Optimising Volumetric Sweep Efficiency in Water Flooding by Streamline Simulation

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Abstract

Early shutting time in production wells due to water production, performs an important role to determine production efficiency and useful life of the reservoir.

In this study, in order to postpone the shut in time of producing wells, increase oil displacement and enhance production efficiency, production and injection wells capabilities with respect to their position in the reservoir were studied by using the concept of streamline.

In the oil reservoirs, increasing injection flow rate does not necessarily enhance oil displacement and recovery. therefore, suitable injection rates according to injection and production wells position have to be optimised. Also, production wells flow rate can affect sweep efficiency optimisation extremely and increase the efficiency of injection wells. In this study, according to the position of production and injection wells and water production rates resulting from injection wells, four scenarios with different injection and production rates were investigated. This optimization has led to a reduced water production and water injection. Also, it increased the production efficiency and reservoir life.

Keywords: Production Efficiency, Oil Displacement Efficiency, Streamline, Production well, Injection well, Optimal positioning

Introduction

Streamline simulation is a powerful tool to the more accurate investigation. In this method, streamlines are drawn by using fluid flow velocity then by the concept of time of flight (TOF), saturation equation is solved. With a time of flight coordinate, three-dimensional saturation equation is converted to one-dimensional equations and the effect of the non-homogeneous reservoir in term of fluid flow time from one point to another is expressed (Datta-Gupta et al.,2007). Equations rather than on cell to cell are solved along the streamlines. Streamline simulation, in large models and more than 80000 cells, uses lower memory and is faster 20 times than Eclipse. Production from hydrocarbon reservoirs requires precise determination of reservoir fluid properties along with their positive impact on real reservoir performance evaluation and fluid in place volume calculation (Nasriani et al., 2015a; Nasriani et al., 2015b). The streamline approach minimises the numerical dispersion and grid orientation effects compared to conventional finite difference method. (Rodriguez et al.,2008; Samier et al., 2001). Streamlines offer the unique ability to define dynamic well allocation factors between injection and producing wells. By this factor relationship between injection and production well pairs for determining parameters are known and can be investigated in details. (Thiele et al., 2003).

Pressure maintenance and different fluid phase injection are the common practices used in the oil and gas fields to alleviate the negative impact of reservoir depletion on hydrocarbon recovery (Zareenejad et al., 2015; Nassiri et al., 2015; Nasriani et al., 2014). Water flooding is the most common way which is used to improve oil production in the world. The success of water flood depends on its ability to sweep remaining oil efficiently. The incorrect or insufficient design may lead to increases in cost associated with water cycling and poor sweep (Izgec et al., 2010). Reservoir heterogeneity, permeability contrast, in particular, can adversely impact the performance of water flooding. It is well-known that the presence of high permeability streaks can severely reduce volumetric sweep efficiency leading to an early water arrival at the producers and bypassed oil. Also, there is an increased cost associated with water recycling and handling. One approach to counteract the impact of heterogeneity and to improve oil displacement is the management of production and injection rate. We can manage the propagation of flood front, delay water breakthrough at the producers and also increase the production efficiency. (Alhuthali et al ., 2006; Grinestaff et al., 1999).

In this project more accurate investigation on wells that have production capability but quickly closed was done. According to the position of production and injection wells and water producing, changes in rates were done (Singhal., 2009 ; Sayyafzadeh et al ., 2010). Wells shutting was postponed and increasing of oil displacement and production efficiency was concluded.

About the model

1) Base Case

Table 1 explains average rock and fluid properties. This model has 12 production and 3 injection wells and the irregular pattern is used for injection. Initially, all production wells were produced with 2000 STB/D and injection wells were injected with 6000 STB/D. Schematic of streamline and wells location is shown in Figure 1.

Methodology

In this model, based on prediction, P2 and P4 were shut at an early time after production. By running two scenarios that changing the injection and production rates were applied and delaying the wells shutting time, the efficiency of two wells and field efficiency were increased. Three parameters to compare the scenarios efficiency are: Oil Displacement in reservoir[1], Oil saturation displaced, Production Efficiency

The amount of oil displacement is determined the proportion of initial oil in reservoir and saturation displaced is the determined proportion of pore volume that both of water and oil fill there.

These parameters are determined by equations 1, 2, 3

Oil Displacement = $\frac{OOIP_i - OIP_i}{OOIP_i}$ Eq-1

OIP_i : Oil remaining between injection – production well pair i

$OOIP_i$: Initial oil in place between injection – production well pair i

Oil Saturation displaced = $\frac{So_i - (So)_i}{So_i}$ Eq-2

So_i : Initial oil saturation between injection – production well pair i

$(So)_i$: Oil saturation remaining between injection – production well pair i

Production Efficiency = $\frac{Qo_i}{Q_t}$ Eq-3

Qo_i : Oil production rates in well i affected by the respective injection wells

Q_t : Total liquid production in well i affected by the respective injection wells

[1] - volumetric sweep efficiency

2) First Scenario (reducing water injection rate of I1)

Since a high portion of water production in P4 is affected by I1, in order to compensate this problem, the flow rate of I1 was reduced to 5000 STB/D. this postpones P4 shutting time two months. Since P3 is influenced by I1 and I2, this task equilibrated the effect of I2 on P2 and P3, This means that P3 was most affected by I2 and shutting of P2 was postponed 4 months.

3) Second Scenario (reducing water injection rate of I2)

Most of the water production in P2 was allocated by I2 (injection well 2). So, at second scenario flow rate of I2 was reduced to 5000 STB/D. P3 was affected by I1 and I2. Since most of the oil production in P2 was influenced by I2 and whereas I2 flow rate was reduced so it caused P3 to be more influenced by I1 and it made P4 flow rate that to be less affected by I1, is reduced. So in order to resolve this problem flow rate of I1 is increased to 6500 STB/D.

These changing in flow rate caused shutting of P2 and P4 to be delayed 7 and 2 months respectively. in this scenario, Field cumulative water production was reduced 1800000 STB .Also, the amount of cumulative water injections was reduced 2024000 STB.

4) Third Scenario (increasing water injection rate of I1 and I3)

In the second scenario, by reducing the injection rate of I2, P2 was more affected by I3 than before and the effect of I3 on P1 was reduced. So in the third scenario, flow rates of I1 and I3 were increased to 6500 STB/D and in order to reduce water production in P2, the I2 flow rate was decreased to 4500 STB/D. But this scenario compared to the second scenario wasn’t efficient. This suggests that just changing in injection rates is not enough for increasing production efficiency. So production flow rate must change too. The fourth scenario performed this process.

5) Fourth Scenario (increasing I1 and I3 injection rate and decreasing I2 injection rate)

P1 and P2 are affected by I3 in the fourth scenario, in order to increase P2 efficiency, I2 flow rate was reduced to 4500 STB/D and I1 , I3 were increased to 6500 STB/D. Since P2 is more affected by I3 than before and P1 is influenced by I3, it causes P2 efficiency to decrease. So I3 flow rate was increased to 6500 STB/D. Due to P11 and P12 vicinity to the aquifer and their low efficiency, flow rates of these wells were decreased to 1000 and 1500 STB/D. also, the P3 flow rate was reduced to 1500 STB/D respectively. it was because of reducing P4 efficiency by P3 .in order to compensate for this production reduction, flow rates of P1 ,P2, P6 and P7 were increased to 2500 STB/D. flow rate increase was done for several reasons:

1. Higher volume of oil in place in related area to these wells

2. Higher production capability than the other wells

3. Increasing the flow rates in injection wells which affect oil production rate, cause better volumetric sweep efficiency in the related area

In the fourth scenario, shutting of P2 and P4 were delayed 11and 9 months respectively. Water production was decreased more than before. Figure 2 shows differences between water production in the base case and four Scenarios.

Figure 3 and 4 show oil displacement and oil saturation displaced for P2 and P4. The fourth scenario was more efficient than the other scenarios and Wells have been able to have more producing time.

Figure 5 shows production efficiency for P2 and P4 at different scenario at the base case P2 and P4 were shut after 3012 days after production, so if production efficiency of all scenarios is compared at the same period of time (3012 days), the fourth scenario is more effective than base case and other scenarios.

Shut-in times of all scenarios are shown in table 2.

Conclusion

With increasing injection flow rate, oil displacement and recovery don’t become better than before necessarily. So, suitable injection rates according to injection and production wells position have to be determined. Also, production wells flow rate can affect sweep efficiency optimisation extremely and increase the efficiency of injection wells. In this study, according to the position of production and injection wells and water production rates resulting from injection wells, four scenarios with changes in the injection and production rates were investigated. This led to being reduced water production and water injection. Also, increasing production efficiency and reservoir life resulted.

Suggestions

- Before field development, distances between production and injection wells should be optimised. It is because of avoiding the cost increase related to drilling repetition and using more water to inject.
- Infill drilling in some areas can be effective if changing in production and injection flow rate cannot sweep this area. Otherwise, this case may lead to higher costs.

- Wells completion in the layers close to the aquifer can cause wells to be shut faster.
- Only changing in water rates of injection wells is not enough for increasing production efficiency. Changing in production flow rate must be applied too.

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Table.1-Average Rock and Fluid properties

Property	Average Amount
Permeability in X direction	**27.5 md**
Permeability in Y direction	**27.5 md**
Permeability in Z direction	**50.4 md**
Porosity	**20%**
Initial Oil Saturation	**75%**
Initial Gas Saturation	**0%**
Initial Water Saturation	**25%**
Oil Density(Standard Condition)	**52.1 Ib/cu.ft**
Gas Density(Standard Condition)	**0.055 Ib/cu.ft**
Water Density(Standard Condition)	**62.3 Ib/cu.ft**
Initial Pressure	**3170 Psia**

Table.2- Wells shut-in times

	Initial	1st Scenario	2nd Scenario	3rd Scenario	4th Scenario
P2	1-May-17	1-Sep-17	1-Dec-17	1-Dec-17	1-Apr-18
P4	1-Aug-14	1-Oct-14	1-Oct-14	1-Aug-14	1-May-15

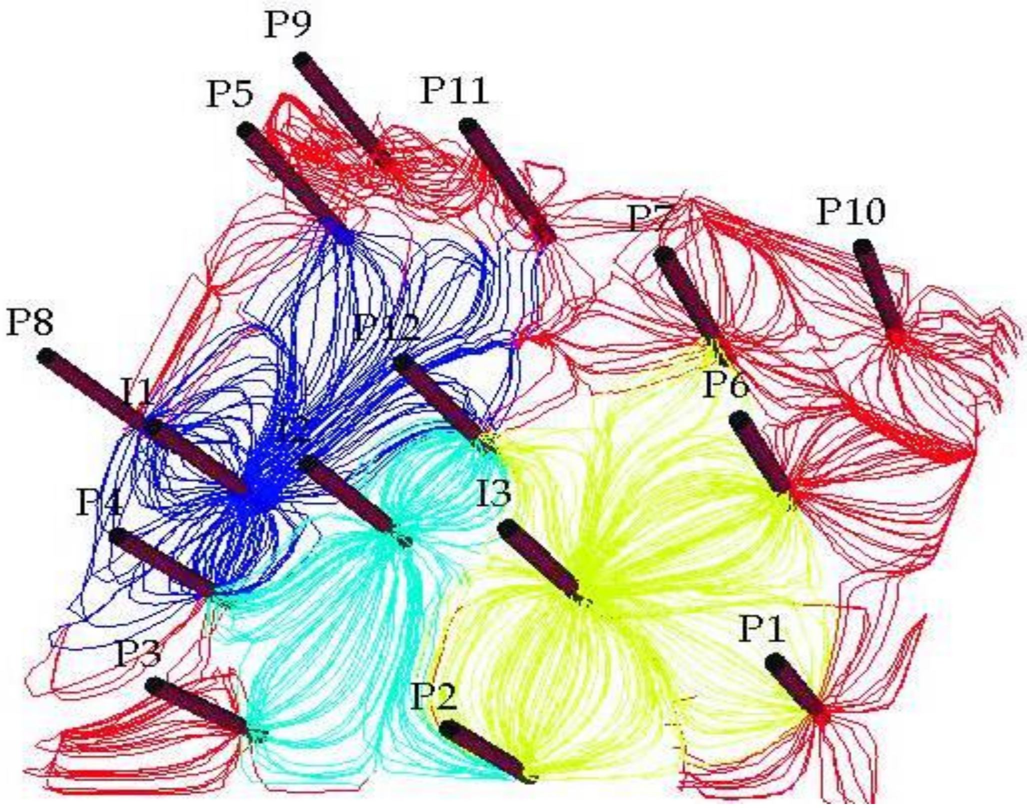


Figure.1- Schematic of stream lines and wells location

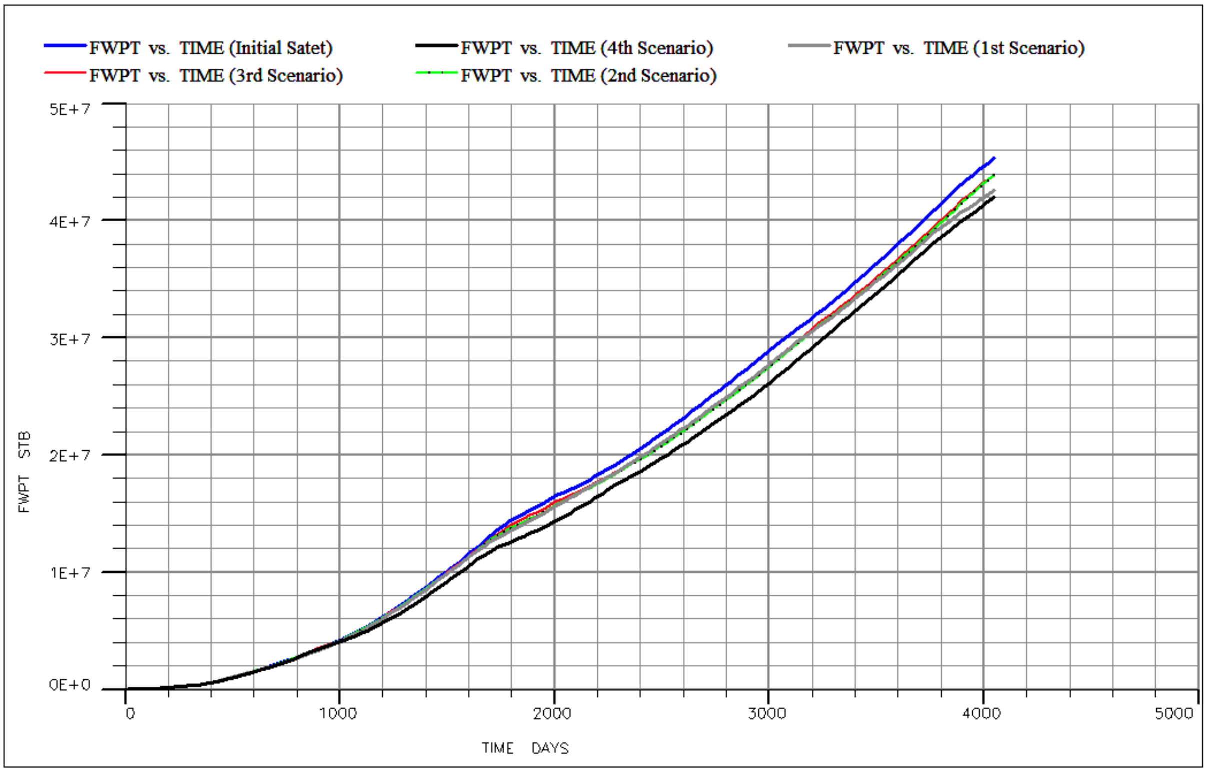
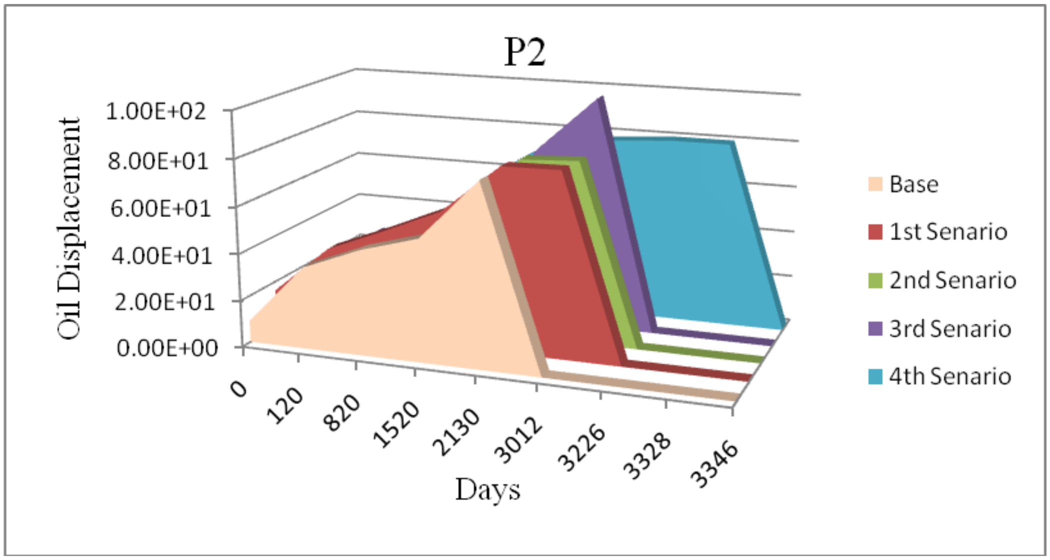


Figure.2-Comparing water production between base case and four scenarios



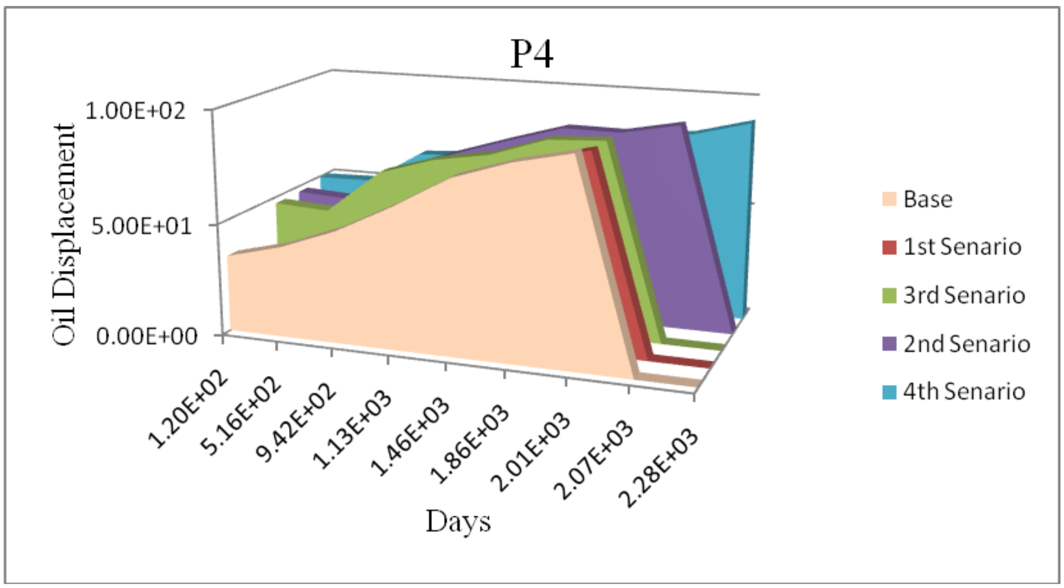


Figure.3-Oil Displacement for area related to P2 and P4

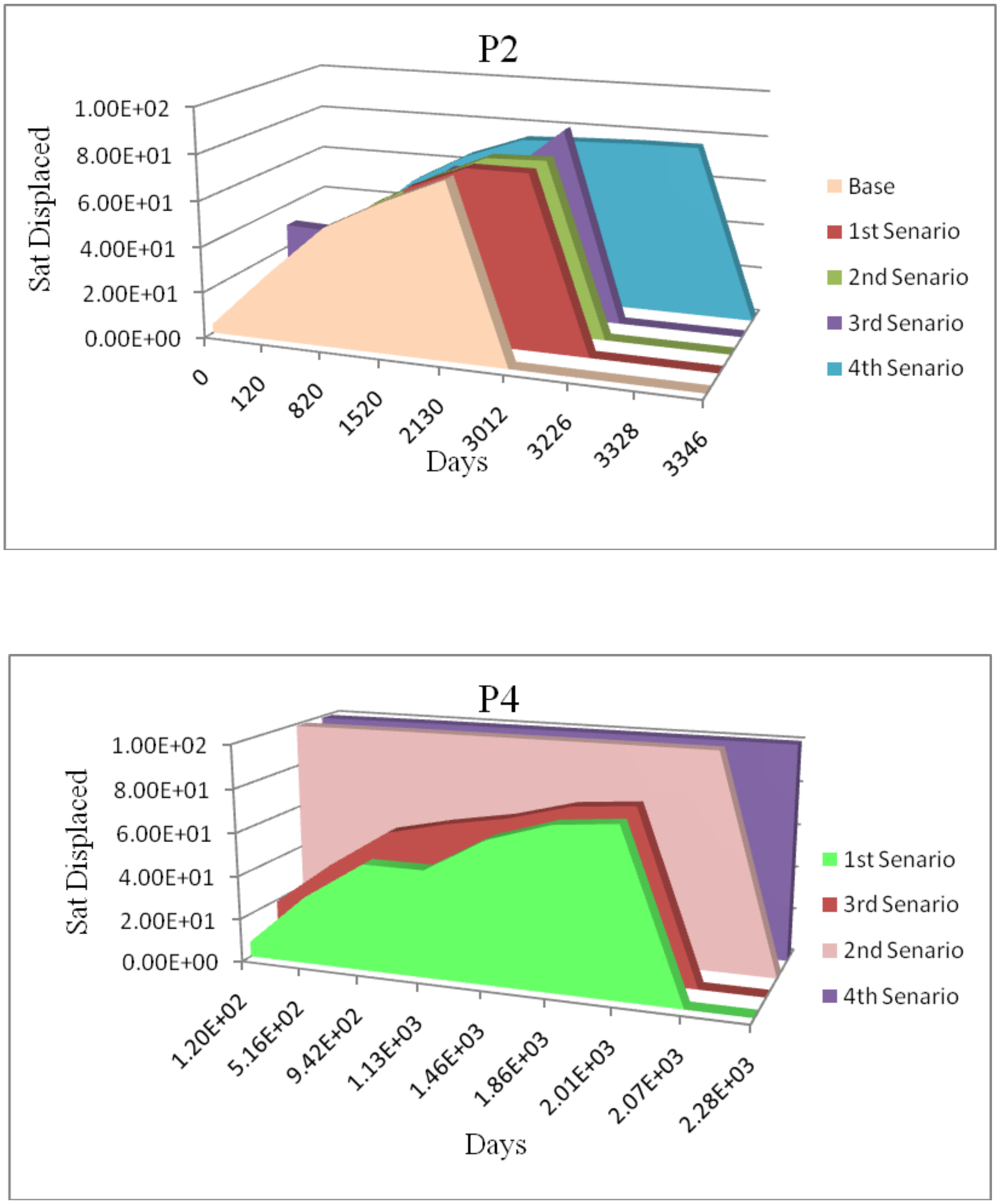


Figure.4-Saturation Displaced for area related to P2 and P4

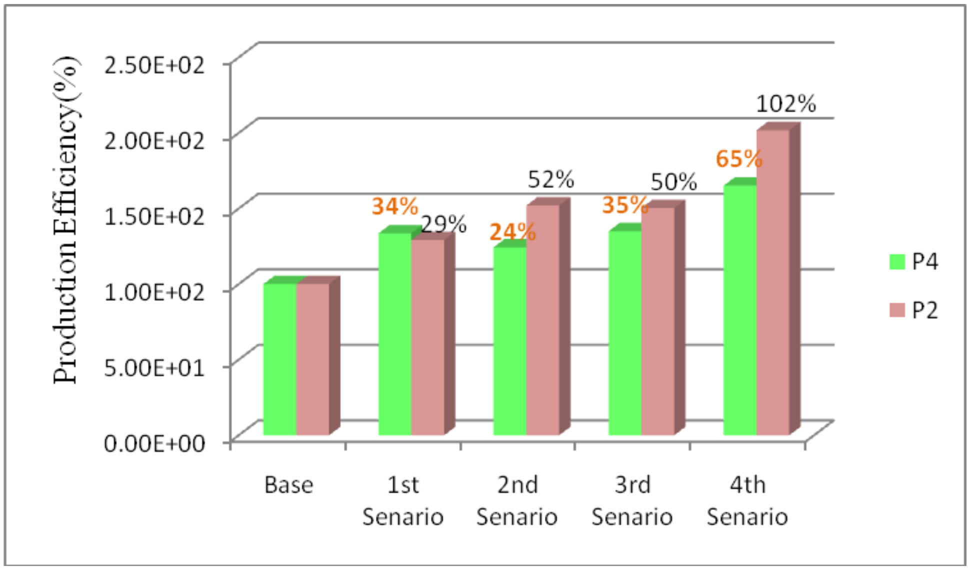


Figure.5- Production Efficiency for P2 and P4