JEAS
Journal of Economics and Administrative Sciences
E-ISSN: 2148-1792 P- ISSN: 1302-2024
Volume 5, Supplement Issue 2
www.jeasweb.org

Study and Modeling of Carbonated Water Injection on Increasing Oil Recycling

Komeil Amirkhanlou
Master of Petroleum Engineering, majoring in Research Engineering, Islamic Azad University, Science and Research Branch, Tehran.

ABSTRACT

Usually, a large amount of oil after natural production remains in the reservoirs. There are different techniques for increasing oil extraction. Among the techniques, water and gas injection are expensively applied. On the other hand, carbon dioxide is progressively used as a factor in increasing extraction in oil reservoirs. Furthermore, these reservoirs act as a platform for the safe disposal of carbon dioxide from excessive consumption of fossil fuels, which will also improve the climate and weather and the satisfaction of national and international institutions to reduce carbon dioxide emissions. Compared to gases such as methane, ethane, and propane, the solubility of carbon dioxide in water is higher. Thus, carbonated water injection is a suitable approach to increase oil recovery in reservoirs. According to previous studies, carbonated water has been used as an injection agent for more than 50 years. This research focuses on a sector model to investigate the impact of carbonated water injection. First, the efficiency of each scenario was tested by examining natural production and then by water injection and carbonated water injection. Finally, the effect of carbonated water injection duration was investigated. Due to the solution of carbon dioxide in the oil at the reservoir, carbonated water injection had a better performance than water injection. Also, by examining the effect of carbonated water injection as continuous and in a short time, it was found that the positive performance of carbonated water injection is not reduced by injecting carbonated water for five years and water injection in continue. It was the most appropriate scenario in this study.
Keywords: Carbonated water injection, increase of extraction, oil recycling, carbon dioxide.

Introduction

About 86% of the world energy consumption is provided by oil, gas, and coal. Due to rising global energy consumption, we predict that demand for fossil fuels will increase in the coming years. However, the world oil reserves have reduced, and new exploration methods have become more difficult and costly. Today, there is an approach called "increasing the recovery factor from oil fields" to use the current situations and resources better. The recovery factor typically increases in three different phases over the life of an oil reservoir. These phases are called primary, secondary and tertiary recycling, respectively. The primary recovery is performed by the natural oil flow and creating a pressure drop along the reservoir to the production wells. However, a significant amount of Oil In Place (OIP) in the reservoir is trapped by the pressure drop due to oil production from the reservoir. At this stage, the oil recovery factor is about 5-20%

of the oil in place in the reservoir [1]. Secondary recycling increases the reservoir recovery factor to 20 to 30% of the oil in place by injecting a gas or liquid phase to compensate for the pressure drop due to production [1]. The third recycling is divided into two methods: heat methods (such as steam injection) and Non-heat methods. Non-heating methods can be classified into two methods, including chemical (such as polymer and surfactant injection) and non-chemical (soluble gas injection). About 25-50% of oil in many world oil reservoirs remains in the reservoir even after the third recycling [1]. Therefore, there is a need to apply new processes to increase the oil recovery factor in this reservoir type. In general, secondary recycling methods involve the injection of a gas such as nitrogen and carbon dioxide and water injection or the intermittent injection of water and gas. Due to the conditions of rock and fluid inside the reservoir, the sweep efficiency is usually poor in these methods. Hence, secondary recycling methods are not normally economically feasible [2]. In recent years, the relationship between injectable fluid and oil in place has increased with intermittent injections of water and gas. However, the sweep efficiency is still low. Carbon dioxide is dissolved in water and then injected into the reservoirs to overcome this problem. This method is called carbonated water injection. The third non-heating method for recycling is used to increase the recovery factor in conventional oil reservoirs or heavy oil reservoirs. In recent years, several laboratory tests and studies have been performed to prove the influence of this method by Norse (1964), Tran et al. (2009), and Riyazi et al. (2009) [3-5]. However, this method is not yet used as a common method. Compared to other available gases, carbon dioxide is considered a soluble gas due to its high solubility in water. The contact surface between carbon dioxide and the oil phase increases with carbonated water injection. It increases the sweep efficiency. Carbon dioxide is transferred from the aqueous phase to the oil phase when an aqueous phase comes in contact with the oil phase. Norse by Buckley-Leverett's analysis on carbonated water injection in 1964 showed that reducing the viscosity and increasing the oil volume improves the oil recovery factor [3]. According to Riyazi studies in 2009 and Tran et al. In 2009, injection of carbon dioxide solved in water reduces the interfacial tension between oil and the aqueous phase [4,5]. In intermittent water and gas injection, displacement is optimized whenever the relative mobility is less than one. Increasing the injected gas viscosity and decreasing the relative permeability of the fluids reduce the relative mobility. Intermittent injection of water and gas reduces the gas phase mobility. The best displacement efficiency can be achieved by adjusting the water to gas ratio in each period. Due to the higher solubility of carbon dioxide in water compared to ethane, methane, and propane, carbonated water injection is a suitable approach to increase oil recovery in the reservoir. According to previous studies, carbonated water has been attracting attention for more than 50 years as an injection agent. Previous laboratory and operational research have confirmed the impact of improved oil recycling by carbonated water compared to the water flooding method. Furthermore, carbonated water injection can be a good alternative to eliminate the disadvantages of carbon dioxide injection, such as very poor sweep efficiency due to the high mobility of carbon dioxide.

Materials and methods

Dynamic model specifications

The reservoir fluid sample prepared in the dynamic sector model has a temperature of 160 ^{0}f, and its bubble point pressure is 2291 psi. The initial reservoir pressure is 2590 psi. To enter reservoir fluid properties, stepwise and equilibrium expansion tests at temperatures of 100, 140, and 160 ^{0}f and decomposition of gases associated with oil and reservoir fluid compositions were used as input data. The oil studied is the API 30/22. The ratio of soluble gases to oil at the beginning of the reservoir life is equal to 0.589 scf/STB, and the viscosity of the fluid in the reservoir conditions is 1.2943 cp. Table 1 shows the composition of fluid components used in the prepared sector model. Eclipse software was used to simulate the model.

Table 1- Weight percentage of fluid used in the sector model

Component	Mole Fraction	Weight Fraction
N2	0.10999	0.025842
H2S	0.23998	0.068585
CO2	0.77992	0.28788
C1	36.746	4.9444
C2	6.3294	1.5963
C3	5.2795	1.9526
C4+	8.4692	4.5098
C6+	12.289	9.6443
C9+	7.2793	8.1592
C12+	22.478	68.811

Static specifications of the prepared sector model

The studied section is in the Asmari layer. This section has 8700 blocks totally, and its dimensions are 29 blocks in X-direction, 15 blocks in Y-direction, and 20 blocks in Z-direction. The general specifications of the model are presented in Fig. 1.

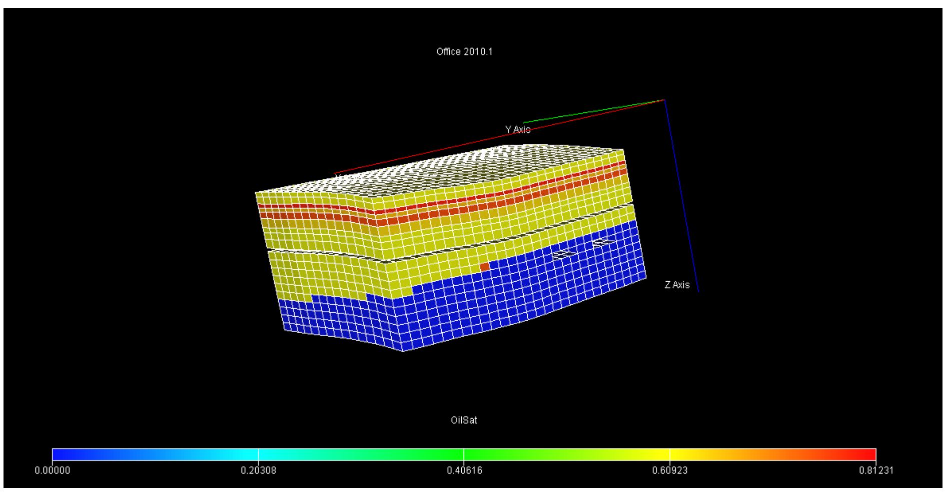


Fig. 1. Schematic of the studied sector model

Because the reservoir pressure is above the bubble point, the reservoir is supersaturating and does not have a primary cap. Hence, there is no gas saturation as a separate phase at the top of the model.

Results

Natural production

The reservoir natural production pattern is the first pattern considered in the field development study in which reservoir production potential is studied without considering any injections. The oil saturation amount and the location of production and injection wells are shown in Fig. 2.

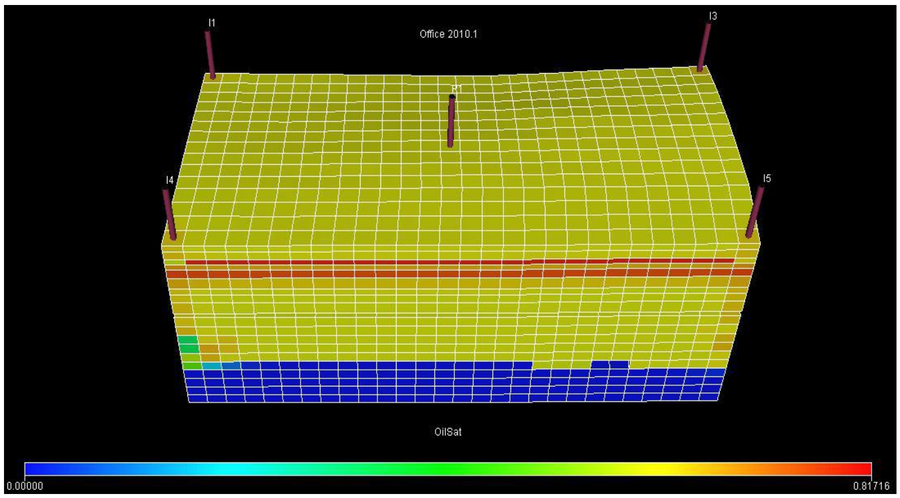
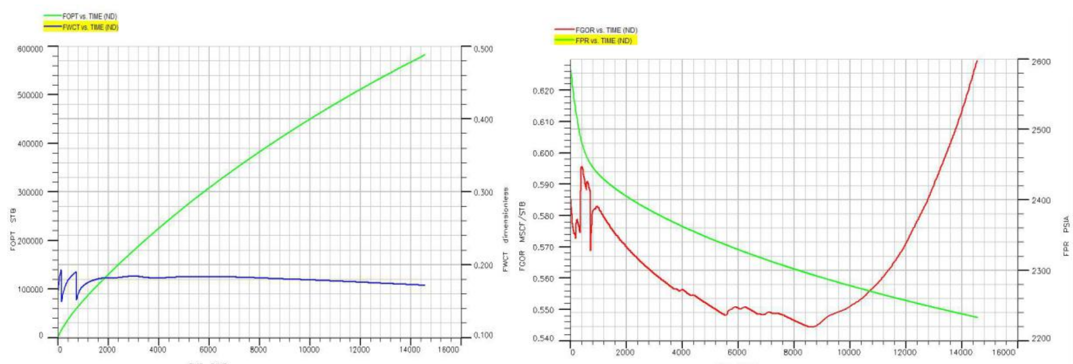


Fig. 2. The oil saturation amount at the beginning of the reservoir life and the location of production and injection wells

The selected pattern for the location of injection and production wells was as five points (as shown in Fig. 2). So that one production well was placed among four injection wells. In natural production, injection wells are kept closed and only open the production well. Fig. 3-a shows the oil total production and WCT, and Fig. 3-b shows the average reservoir pressure and GOR in a normal production state for 40 years.



(a) (b)

Fig. 3. (a) oil total production and WCT in natural production (b) GOR and average reservoir pressure in natural production state

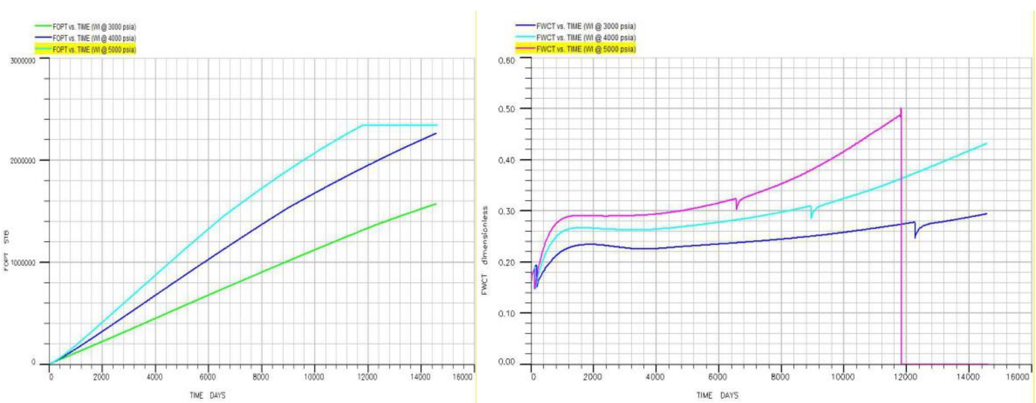
Due to the lack of aquifer, the amount of water produced from the reservoir is constant, increasing production time in the normal state (as shown Fig. 3-b). The average pressure decreases significantly with the normal production from the reservoir so that the reservoir pressure reaches below the bubble point pressure after 8400 days. It causes the gas to be released from the oil, an enhancing factor of GOR in the reservoir. The oil recovery factor is 3.09% in a normal production mode. Natural production from reservoirs for a long time without performing EOR methods causes irreparable damage to the reservoir, and the oil amount that cannot be extracted from the reservoir increases due to the immobilization of parts of the oil.

Water injection

Water injection is the first scenario studied for increasing extraction. In this scenario, in addition to increasing the reservoir pressure, the oil recycling amount increases with the microscopic displacement in the reservoir. The scenarios studied in this investigation for water injection state are as follows:

- Water injection with an injection pressure of 3000 psi
- Water injection with an injection pressure of 4000 psi
- Water injection with an injection pressure of 5000 psi

Fig. 4 shows the oil total production and WCT in water injection at 3000, 4000, and 5000 psi pressures.



(a) (b)

Fig. 4 (a) The oil total production amount in water injection with pressures of 3000, 4000, and 5000 psi, (b) The amount of WCT in water injection with pressures of 3000, 4000, and 5000 psi

As shown in Fig. 4, more water is injected into the reservoir as the injection pressure increases. Production from the sector model increases as the injection pressure increases. However, this increase in production and injection increases the amount of water produced (WCT) in the sector model. Since this model uses the CECON keyboard (production economic study), the well is completely closed after the water production from the well reaches the selected amount. The injected water moves with a more stable front, and production continues with a positive trend at injection pressures of 4000 and 3000 psi. However, the fingering phenomenon is observed at a pressure of 5000 psi after 11771 days. Therefore, although we observe an initial increase in production at an injection pressure of 5000 psi, production at a pressure of

4000 psi is more optimal economically and damages the reservoir. Oil recovery factors from the reservoir in water injection state with pressures of 3000, 4000, and 5000 psi are 8.36, 12.04, and 12.46, respectively.

Carbonated water injection

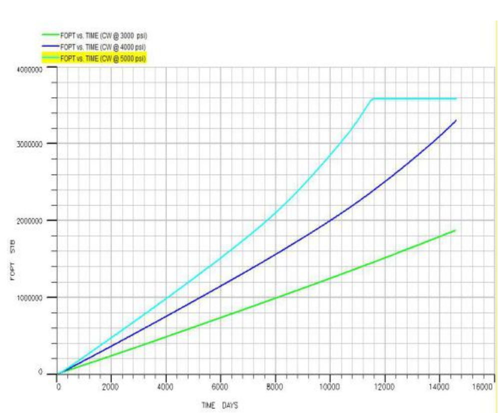
The scenarios studied in the state of carbonated water injection are as follows:

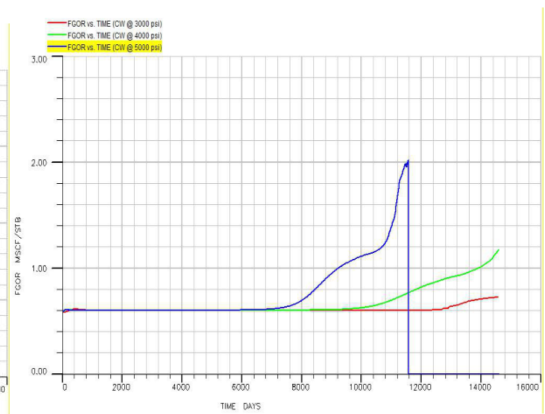
• Inject carbonate water at a pressure of 3000 psi

• Inject carbonate water at a pressure of 4000 psi

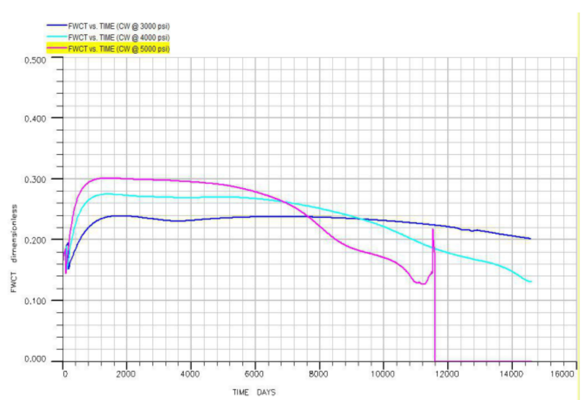
• Inject carbonate water at a pressure of 5000 psi

Fig. 5 shows the oil total production, GOR, and WCT in carbonated water injection state at 3000, 4000, and 5000 psi pressures, respectively.





(a) (b)



(c)

Fig. 5 (a) oil total production amount in carbonated water injection state at pressures of 3000, 4000, and 5000 psi, (b) GOR rate in carbonated water injection state at pressures of 3000, 4000, and 5000 psi, (c) WCT rate in a carbonated water injection state in pressures of 3000, 4000, and 5000 psi

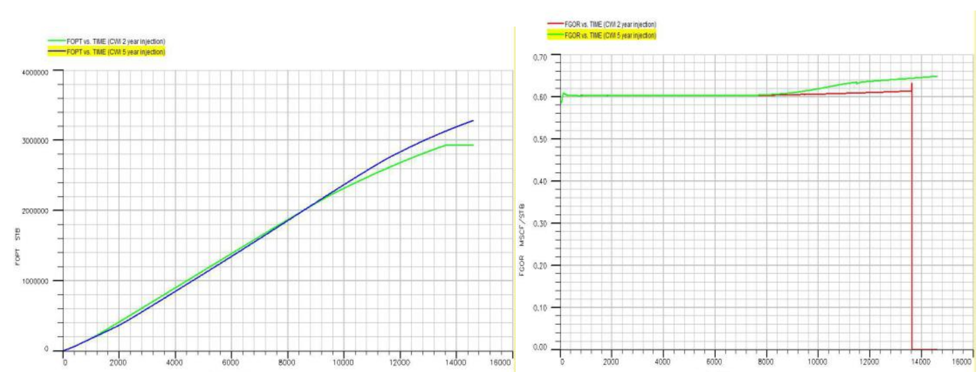
By comparing the diagrams of oil total production in water and carbonated water injection, we understand well that more oil is recycled in carbonated water injection, and this shows the positive effect of carbon dioxide solved in water and then in oil within reservoir. The oil production amount increases with increasing injection pressure, according to Fig. 5. The amount of injected gas and water increases with increasing injection pressure. Therefore, due to the use of economic keyboards in the model, increasing gas and water production from the reservoir causes the production and injection wells to be closed. These factors are very obvious in the state of carbonated water injection at a pressure of 5000 psi and cause the injection front to reach the production well faster, which stops production from the sector model. Since the economic aspects are very important, injecting carbonated water at this pressure is not economical. In the state of carbonated water injection at 3000 psi, we could not use the reservoir capacity well during the injection period. Therefore, the most suitable injection pressure in carbonated water injection is 4000 psi. Although the production amount at the injection pressure of 5000 psi is high at the beginning of the injection period, the injection front column is more stable in the carbonated water injection state with a pressure of 4000 psi, which helps remove the remaining oil in the reservoir. The oil recovery factor from the sector model in carbonated water injection with 3000, 4000, and 5000 psi pressures are 9.95, 17.58, and 19.05, respectively.

Investigation of the effect of time on carbonated water injection

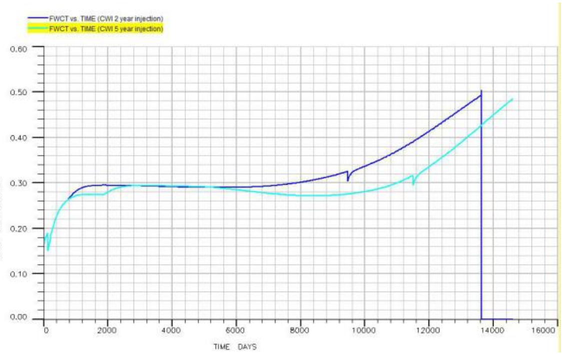
Because carbon dioxide production is difficult in countries that do not have pipelines, the production of this gas for a long time has high collection costs and requires much equipment. In this section, by examining the duration of carbonated water injection, we follow the water injection and examine the effect of this condition with continuous carbonated water injection. The scenarios studied in this state are as follows:

- Carbonated water injection for two years followed by water injection
- Carbonated water injection for five years followed by water injection

An injection pressure of 4000 psi was selected in this investigation due to the improved production performance from the reservoir in the previous states at this pressure. Fig. 6 shows the total oil production of GOR and WCT in the state of carbonated water injection for two and five years.



(a) (b)



(c)

Fig. 6. (a) Total oil production in the carbonated water injection for 2 and 5 years, (b) GOR rate in the state of carbonated water injection for 2 and 5 years, (c) WCT amount in the state of carbonated water injection for 2 and 5 years

Table 2 shows the oil recovery factor for carbonated water injection for 2 and 5 years and continuous.

Table 2. Oil recovery factor for carbonated water injection for 2 and 5 years, and continuous

Scenario	RF%
CWI @4000 psia	17.58
CWI 2 year @4000 psia	15.59
CWI 5 year @4000 psia	17.46

Oil recovery factor in the carbonate water injection for five years then water injection, according to the results of Table 2, can have a favorable result in oil recovery and reduction of costs in the carbon dioxide supply and equipment. Initially, injection in the adjacency of oil is of the carbonate water type. It causes carbon dioxide to enter the oil and be solved in it. Then, the injected waterfront acts as a carbonated water injection fluid covering. Fig. 7 shows the total oil production for all scenarios designed at 4000 psi injection pressure and natural production for the sector.

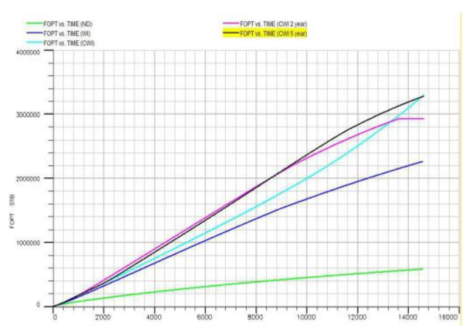


Fig. 7 Total oil production for all scenarios designed at 4000 psi injection pressure and natural production for the sector

Bar diagram of oil recovery factor of all states in this study is shown in Fig. 8.

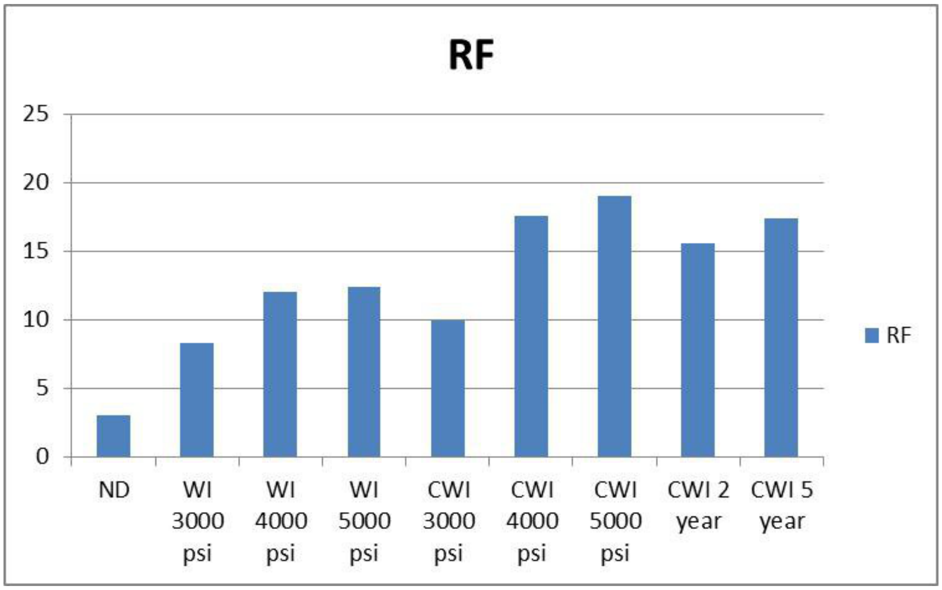


Fig. 8. Bar diagram of oil recovery factor of all states in this study

In natural production and according to Fig. 8, the reservoir does not have enough capacity to produce high oil, and it is necessary to perform the overdraft method. Compared to water injection, carbonated water injection has better performance, indicating the degree of solution of carbon dioxide in oil and, as a result, an increased oil recovery. Finally, continuous carbon dioxide injection was not much different from carbonated water injection for five years. Therefore, carbonate water injection was the best-selected scenario in this study for five years and then water injection.

Conclusions

The present study aimed to investigate and model carbonated water injection to increase oil recycling. The results are as follows.

1. A water injection at a pressure of 5000 psi can be suggested if there is a rapid need for oil and high-speed production from the reservoir according to the country conditions and high speed in achieving high efficiency. However, in this condition, the Water-Cut (WCUT) amount increases, and the interpolation phenomenon occurs faster, and, as a result, a reduction in the final recovery factor will be observed.

2. If it is not necessary to produce rapid oil from the field, an injection pressure of 4000 psi can be used for each injection scenario so that the optimal injection pressure is 4000 psi.

3. The amount of GOR and WCT in carbonated water injection at a pressure of 5000 psi is higher than the pressure of 4000 psi. In addition, it shows a negative influence on oil production and requires more carbon dioxide gas.

4. A periodic carbonated water injection then water injection compared to continuous carbonated water injection has a small production rate difference. This state will require less dioxide than a continuous injection, an important economic factor.

5. The highest recycling rate in the carbonated water injection state was at 5000 psi, whereas the most optimal injection state was the carbonated water injection for five years, then the injection of water.

6. High carbonated water efficiency is as high as the inflation caused by carbonated water injection, which is mainly due to the penetration of carbon dioxide into the oil within the reservoir and the mobilization of unmovable dispersed oils (by inflation generated in the oil and the clinging of unmovable oil clots).

The results of the present investigation were consistent with previous studies. Sohrabi used a micromodel to investigate the carbonated water flooding [6-9]. The experiments pressure and temperature were 2000 psi and 100.4 ^{0}f, respectively. Oil with a viscosity of 16.5 and 0.8 centipoises was used. A recycling increase of 8.8% for light oil and 23.8% for heavier oil was reported. Their results also indicate that the governing mechanism in the oil inflation process is the adhesion of oil particles and the redistribution of oil in the pits. They also studied the benefits of reducing pressure after injecting carbonated water. Dong [10] studied the injection rate impact on extraction increase using the carbonated water method. They performed their experiments on compacted sand using the Gulf of Mexico crude oil with a viscosity of 70.7 centipoises at a temperature of 104 ^{0}f and a pressure of 600 psi. Their results show that the carbonated water injecting recovers more oil than water flooding in secondary and tertiary states. The carbonated water injection into carbon dioxide gas storage and the extraction increase in secondary injection were investigated by Kachat [11]. He performed his experiments on two rock samples using normal decane and crude oil in reservoir conditions. The results showed that this method in the second state is better than water flooding, and from 45 to 51% of the carbon dioxide gas injected is stored in the core. In another study, he compared the results of laboratory studies and simulations methods [12]. Molecular diffusion of carbon dioxide was considered to simulate carbonated water injection on a laboratory scale properly. Riyazi developed a mathematical model for the carbonated water process [13]. In his model, oil inflation is simulated when it is in direct contact with carbonated water and the carbon dioxide gas is separated from the water and diffuses into the oil drop. In this research, he has examined the effective parameters in the diffusion process and the sensitivity of the influence of these parameters. Riyazi et al. performed carbonated water experiments using micromodels [14]. Their experiments were performed at a pressure of 2000 psi and a temperature of 38°C. They used normal decane. Their investigation showed that carbonated water is better than water flooding in both secondary and tertiary states and increases the recycling rate. They also showed that the adhesion of oil particles and oil redistribution in the pits are the governing mechanism in the oil inflation process. They also studied the benefits of reducing pressure after injecting carbonated water. Solution of gas of injected water within the oil in the reservoir and increase oil mobility is one of the main advantages of using carbonated water. Oil mobility is affected in two ways, including (i) oil phase inflation and (ii) reduced viscosity. These two factors will increase the oil relative permeability, improving oil mobility. Normally, a large amount of carbon dioxide is needed to inject carbon dioxide. Thus, we need a reliable and low-cost source of carbon dioxide. However, natural sources of carbon dioxide are often located far away from oil fields. The high storage costs of large amounts of carbon dioxide from power plants with fossil fuel have made carbon dioxide injecting typically unaffordable even for reservoirs suitable for carbon dioxide storage and extraction increasing [15]. Another appropriate solution is carbonated water injection. Much less carbon dioxide is consumed in this process than the conventional injection of carbon dioxide. This process is very attractive for offshore reservoirs and reservoirs with poor access to carbon dioxide sources. Due to its higher density than the water in the reservoir, the carbonated water goes to the lower and safer parts after injecting and provides a suitable environment for storing carbon dioxide. The carbon dioxide solubility at normal pressures and temperatures of oil reservoirs is much higher than other hydrocarbon gases, which is very significant in terms of oil extraction increasing and carbon dioxide storage. Considering carbonated water as a phase versus oil, the mobility difference between the two phases is much more favorable than the mobility difference between the carbon dioxide and oil phases. This causes carbon dioxide to be distributed uniformly throughout the reservoir, and its breakthrough time and sweep efficiency increased [16].

References

1. Ahmed, T.: Hydrocarbon Phase Behavior, Gulf Publishing Co., Houston (1989).
2. A.J.E. Steffens, Modeling and Laboratory Study of Carbonated Water Flooding, Master thesis, Delft University of Technology, Delft, Netherlands, October 2010
3. Nevers De, A Calculation Method for Carbonated Water Flooding [Book], 1964
4. Tran T.S. and Zitha P. L. J. Electromagnetic Assisted Carbonated Water Flooding for Heavy Oil Recovery [Conference] // World Heavy Oil Congress. - [s.l.]: WHOC, 2009.
5. Riazi M [et al.] Oil Recovery Improvement Using CO2 - enriched water injection [Journal] // Society of Petroleum Engineers. – 2009
6. Dong, Y., Dindoruk, B., Lewis, E. J., Kubicek, T., "An Experimental Investigation of Carbonated Water Flooding," SPE 145380-MS, Prepared for SPE Annual Technical Conference and Exhibition, Colorado, Oct. 30 – Nov. 6, 1976
7. Sohrabi, M., Riazi, M., Jamiolahmadi, M., Ireland, S., and Brown C., Carbonated Water Injection (CWI) studies, presented at 29th Annual Workshop & Symposium, IEA Collaborative Project on Enhanced Oil Recovery, 2008.
8. Sohrabi, M., Riazi, M., Jamiolahmady, M., Ireland, S., and Brown, C., Mechanisms of Oil Recovery by Carbonated Water Injection, SCA Annual Meeting, 2009, Paper No. 26.
9. Sohrabi, M., Kechut, N.I. Riazi, M. Jamiolahmady, M. Ireland, S., Robertson, G.J., Coreflooding Studies to Investigate the Potential of Carbonated Water Injection as an Injection Strategy for Improved Oil Recovery and CO2 Storage, Journal of Transport in Porous Media. 2012, 91, 101–121.
10. Dong, Y., Ishizawa, C., Lewis, E., Dindoruk, B., Carbonated Water Flood: What We Observed in Sand Pack Experiments, Presented at International Symposium of the Society of Core Analysts, Austin, Texas, SA, September 18–21, 2011, Paper SCA2011-34.
11. Kechut, N.I., Riazi, M., Sohrabi, M., Jamiolahmady, M, Tertiary Oil Recovery and CO2 Sequestration by Carbonated Water Injection (CWI). presented at SPE International Conference on CO2 Capture, Storage, and Utilization, New Orleans, Louisiana, USA, November 10–12, 2010, Paper SPE 139667.
12. Kechut, N.I., Sohrabi, M., Jamiolahmady, M, Experimental and Numerical Evaluation of Carbonated Water Injection (CWI) for Improved Oil Recovery and CO2 Storage, presented at SPE EUROPEC/EAGE Annual Conference and Exhibition, Vienna, Austria, May 23–26, 2011, Paper SPE 143005.
13. Riazi, M. Pore Scale Mechanisms of Carbonated Water Injection in Oil Reservoirs. Ph.D. Dissertation, Herriot-Watt University, Edinburgh, UK, 2011.
14. Riazi, M., Jamiolahmady, M., Sohrabi, M., Theoretical Investigation of Pore-Scale Mechanisms of Carbonated Water Injection, Journal of Petroleum Science and Engineering, 2011, 75, 312–326.
15. sohrabi M [et al.] Carbonated Water Injection-A Productive Way of Using CO2 for Oil Recovery and CO2 Storage, Energy Prodecia, 2011, 4, 2192-2199
16. Sohrabi, M., Riazi, M., Jamiolahmady, M., Kechut, N.I., Ireland, S., and Robertson, G. Carbonated Water Injection (CWI) – A Productive Way of Using CO2 for Oil Recovery and CO2 Storage, Energy Procedia, 2011, 4, 2192–2199