FEASIBILITY ANALYSIS OF THE STEAM FLOODING PROCESS IN AN IRANIAN FRACTURED LIGHT OIL RESERVOIR

^a Bagheripour Haghighi, M.¹; ^a Shabaninejad, M.

^a South Zagros Oil & Gas Production Company, NIOC

ABSTRACT

Steam flooding is applied to heavy and extra-heavy oil reservoirs, but it may be used in light oil reservoirs when water injection does not work effectively. In this simulation study, the feasibility of the steam flooding method applied as enhanced oil recovery process to one Iranian oil-wet fractured reservoir is investigated. For this purpose, a simulation model based on a sector of this reservoir was prepared and history matched with available production data. Steam flooding has been simulated for this reservoir and has been compared with conventional water injection process. A sensitivity analysis has been performed in order to study the effects of important parameters. The results show that the steam flooding process is likely to be profitable for this reservoir, when compared with water injection, improving the oil recovery factor by nearly 14 %.

KEYWORDS

simulation; steam; light oil; Iranian reservoir; optimization

¹ To whom all correspondence should be addressed.

Address: South Zagros Oil & Gas Production Company, NIOC, Shiraz, Iran.

Telephone: +989179154990 | e-mail: MBPH471@gmail.com

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1. INTRODUCTION

Steam injection into heavy oils has been well characterized over the last 40 years, and, while steam has been injected into light oils almost as long, the mechanisms and effectiveness of this process are much less understood (Hoffman and Kovscek, 2004). Blevins et al. (1984) found that, regardless of differences in effective recovery mechanisms in heavy and light oil reservoirs, this process is an efficient enhanced oil recovery (EOR) method.

Steam flooding has wide application in recovery of heavy and light oil reservoirs. In the 1960s, one of the first light-oil steam flood field trials was initiated at the Brea Field near Los Angeles, California (Volek and Pryor, 1972). It should be emphasized that the development of further light oil projects was not as rapid as those on heavy oil, because water flooding is seen as less risky, with a lower initial investment than steam injection.

In 1970, Chevron Petroleum Technology Company applied steam to USA light oil reservoirs. Hong (1986), as a researcher of this company, had been studying steam flooding in USA light oil reservoirs for ten years. The results showed that steam flooding is a good alternative for water injection. Also steam distillation is a main recovery mechanism in light oil steam flooding. Consideration of the details of reservoir geology is critical for evaluation of light oil steam flooding projects. The resulting steam projects may be considerably different in their implementation from conventional heavy oil steam floods in injection rates, well spacing and process optimization (Dehghani and Ehrlich, 2001).

Physical and numerical simulation of steam flooding to Lake Maracaibo reservoir, in Western Venezuela, showed acceleration in oil production with an increase of 14 to 20 % of oil recovery with respect to the original oil in place (OOIP) after water flooding. Additionally, the use of steam drive as a primary recovery method showed a further 5 % increase in cumulative oil production (Ovalles et al., 2002).

Results of an experimental study on steam flooding in the Middle East oil-wet reservoirs showed that water injection does not work effectively for such reservoirs. Also, oil thermal expansion and gas-drive mechanisms mostly

contribute to the ultimate oil recovery (Verelan et al., 2008). Several other successful field tests were reported in the literature focusing on light oil reservoirs (Olsen et al., 1992; Perez-Perez and Gamboa, 2001).

The objective of this study is to determine if steam flooding method is a suitable candidate to be implemented in one Iranian light oil reservoir. The CMG thermal simulator (STARS module) with an option for dual permeability concept was chosen for this simulation study. In fact, in this simulation study the fluid flow is considered for both matrix and fractures.

2. MATERIALS AND METHODS

2.1 Model description

The reservoir under investigation, an Iranian oil-wet carbonate reservoir, was named "reservoir A". It is a giant, highly fractured reservoir located in southwestern Iran, containing a huge amount of original oil in place (about 28 billion barrels), and has been producing oil for about 40 years now. In Table 1, some of the important properties of this reservoir are summarized. However, oil production from this reservoir is decreasing; thus, it is a good candidate for enhanced oil recovery methods. In order to simulate steam flooding techniques, a sector of this reservoir was selected as follows. It has a low dip to ensure that all oil recovery is related to steam flooding and not gravity drainage. In addition, this sector has less heterogeneity compared with the rest of the reservoir. In this sector there are four wells which produce oil by natural depletion. The minimum bottom hole

Table 1. Some properties of reservoir "A".

Property	Value
Area of the reservoir (acre)	3036
Original oil in place (barrel)	1×10^9
Solution gas density (lbm/m ³)	16.49
Dead oil density (lbm/m ³)	2.21×10^{-6}
Water-oil contact (ft)	8796.6
Gas-oil contact (ft)	4642.5
Water compressibility (1/psi)	2.21×10^{-6}
Oil compressibility (1/psi)	2.099×10^{-5}
Initial pressure at 7546 ft (psi)	4350
Initial temperature (°F)	172.2

pressure for these wells is about 1200 psi. By history matching with available production data, this sector was prepared in order to apply steam flooding.

3. RESULTS AND DISCUSSION

3.1 Location of new injection wells

Two new injection wells were drilled in the desired sector. Sensitivity runs were made to determine their appropriate locations. Three possible locations were investigated: the edge water, five spot patterns and nine spot patterns. Figure 1 shows cumulative oil production at three different situations. It is shown that the injection wells with five spot patterns have the highest ultimate oil recovery. Figure 2 shows the selected sector with location of new injection wells.

Figure 1. Cumulative oil production as a function of injection wells location.

Figure 2. The 3D schematic of the model.

3.2 Appropriate injection time

In this section, it is supposed that four production wells will produce oil naturally from 2010 for the next 20 years with the same condition

as previous years. The total oil rate for this sector in this 20-year period was assigned at 20000 barrels per day. Figure 3 shows oil production rate from the beginning of the field development until 2030. According to the results, due to increasing pressure drop, the oil rate is supposed to decrease by 2020. A sensitivity analysis was performed in order to determine the best time of steam injection. Figure 4 shows the results, indicating that the best time of injection should be from 2018. This selection was made based on good performance and higher cumulative oil production.

Figure 3. Oil production rate by natural depletion.

Figure 4. Cumulative oil production as a function of time for different injection times.

3.3 Steam flooding evaluation

In this part, the steam flooding process was simulated for this reservoir sector. Steam must be injected for ten years (from 2018) into the injection wells as shown by the model in Figure 2. Also, water flooding was applied under the same conditions for comparison of its performance and

effectiveness. In Figure 5 the results of this work show that steam injection has higher cumulative oil production rate compared to water injection. Table 2 summarizes the final results. It should be pointed out that incremental oil production and recovery factor is counted with respect to 2010.

Naturally fractured reservoirs are not good candidates for conventional EOR processes like water flooding. The high fracture permeability prevents significant pressure differential across oil-bearing matrix blocks (Bychkov et al., 2008). In Middle East fractured carbonates, the matrix rock is commonly oil-wet or mixed wet, so other methods are suggested instead of water injection. Steam flooding is one of these alternative processes which could improve oil recovery better than water injection, as shown above. One of the main reasons is that, with the injection of steam, heat penetrates particular regions (for example, low permeability regions) via conduction, even when injected fluids such as water are not able to do so.

3.4 Optimization of operational parameters

An extensive sensitivity analysis was performed to determine the effect of input and modeling parameters before conducting the simulation study reported here. The important steamflood operational parameters include the following concepts:

- Steam injection rate
- Steam quality
- Injection well perforation

3.4.1 Steam injection rate

As the steam injection rate increases, the cumulative oil production from the field increases slightly. There are several criteria for determination of the best injection rate, including economical factors, steam production cost, steam generator

Figure 5. Cumulative oil production as a function of time for different types of process.

capacity and cost, as well as injectivity, wellbore facilities, surface facilities, oil price, among many others (Bahonar et al., 2007).

In this study, the best steam injection rate was optimized according to the steam-oil ratio, produced water and gas-oil ratio. For this purpose, four injection rates have been investigated. Figure 6 shows the cumulative oil production for different steam injection rates. As expected, the cumulative production increase with increasing steam injection rate.

Figure 6. Cumulative oil production as a function of time for different steam injection rates.

A steam-oil ratio (SOR) between 1 and 1.7, producing a gas-oil ratio (GOR) lower than 1000 SCF/STB and water cut lower than 50 % give reasonable amounts of oil, gas and water from the

Table 2. Comparison of water injection with steam flooding.

Process	Cumulative oil production (bbl)	Incremental oil production (bbl)	Recovery factor (%)
Natural depletion	5.4395×10^8	1.1845×10^8	9.13
Water injection	5.5384×10^8	1.2834×10^8	10.24
Steam flooding	5.8661×10^8	1.7004×10^8	14.17

Table 3. Final simulation data for different steam injection rates.

Injection rate (bbl/day)	Steam-Oil Ratio (SOR)	Gas-Oil Ratio (GOR) (SCF/STB)	Water cut (%)	Cumulative production(bbl)	Incremental recovery factor (%)
4000	1.32	463	30	5.6951×10^8	13.75
6000	1.37	1375	29	5.7122×10^8	13.79
8000	1.48	917	39	5.7748×10^8	13.94
10000	1.63	544	43	5.8661×10^8	14.17

Table 4. Final simulation data for different steam qualities.

Steam quality	Incremental cumulative production (bbl)	Incremental recovery factor (%)
0.4	5.8516×10^8	14.13
0.6	5.8636×10^8	14.16
0.8	5.8661×10^8	14.17
0.95	5.8748×10^8	14.19

field. Therefore the best injection rate was selected based upon these criteria. Table 3 demonstrates that the injection rate of 10000 bbl/day is the best injection rate for this reservoir.

3.4.2 Steam quality

In this part of the study, different steam qualities were investigated to determine the best specification. Steam quality of 0.4, 0.6, 0.8 and 0.95 were assessed. The results shown in Figure 7 confirm that, unlike heavy oil reservoirs, steam quality has no significant effect on oil production in this light oil reservoir. Therefore, for economic purposes, the steam quality was fixed as low as possible. This is especially justified because light oil reservoirs have low initial viscosity, and consequently do not require a large amount of latent heat in the application of the recovery method. Table 4 summarizes the final simulation data for different steam qualities, and the final selection of the 0.8 ratio was made for this reservoir.

Figure 7. Cumulative oil production as a function of time for different steam qualities.

3.4.3 Injection well perforation

Well completion strategy is a very important operational parameter. By sensitivity analysis, the best injection well layers perforation were determined for this reservoir. Three different scenarios were studied, as follows:

- Case 1: four bottom layers were perforated.
- Case 2: four top layers were perforated.
- Case 3: all layers were perforated.

The results are shown in Figure 8, where it can be seen that case 2 is the best perforation strategy. This can be explained in terms of steam, water and oil gravities. Steam has low gravity compared to oil and water, therefore it goes to the upper layers and pushes the oil down to the bottom layers. Also, early water breakthrough can be delayed in this case. In fact, if bottom layers were perforated, it would be seen that, as the steam condensates and

Figure 8. Cumulative oil production as a function of time for different well perforations.

changes into water, it moves from the top layers and quickly reaches the producer wells, whilst large amounts of reservoir area would be kept unswept. It should be noted that, although case 3 gave almost the same results, case 2 was chosen for this reservoir because of lower well completion costs. Table 5 illustrates the final simulation data of these cases.

Table 5. Final simulation data for different well perforations.

Perforation case	Incremental cumulative production (bbl)	Incremental recovery factor (%)
Case 1	5.8321×10^8	14.08
Case 2	5.8661×10^8	14.17
Case 3	5.8691×10^8	14.17

4. CONCLUSIONS

In this communication, the feasibility of steam flooding process in one Iranian light oil reservoir was investigated. This study has led to the following conclusions:

- Steam flooding shows good performance and higher cumulative oil recovery with respect to water flooding and improves the oil recovery factor up to 14 %.
- The best steam injection wells location and time of injection have been determined for this reservoir.
- As the steam injection rate increases, cumulative oil production rate increases. For optimum injection rates, parameters such as steam-oil ratio (SOR), gas-oil ratio (GOR) and water cut must be considered.
- Unlike heavy oil reservoirs, steam quality has no significant effect on oil recovery for light oil reservoirs. Therefore, for economic reasons, the steam quality should be kept as low as possible.
- The best injection well perforation strategy in this reservoir was obtained with four top layers completed.

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