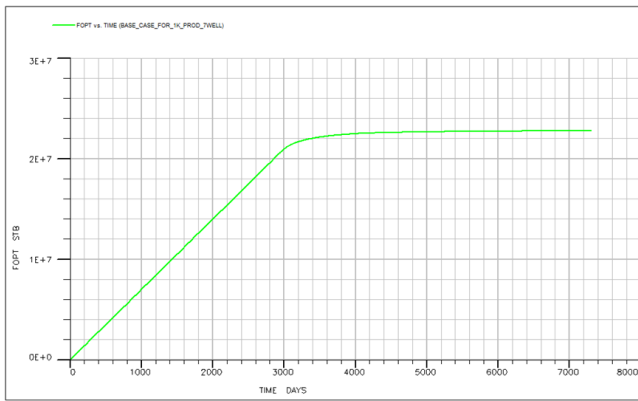


Figure 4: Oil Production Cumulative for 1000 STB/day

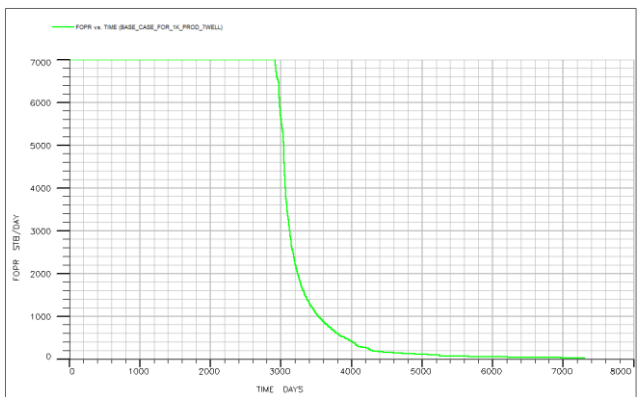


Figure 5: Oil Production rates for 1000 STB/day

B. Oil Production for 7 Injection Well with 2000 MScf/Day Continuous Injection Rates

For a continuous injection with 2000 MScf/day rates after 10 years of production, it is observed that, there is slight increase of oil production. For about 3.6% of recovery factor were discovered, where the production without injection produce for about 22 MMSTB while with injection of carbon dioxide, for about 23 MMSTB, the total increasing production is approximately about 852730 STB. Figure 6 and 7 shows the pattern of cumulative and rates of oil produce compared to the production without injection respectively.

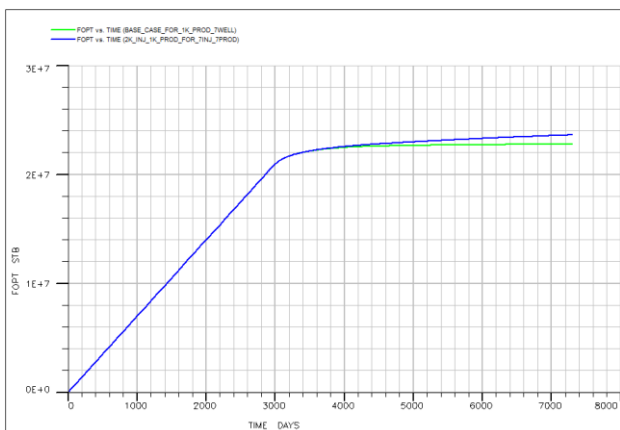


Figure 6: Oil Production cumulative for 2000Mscf/day (Continuous Injection)

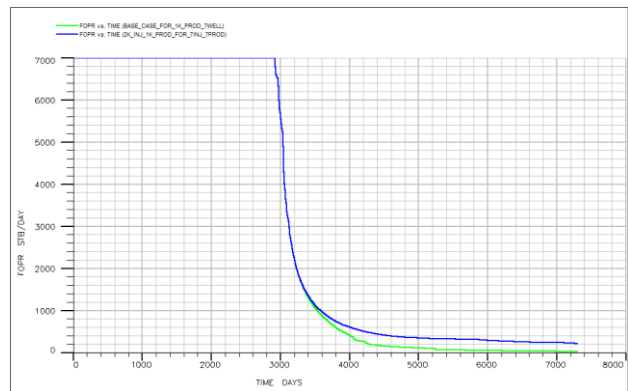


Figure 7: Oil Production rates for 10000Mscf/day (Continuous Injection)

C. Oil Production for 7 Injection Well with 6000 MScf/Day Continuous Injection Rates

For 6000MScf/day injection, the observed oil produce compared to the base case of oil production without injection shows another improvement where, the total oil produce by injection is 2461502 STB. The cumulative oil production by 6000 MScf/day injection rates is 25228660 STB, which shows for about 9.76% increment of oil recovered. Figure 8 and 9 shows the pattern of cumulative and rates of oil produce compared to the production without injection respectively.

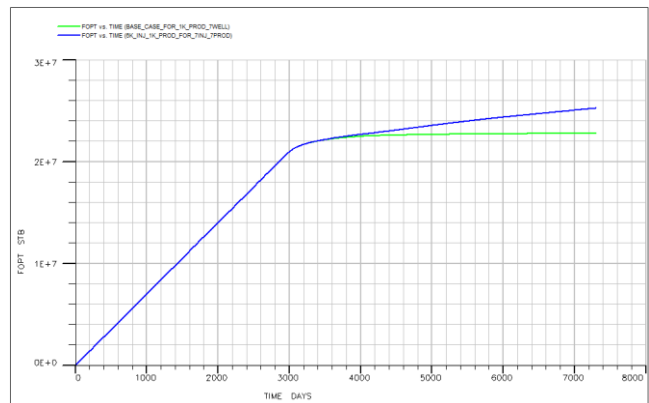


Figure 8: Oil Production cumulative for 6000Mscf/day (Continuous Injection)

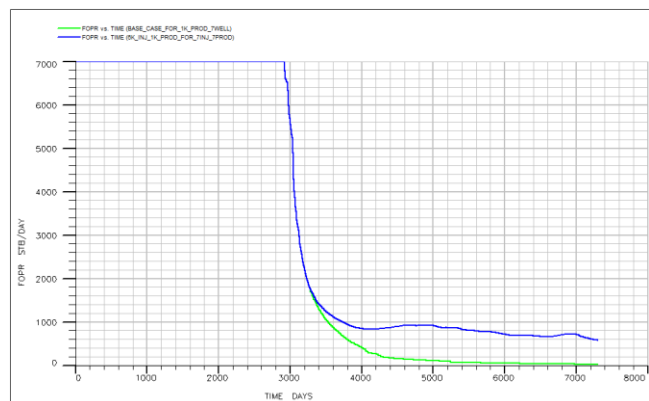


Figure 9: Oil Production rates for 6000Mscf/day (Continuous Injection)

D. Oil Production for 7 Injection Well with 10000 MScf/Day Continuous Injection Rates

Next, for the third cases, by increasing the injection rates to 10000 MScf/day, the results shows an improvement of oil recovered, where the total of oil produce by increasing the injection rates is 3753838 STB, where initially, the oil produced without injection is 22767158 STB while with 4000 MScf/day injection, the cumulative oil recovered is 26520996 STB which shows about 14.15% increasing of oil recovered. Figure 10 and 11 shows the pattern of cumulative and rates of oil produce compared to the production without injection respectively.

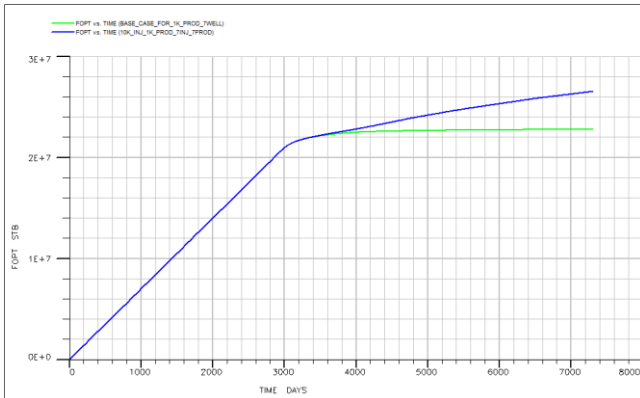


Figure 10: Oil Production cumulative for 10000Mscf/day (Continuous Injection)

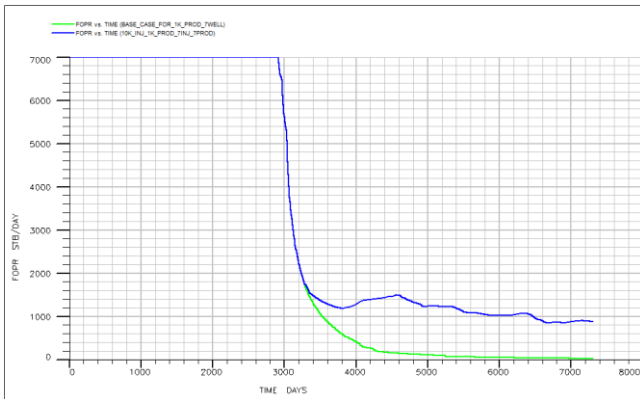


Figure 11: Oil Production rates for 10000Mscf/day (Continuous Injection)

E. Oil Production for 7 Injection Well with 2000 MScf/Day Intermittent Injection Rates

Proceeding to the next strategies, where the carbon dioxide were injected in an intermittent manner, for the 2000 MScf/day rates, there is a minor increase in the cumulative of oil production, which may be due to the interval of injection, which could not maintain the pressure in order to increase the oil production. The total oil production for this cases is 23118410 STB compared to the base case of production which is 22767158 STB which shows for about 1.52% increment of oil productivity. Figure 12 and 13 shows the pattern of intermittent injection for cumulative and rates of oil produce compared to the production without injection respectively.

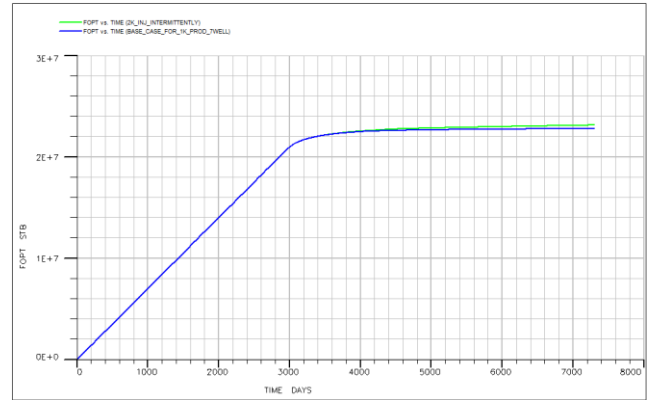


Figure 12: Oil Production cumulative for 2000Mscf/day (Intermittent Injection)

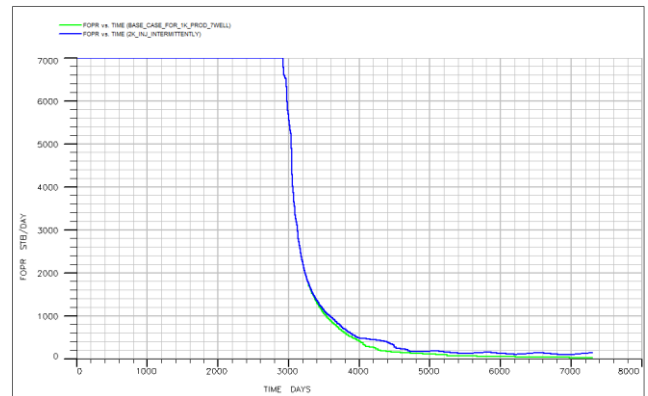


Figure 13: Oil Production rates for 2000Mscf/day (Intermittent Injection)

F. Oil Production for 7 Injection Well with 6000 MScf/Day Intermittent Injection Rates

Next, for the injection with 6000 MScf/day, shows quite an improvement compared to the 2000 MScf/day injection by intermittent manner. The cumulative of oil production in this case were 24049292 STB which shows an increment of 5.33% of oil recovered. Figure 14 and 15 shows the pattern of intermittent injection for cumulative and rates of oil produce compared to the production without injection respectively

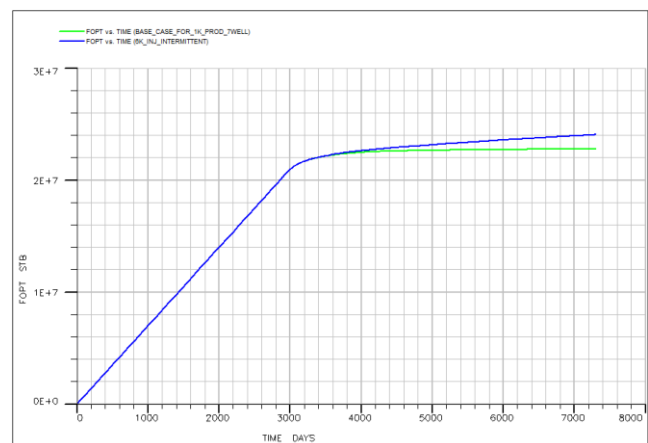


Figure 14: Oil Production cumulative for 6000Mscf/day (Intermittent Injection)

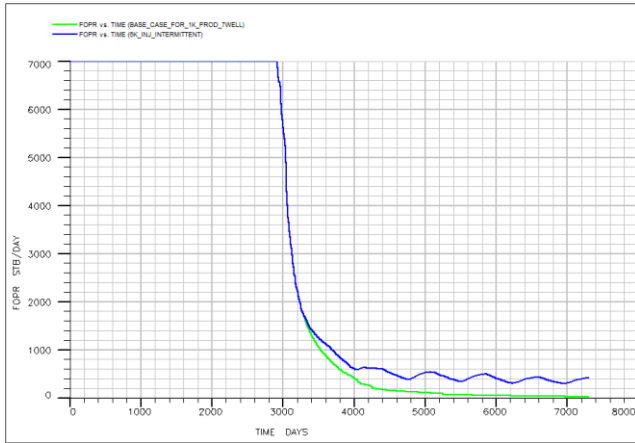


Figure 15: Oil Production rates for 6000Mscf/day (Intermittent Injection)

G. Oil Production for 7 Injection Well with 10000 MScf/Day Intermittent Injection Rates

For the final cases, with an injection of 10000 MScf/day injected in intermittently manner, the results shows quite an improvement of oil recovered, where the total of oil produce by increasing the injection rates is 2182746 STB, where initially, the oil produced without injection is 22767158 STB, the cumulative oil recovered is 24949904 STB which shows about 8.75% increasing of oil recovered. Figure 16 and 17 shows the pattern of intermittent injection for cumulative and rates of oil produce compared to the production without injection respectively

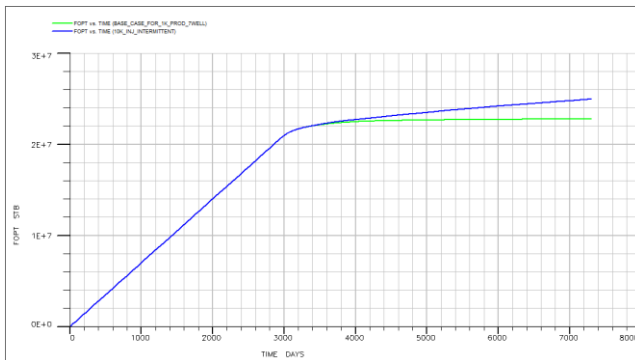


Figure 16: Oil Production cumulative for 10000Mscf/day (Intermittent Injection)

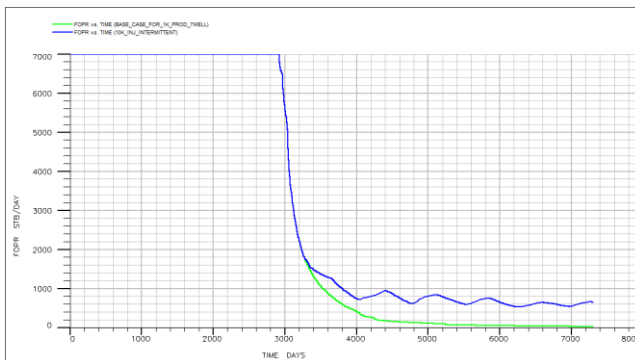


Figure 17: Oil Production rates for 10000Mscf/day (Intermittent Injection)

Table 2: Simplified Results of Percentage of Oil Recovered for both Continuous and Intermittent Injection

Cumulative Oil Produce Without Injection	22767158		
Injection Rates, MScf/day	2000	6000	10000
Cumulative Oil Production for Continuous Injection, STB	23619888	25228660	26520996
Percentage Oil Recovered for Continuous Injection	3.61%	9.76%	14.15%
Cumulative Oil Production for Intermittent Injection, STB	23118410	24049292	2949904
Percentage Oil Recovered for Intermittent Injection	1.52%	5.33%	8.75%

H. Discussion

Basically, by observing the results obtained from the table 4.1, almost all the cases shows an improvement of oil recovered, as the injection of carbon dioxide increases whether in continuous injection manner or in intermittent manner. Subsequently, the result for the intermittent manner injection shows a decreasing of oil recovered, which this may be due to the injection rates could not sustain or maintain the pressure, which later on leads to the decreasing of oil produce.

However, although increasing the injection rates can improve the oil recovered, the carbon dioxide breakthrough problem might also occur in this certain cases since higher injection rates increase the potential of carbon dioxide to break through the oil, which later found out, that high gas production. Figure 4.15 and 4.16 shows the pattern of cumulative gas produce for normal and intermittent injection respectively.

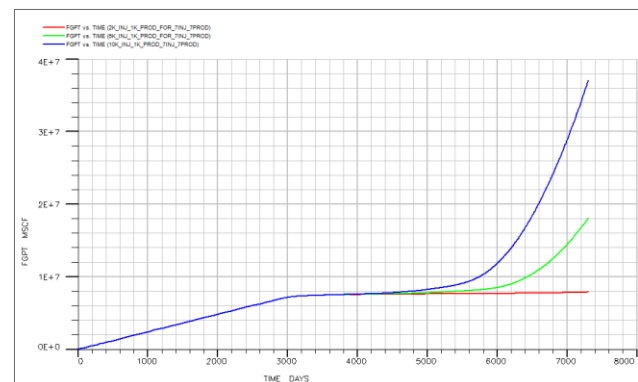


Figure 18: Pattern for cumulative gas produce for (Continuous Injection)

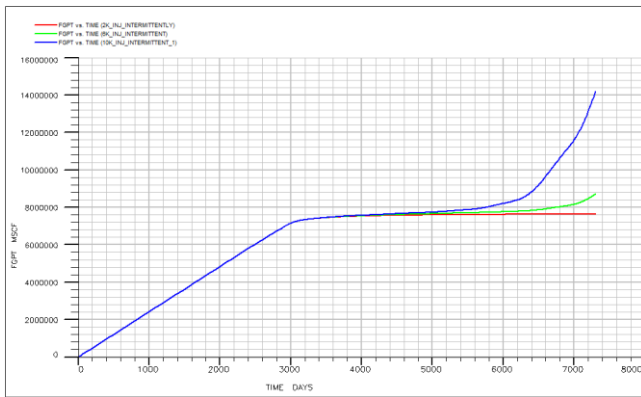


Figure 19: Pattern for cumulative gas produce for (Intermittent Injection)

Table 3: Simplified Results of Percentage of Gas Production for both Continuous and Intermittent Injection

Cumulative Gas Production Without Injection, MSCF	7576097		
Injection Rates, MSCF/day	2000	6000	10000
Cumulative Gas Production for Continuous Injection, MSCF	7878442	18099876	37085688
Percentage Gas Production for Continuous Injection	3.83%	58.14%	79.57%
Cumulative Gas Production for Intermittent Injection, MSCF	7647913	8744357	14197359
Percentage Gas Recovered for Intermittent Injection	0.93%	13.36%	46.63%
Difference in Gas Production, MSCF	230529	9355519	22888329

Based on the figure 18 and 19, the graph shows the difference in between the gas production for both continuous and intermittent gas injection respectively. Table 2 shows the total number of gas production and the percentage difference for both continuous and intermittent injection. Thus for continuous injection, the gas productivity shown is quite high compare to the intermittent injection where for about 79.57% increment of gas production were shown compare to intermittent with only 46.63% of gas production. Therefore, this shows that, as the gas injected continuously, the potential of the same gas to be produce is quite high, compared to the gas injected in an intermittently manner, where, as shown in the figure 4.16 and table 3, the production of gas is quite lower. This shows that, although the intermittent injection shows a slightly lower for percentage of oil recovered, but it is more efficient, since, lesser injection of gas use for recovering oil in the reservoir.

IV. CONCLUSION

In conclusion, this simulation has conducted and considered successful since, it fulfill the objective of this thesis based on the results obtained, which is to understand the effect of the intermittent carbon dioxide injection in sandstone reservoir in Sabah Basin and also to analyze the optimal recovery percentage obtained by intermittent carbon dioxide injection method. By comparing the method of injection where continuous injection and intermittent injection, which shows quite large gap in between the recovered percentage, but the efficiency for the strategies use is vital in this part, since, the most important part is to recovered oil and to avoid producing the same gas that were injected into the reservoir. This research has showed that, the intermittent carbon dioxide injection method is suitable to use in the Sabah Basin, since carbon dioxide injection, is usually used in heavy oil reservoir, but, as the results shows .this enhanced oil recovery method can also be used for an intermediate type of oil reservoir, where about 8.75% of oil can recovered and less of injected gas produced by using this method.

A. Recommendation

There are a few recommendations that can be made in order to improve this research in future onwards. All the recommendations are listed below:

- 1- By using different strategies such as, shorten the interval time in between the open and shut-off well, from 1 year period into half-year.
- 2- Increasing or decreasing the concentration of carbon dioxide injected, which could potentially avoid the drawback of carbon dioxide breakthrough, which this could lead to increasing in injection rates that could increase the oil productivity.
- 3- By varying the injection rates for intermittent injections, in order to observe the pattern of oil recovered and also to sustain the reservoir pressure for a consistent production of oil.

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