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Field Scale Simulation Study of Miscible Water Alternating CO_2 Injection Process in Fractured Reservoirs

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Abstract

Vast amounts of world oil reservoirs are in natural fractured reservoirs. There are different methods for increasing recovery from fractured reservoirs. Miscible injection of water alternating CO_2 is a good choice among EOR methods. In this method, water and CO_2 slugs are injected alternatively in reservoir as miscible agent into reservoir. This paper studies water injection scenario and miscible injection of water and CO_2 in a two dimensional, inhomogeneous fractured reservoir. The results show that miscible water alternating CO_2 gas injection leads to 3.95% increase in final oil recovery and total water production decrease of 3.89% comparing to water injection scenario.

Keywords

Simulation Study, CO_2, Water Alternating Gas Injection, Fractured Reservoirs

1. Introduction

Miscible gas injection is one of the most important mechanisms of enhanced oil recovery from fractured reservoirs. Miscible gas injection may liberate and lead to production of a lot of amounts of oil that is entrapped into matrixes. Recovery from fracture-matrix system in laboratory scales started from 1970. Thompson and Mungan investigated results of laboratory experiments of gravity drainage in a fractured porous media under first contact miscible conditions. Basically, they compared replacement velocity with critical velocity and investigated its effect on oil recovery factor [1]-[5]. Water alternating gas injection is an effective method for controlling high mobility of gas in horizontal flooding which is used in so many reservoirs around the world and reported as

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successful operation. On the other hand, immiscible water alternating gas injection in oil reservoirs is not common [2]. Application of immiscible water alternating gas injection in USA is usually limited to onshore reservoirs. There are so many gas types with different characterizations used in miscible injection. Although many miscible gases include CO_2 and hydrocarbon gases, abundance of CO_2 and technical availability is an important parameter for improving miscible gas injection in USA [3]. Oil recovery factor using water alternating CO_2 gas injection is more than water injection, CO_2 injection, and hot CO_2 injection. Because of gas mobility, it penetrates into places which are unavailable during common injections [4].

Water flooding is an EOR method. One of the problems of water flooding is that the ions in water may be incompatible with reservoir fluid. It can lead to problems in ionic equilibrium which causes precipitation of heavy components of oil that can be a serious challenge in recovery from reservoir. Miscible water alternating CO_2 solves this inconvenience. Purpose of this study is to compare water injection and water alternative CO_2 gas injection and investigation of its effect on recovery factor and water cut from reservoir.

2. Interpreting Reservoir Model

Simulation of different phases in this project is done using a commercial software. Water flooding and water alternating CO_2 gas is tested in a two dimensional 1 × 25 × 25 grid block network.

A reservoir with all of no-flow boundaries are studied in this project. There are two phases of water and oil and no free gas. This model indicates a 200 acre (about 2950 ft × 2950 ft) reservoir. There is an injection well named INJ at the center of reservoir (at 13:13:1 grid block) and four production wells at the corners named P1, P2, P3, and P4. Production well P1 is at 1:1:1 grid block, P2 at 25:1:1, P3 at 1:25:1, and P4 is placed at 25:25:1.

Figure 1 depicts this reservoir from above. The wells are drilled with a 40 acre distance from each other and all of the wells started to production simultaneously. Depth from top surface of reservoir is 10,000 ft and reservoir net pay thickness is 50 ft.

Basic geological characteristics and different rock properties (porosity, absolute permeability, etc.) in each grid are specified at center of the grid block. Empty space volumes of blocks and inter-block transmissibility are calculated via simulator. The keywords used in this part depend on selected geometry option in initialization section. Cartesian, block-centered geometry option is used in this project. Porosity distribution is assumed to be homogeneous in reservoir and its value is 25%. But, permeability is inhomogeneous and has an average amount of 60 mD for the basic case. Original fluids in place including water and oil are saturated. Water occupies 20 percent of empty volumes and oil 80 percent. Residual oil and connate water are 15% and 20%, respectively. Initial pressure of reservoir is 4500.

As explained before, all the wells are drilled vertically. Inside diameter of wells are 0.5 ft and their depth is 10,050 ft and all the wells started production simultaneously (1st January 2010). All the wells produced for a period of 10 years with a constant 6 month controllers. There are 20 controller for each well in production period. Injection program has a controlled rate. Injected water rate is 3500 STB/day and injection rate of water alternating CO_2 is 3500 STB/day and 3000 Cuf/day, respectively. Production wells bottom-hole pressures are considered as constraints in water flooding. Minimum acceptable bottom-hole pressure is considered 2500 psi.

3. PVT Properties of Reservoir Fluids

Reservoir fluids are water and oil. The oil contains a constant and homogeneous saturation of dissolved gas with amount of 0.2 MSTB/day. Oil bubble pressure assumed 400 psi. Oil viscosity in base pressure of 4500 psi is 2.4 cp. Oil formation volume factor is 0.972. At the condition that water density assumed 2.4 lb/cuft, oil density would be 56 lb/cuft. Water compressibility assumed 3×10^{-6} psi^{-1}. At basic pressure of 4500 psi water formation volume factor assumed 1.0034 rb/stb and water viscosity assumed 0.96 cp. Rock compressibility assumed 1.4×10^{-6} psi^{-1}.

4. Water Injection and Miscible Water Alternating CO_2 Gas Injection Simulation

First, permeability distribution is depicted in **Figure 2**.

Cumulative oil production and water cut decrease during water flooding and miscible water alternating CO_2 gas flooding is shown in **Figure 3** and **Figure 4**, respectively. After miscible water alternating CO_2 gas injection, cumulative produced oil increases 3.95 percent and cumulative produced water decreases 3/89 percent.

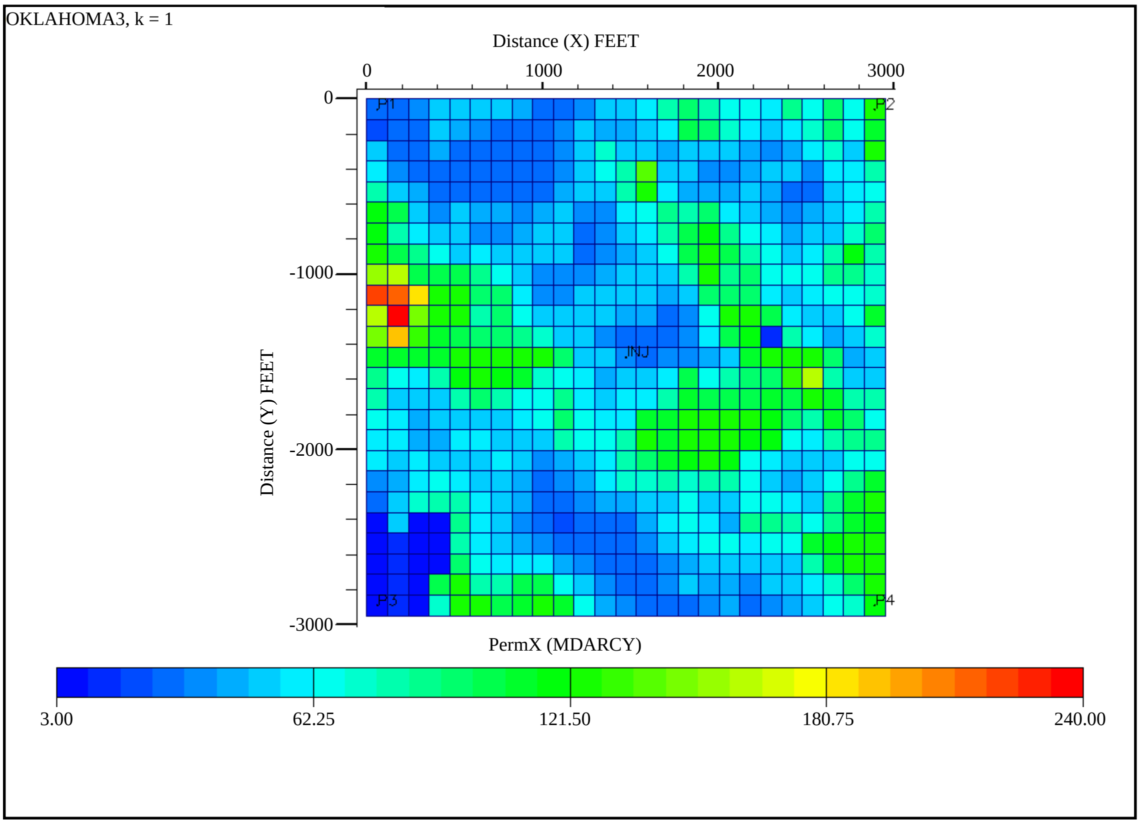

Figure 1. View of model from above that show permeability distribution in field and places of wells.

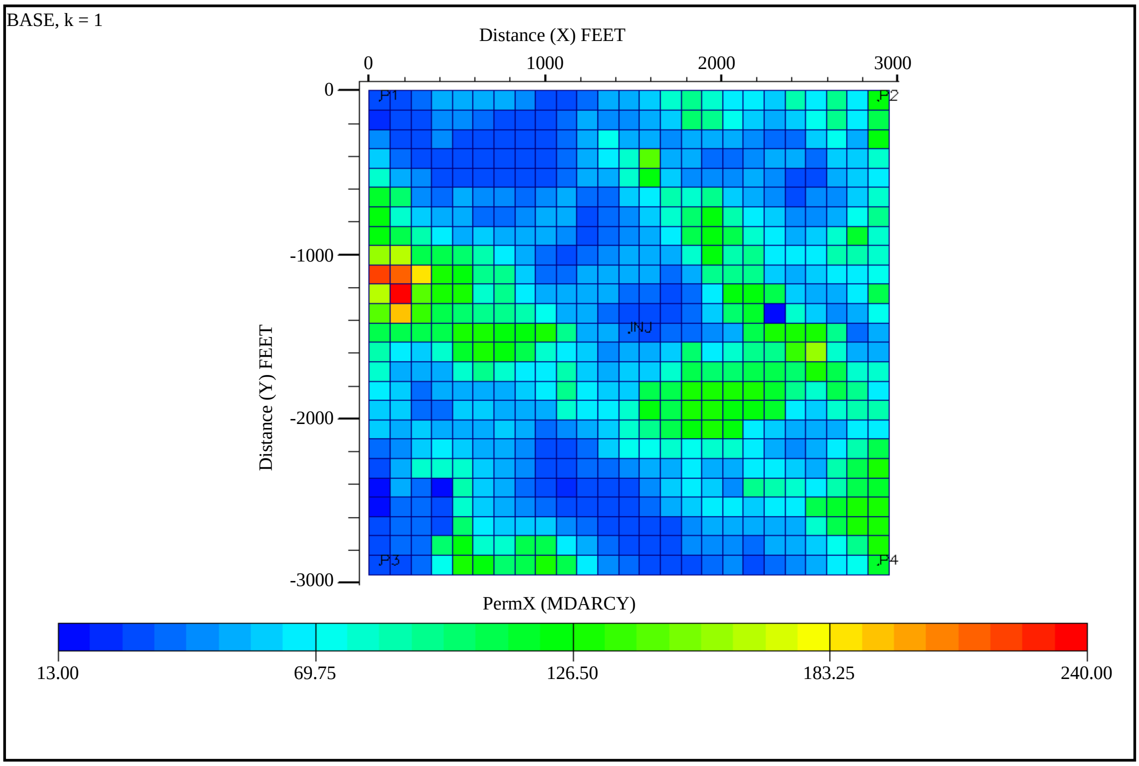

Figure 2. Assumed reservoir permeability distribution.

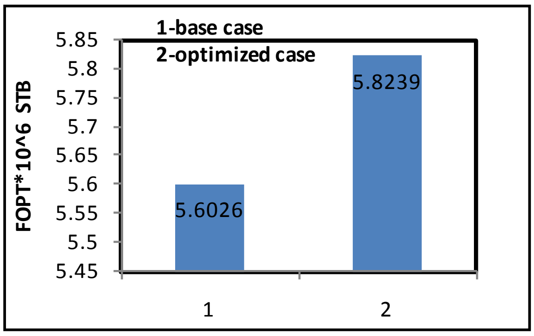

Figure 3. Cumulative produced oil in water flooding (1) and miscible water alternating CO_2 gas injection (2).

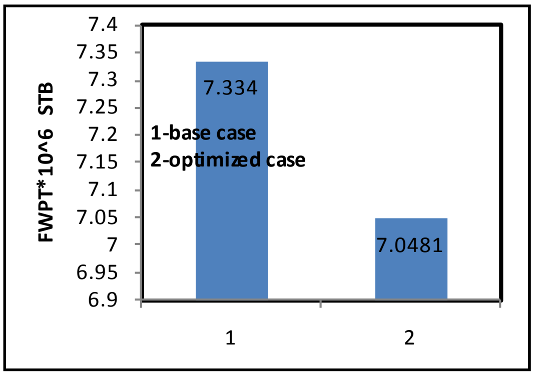

Figure 4. Cumulative produced water in water flooding (1) and miscible water alternating CO_2 gas injection (2).

Effect of miscible water alternating CO_2 gas injection on water saturation is shown in **Figure 5** and **Figure 6**.

There is a noticeable change in water saturation distribution in all over the reservoir before the breakthrough. This can be seen in **Figure 5** and **Figure 6**. **Figure 5** shows water saturation distribution during water injection and **Figure 6** shows water saturation distribution after miscible water alternating CO_2 gas injection. Via comparing **Figure 5** and **Figure 6** it is obvious that water saturation is more homogeneously distributed all thorough the reservoir in **Figure 5**. This means that sweeping efficiency increases after miscible water alternating CO_2 gas injection.

Figure 7 shows water cut for all the wells for water injection and **Figure 8** shows water cut for all the wells in miscible water alternating CO_2 gas injection.

Water cuts of four wells are shown in **Figure 7** and **Figure 8** before and after miscible water alternating CO_2 gas injection. Via comparing **Figure 7** and **Figure 8** it is obvious that water breakthrough time and water cut curves almost tend to cover each other.

Water production rate curve for each production well during water flooding and miscible water alternating CO_2 gas injection also are shown in **Figures 9-12**.

By comparing above figures it can be seen that water production rate of production wells P1 and P3 increases after miscible water alternating CO_2 gas injection and water breakthrough happens earlier. It is because of bottom-hole pressure decrease of production wells P1 and P2 and oil production rate increase from these wells. Also, it is obvious that water production decreases from production wells P2 and P4 after miscible water alternating CO_2 gas injection and water breakthrough time is delayed. It is because of bottom-hole pressure increase of production well P2 and P4 and decrease in produced oils of these wells. Cumulative produced oil and water vs. time curves during water injection and miscible water alternating CO_2 gas injection are shown in **Figure 13**.

Cumulative produced oil and water plots are shown above. Via comparing these curves it is obvious that cumulative produced oil is increased after miscible water alternating CO_2 gas injection and cumulative produced water is decreased. In this project, cumulative produced oil is increased 3.95% and cumulative produced water is decreased 3.89.

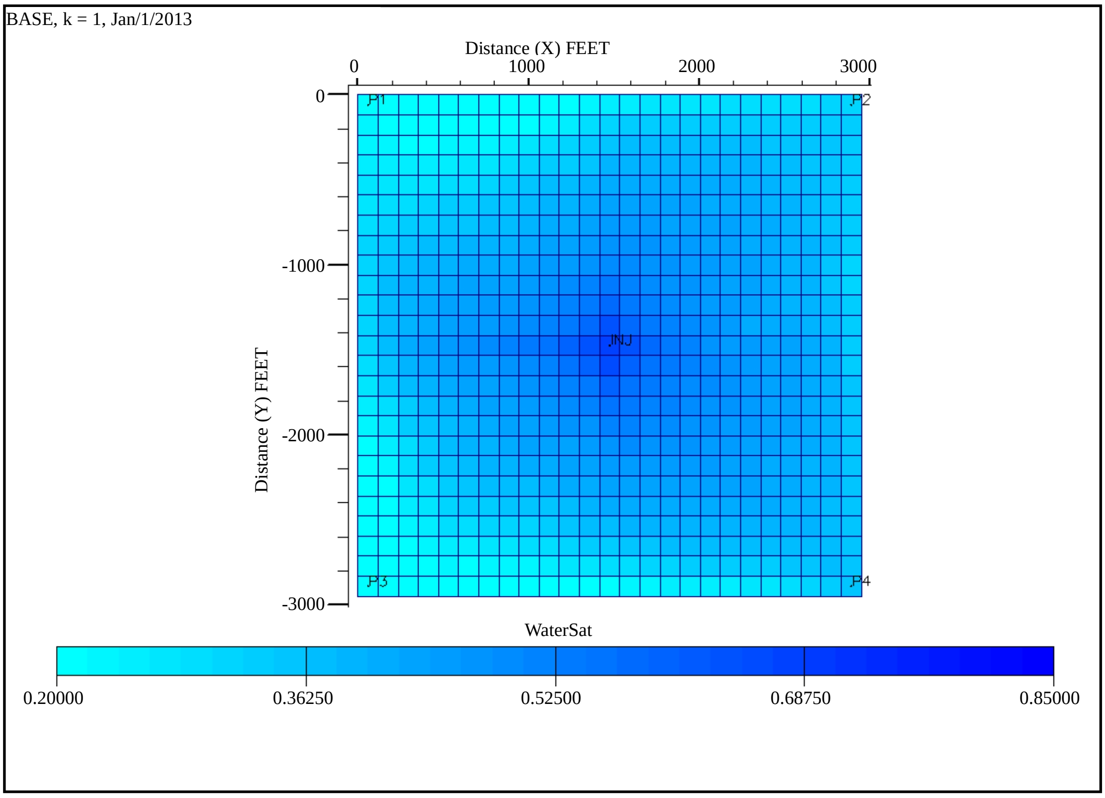

Figure 5. Water saturation distribution in water flooding.

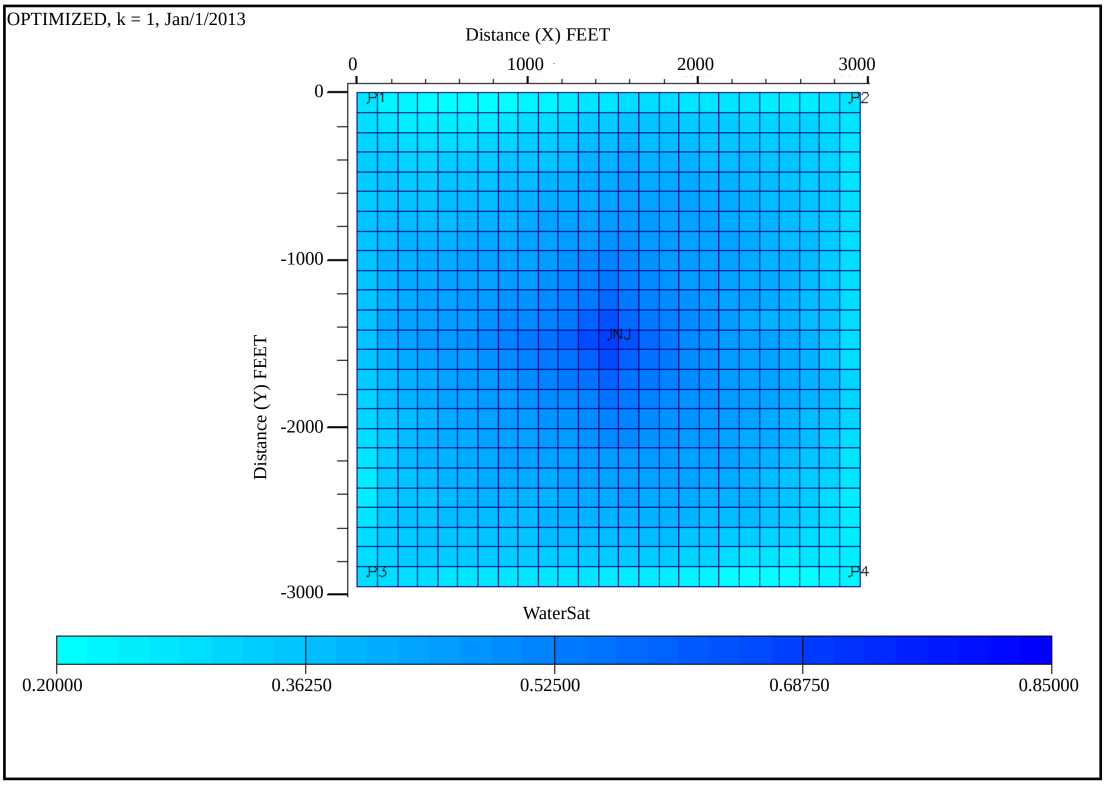

Figure 6. Water saturation distribution in miscible water alternating CO_2 gas injection.

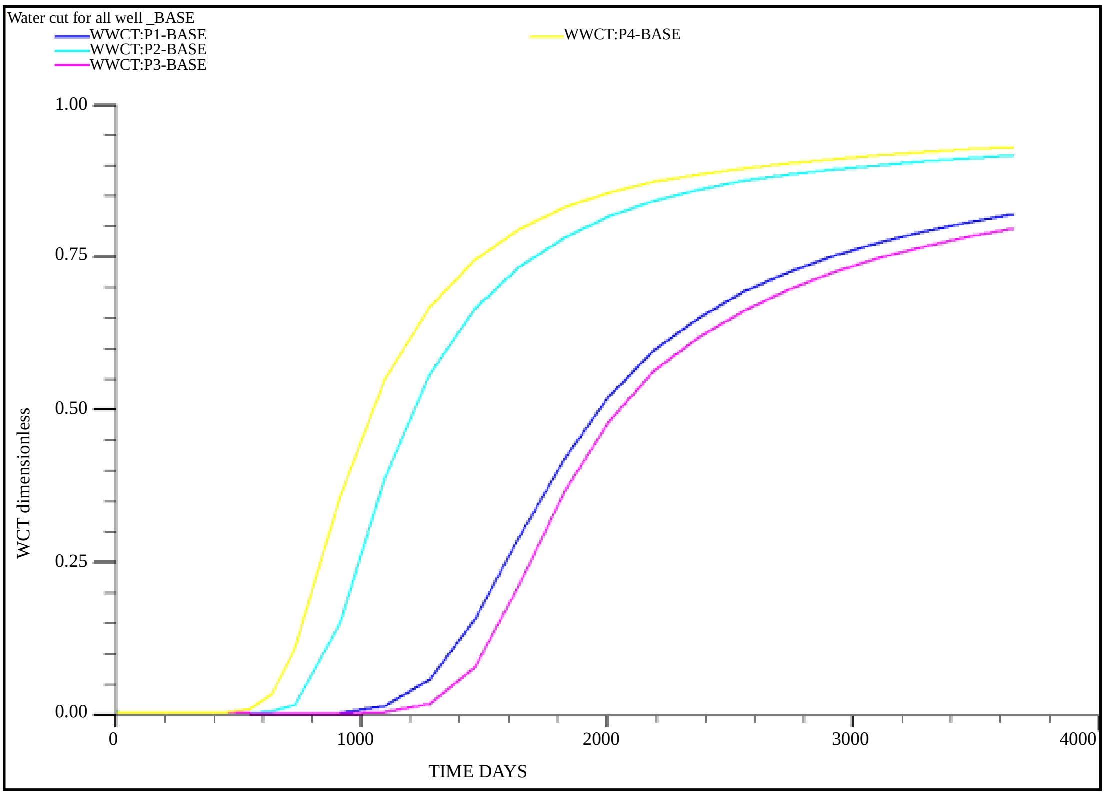

Figure 7. Water cut curves for all the wells during water injection.

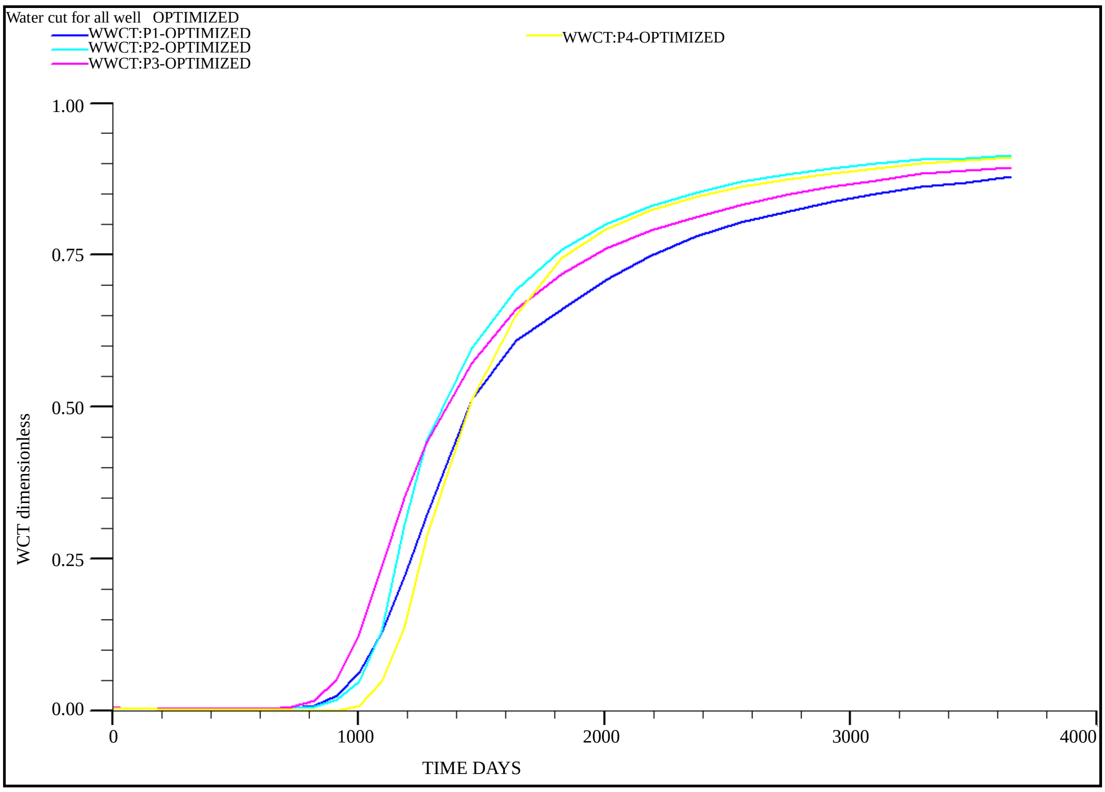

Figure 8. Water cut curves for all the wells during miscible water alternating CO_2 gas injection.

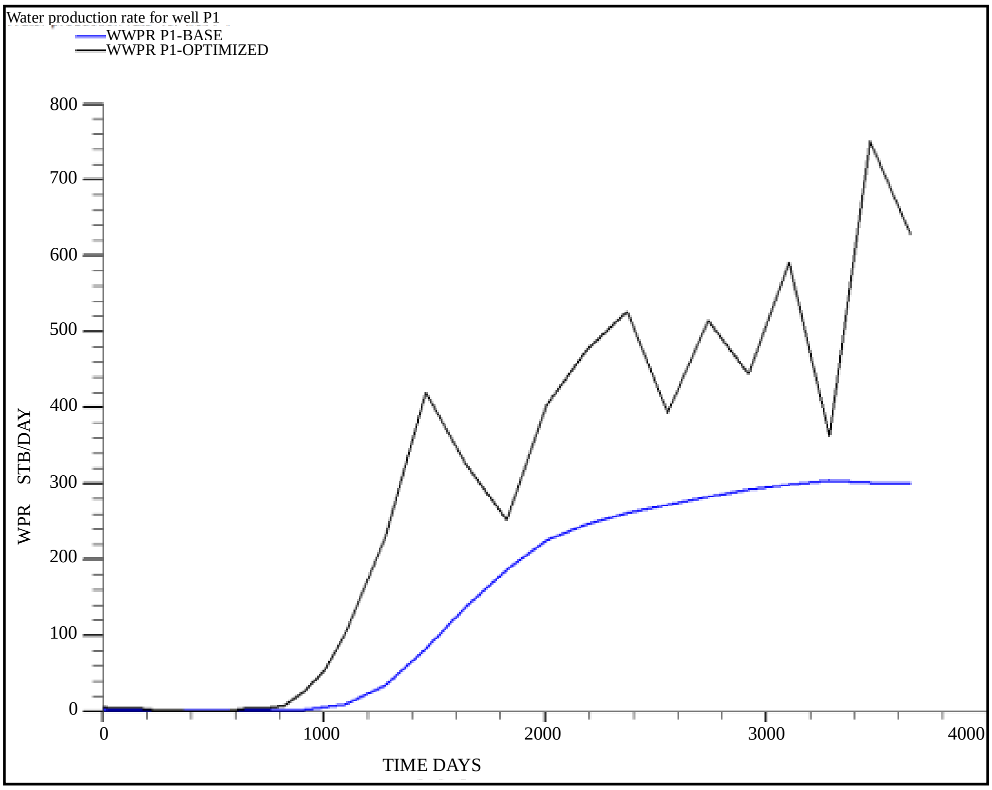

Figure 9. Water production rate from well P1 during water injection and miscible water alternating CO_2 gas injection.

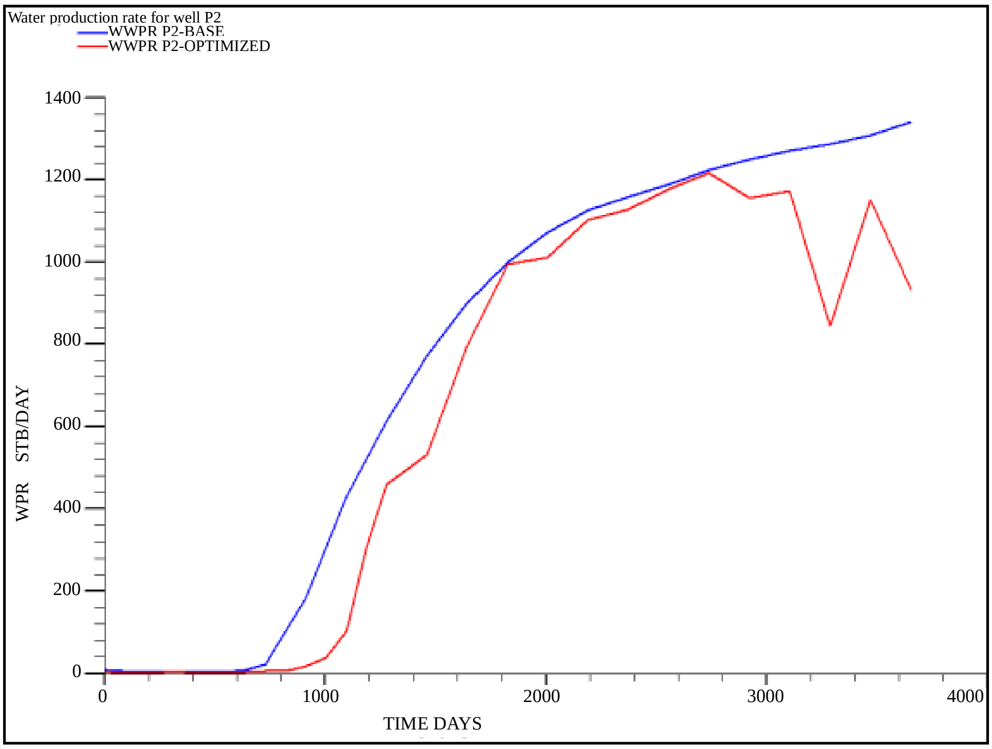

Figure 10. Water production rate from well P2 during water injection and miscible water alternating CO_2 gas injection.

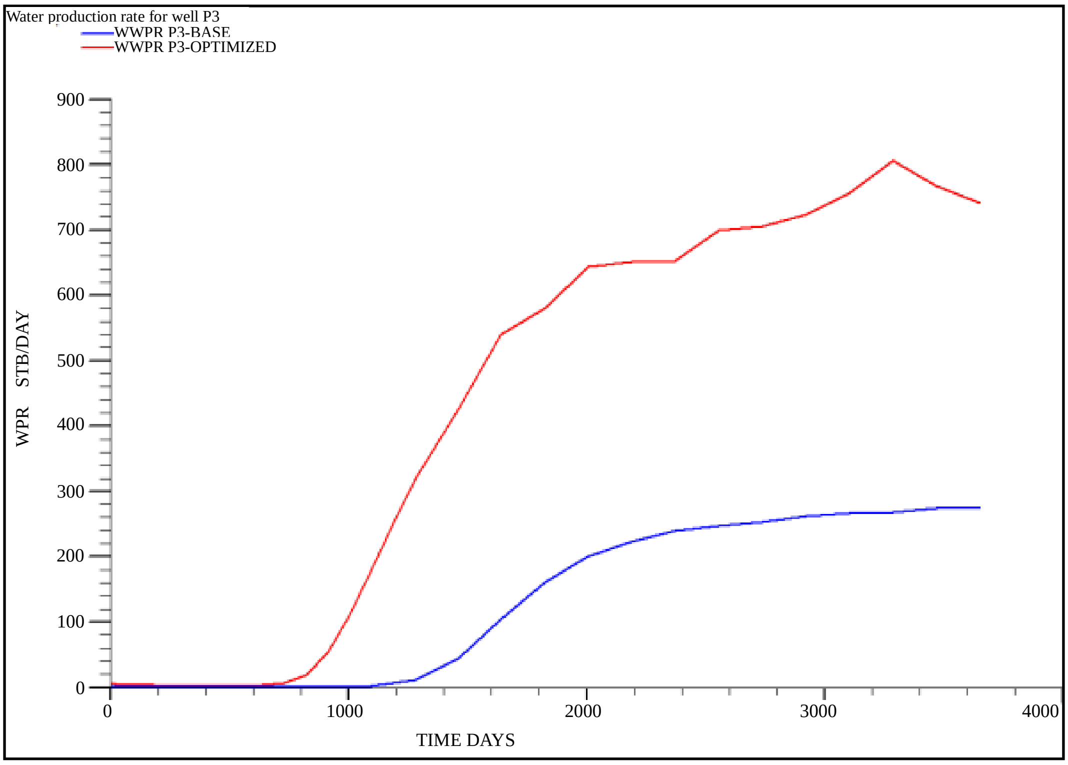

Figure 11. Water production rate from well P3 during water injection and miscible water alternating CO_2 gas injection.

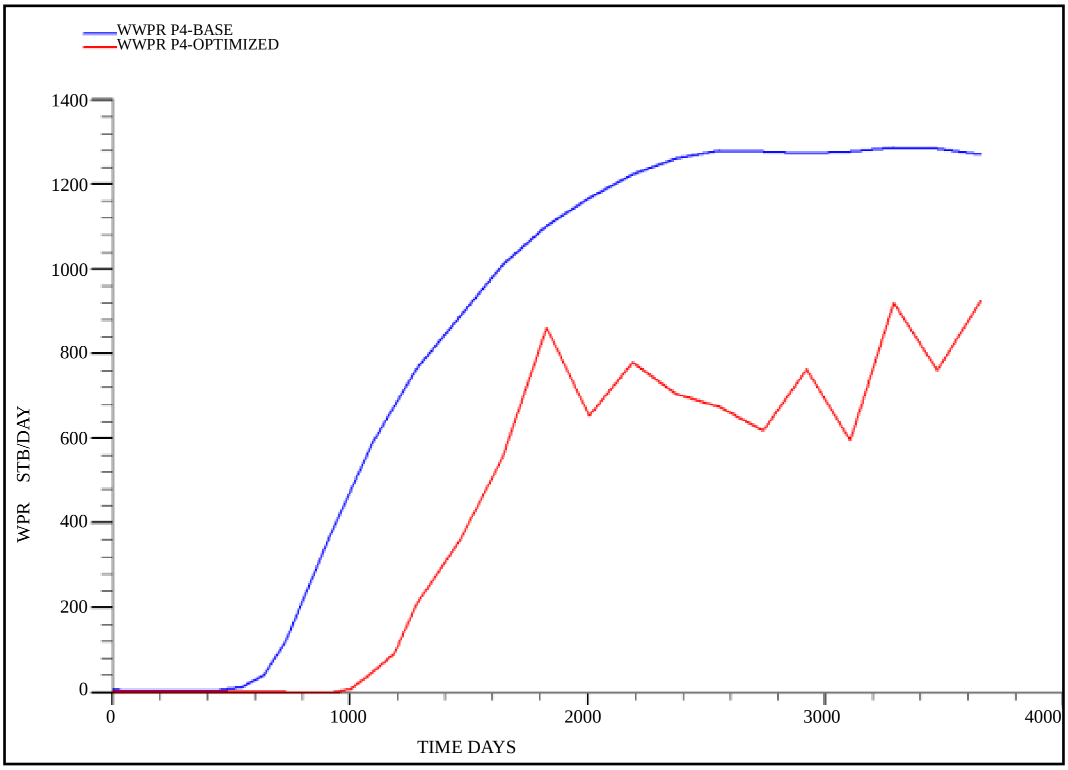

Figure 12. Water production rate from well P4 during water injection and miscible water alternating CO_2 gas injection.

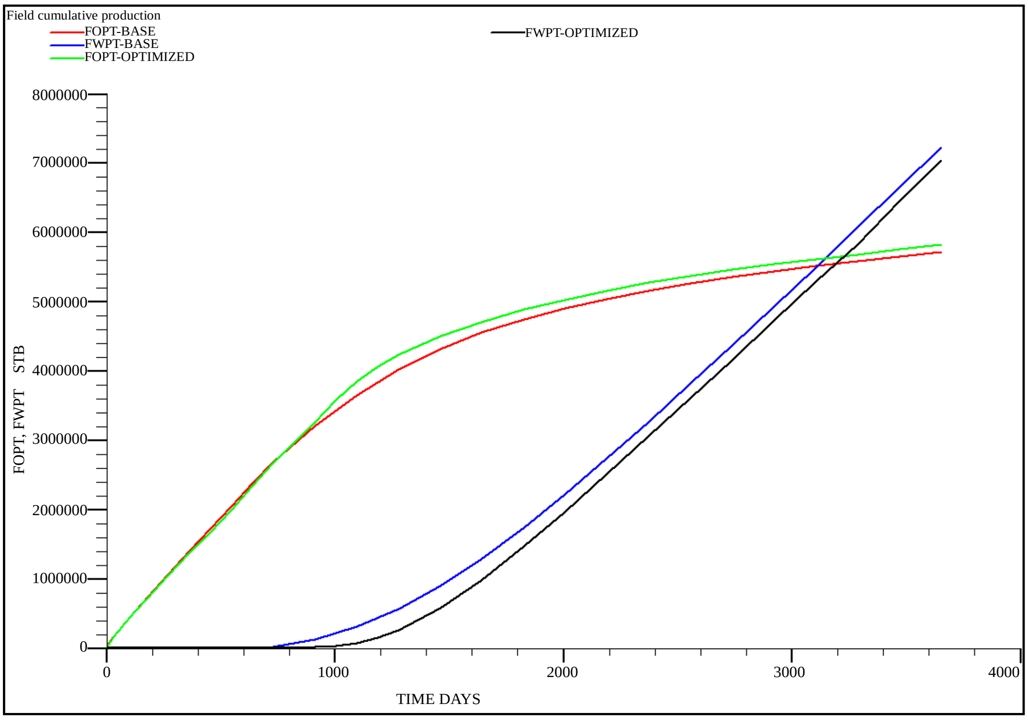

Figure 13. Cumulative produced oil and water during water injection and miscible water alternating CO_2 gas injection.

5. Conclusions

- Comparing water injection and miscible water alternating CO_2 gas injection, scenarios show that miscible water alternating CO_2 gas injection scenario has more efficiency comparing to water injection and produced oil and recovery factor would be greater in this method.
- Comparing water injection and miscible water alternating CO_2 gas injection, scenarios show that produced water during water miscible water alternating CO_2 gas injection scenario would be less comparing to water injection method.
- Water saturation during water injection scenario is more homogeneous all over the reservoir comparing to miscible water alternating CO_2 gas injection scenario. This would mean that sweep efficiency increases after miscible water alternating CO_2 gas injection.
- Most of Iranian oil reservoirs are fractured. So described method of miscible water alternate CO_2 injection is a suitable and recommended choice to be used in Iranian oil reservoirs.

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