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Quantitative Study and Simulation of Carbon Dioxide Disposal and Storage in Oil Reservoirs

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Abstract: Increasing emissions of greenhouse gases have caused climate change as well as global warming. As a result, reducing carbon dioxide production or its disposal is very important. One way to solve this problem is to inject carbon dioxide into oil tanks to increase hydrocarbon extraction. In this research, a simulation of carbon dioxide storage in an oil reservoir has been performed using a hybrid method. The results show that horizontal wells have better potential than vertical wells for storage.

Keywords: carbon dioxide storage; disposal tanks simulation; vertical and horizontal wells; oil reservoirs.

1. Introduction

The earth is warming, and the environmental damage caused by the country's climate change is threatening, and the increase in greenhouse gases is one of the most important challenges of the present century. Most of the greenhouse gases are carbon dioxide. Antarctic ice study shows that with the increasing use of fossil fuels, the amount of carbon dioxide in the atmosphere has risen from 280 ppm to 380 ppm over the past 200 years [1]. The most common cause of carbon dioxide emissions is the consumption of fossil fuels [2], and the use of fossil fuels worldwide produces 27 billion tons of carbon dioxide annually, which has very severe adverse effects on the climate [3].

In Iran, the production of carbon dioxide from the combustion of fossil fuels in industrial sectors in 1998 was 271.7 million tons, which in 2008 increased to 453.7 million tons [4] and according to the latest statistics According to the International Energy Agency in the list of countries based on greenhouse gas emissions in 2015, Iran is in ninth place with 630 million tons of carbon dioxide [5]. Suggested strategies for carbon dioxide disposal and storage are: -Deep ocean bed storage - Injection into geological formations - Sedimentation as solid carbon [6].

Injection into geological formations has been considered a more durable and acceptable option. The structures considered in the geological formation are [7]: -Drained oil tanks - Drained gas tanks-Deep watercourses-Non-mineral coal substrates [8].

Injection of carbon dioxide gas in the lower part of the water-oil contact surface in oil tanks is possible. In gas tanks, storage occurs below the contact surface of gas and water, which have high permeability and porosity in these places. In 2009 this hypothesis was stated only for oil reservoirs [7].

In the injection method in coal tanks, a significant amount of carbon dioxide is absorbed by the coal, which prevents the uptake of methane by the coal and will lead to the release of methane and improve its harvest [8]. One way to eliminate carbon dioxide is to inject it into geological formations such as water and depleted oil and gas reservoirs. It is also another way of injecting carbon dioxide into geological formations in oil reservoirs to increase oil extraction. This method causes some other benefits such as increasing the oil recovery factor. The advantages such as low minimum mixing pressure, which has carbon dioxide injection, have been highly regarded. Injection of carbon dioxide is the harvest of additional CO2 that causes some other benefits, which is not such an advantage in the discharge storage scenario [9]. Carbon dioxide can be stored in the abyss in four states: as a bulk phase in the abyss structure, as a phase trapped by capillary forces, a water-soluble phase, and as a deposited mineral [10]. Figure 1 shows the mechanisms by which carbon dioxide is trapped. Mineral entrapment is one of the important mechanisms of long-term storage [11].

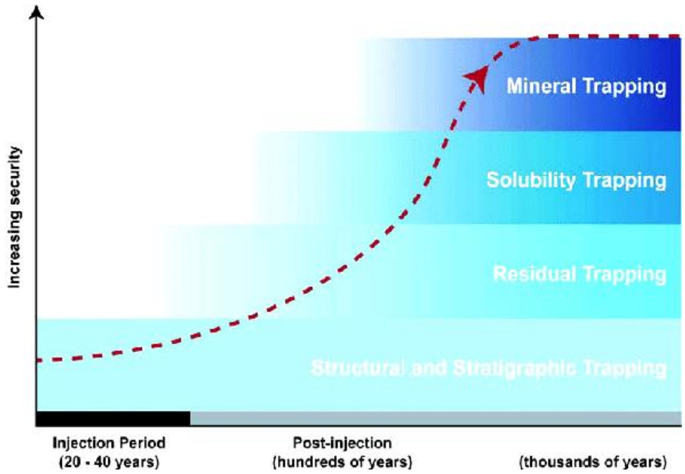

Figure 1. Trapping mechanisms of CO_2. Image created based on the text available in ref [11].

Due to the high capacity of aquifers for long-term carbon dioxide storage and trapping of this gas in the aquifer by hydrodynamic and geochemical mechanisms in aquifers, numerous geological formations, this scenario can be a successful solution for carbon dioxide disposal. Disposal of carbon dioxide in streams is an operation with high economic costs that using ways to reduce carbon dioxide production can be more economical [12-14]. In a study, Jamshidi *et al*. [15] investigated the simultaneous optimization of increasing gas extraction and carbon dioxide storage in natural gas reservoirs. For this purpose, three scenarios have been considered; in each of these scenarios, the amount of net production value and stored and produced carbon dioxide were compared. These three scenarios are: -Production from the tank with discharge mechanism, without carbon dioxide injection (Scenario 1) - Carbon dioxide injection from the beginning of production (Scenario 2) - Carbon dioxide injection after tank discharge (Scenario 3).

In Scenario 3, first, the amount of natural gas produced is higher than Scenario 1, and second, the amount of carbon dioxide produced is much lower than Scenario 2. This is while the net production value of Scenario 3 is ultimately higher than the previous two scenarios.

Song *et al*. [16] investigated the reaction potential of carbon dioxide with saline water and reservoir rock in a saline formation with constant conditions and carbon dioxide uptake over six months. After the sandstone was exposed to carbon dioxide, a 50% reduction in permeability was observed, possibly due to feldspar decomposition, migration, and secondary deposition of minerals in the sandstone core structure.

Jafari Rad *et al*. [17] numerically simulated the injection of carbon dioxide into groundwater aquifers, and in this study, the effect of salinity of the injected aquifer environment on the onset of natural displacement was investigated. Six scenarios were studied to do this, focusing on differences in salinity percentage and keeping other variables involved in the process constant. The results obtained from the scenarios show an increase in the percentage of soluble salt by changing the values of density and viscosity of the fluid and then the delay in the onset of natural displacement due to buoyancy.

2. Materials and Methods

In this research, the simulation of carbon dioxide excretion in an oil tank's water is studied. Carbon dioxide is stored in streams for a long time, so injected gas can be disposed of in various states such as free gas, trapped gas, and water-soluble gas. This study aims to study the feasibility of injection and disposal of carbon dioxide in oil reservoirs. Challenges in modeling calculations for the injection of carbon dioxide into the aquifer, such as chemical reactions and complex mechanical processes, require various studies. Injected carbon dioxide changes the water's pressure and quality and drives some of the water to the reservoir. There is also a risk of leakage of this gas from permeable pathways such as faults and crevices, which poses environmental hazards such as groundwater pollution or ecosystem change.

2.1. Case study.

Simulation To study the storage potential of carbon dioxide in the abyss of an oil tank by a combined simulation model [9] using Eclipse 300 software [10] has been done. The studied geological structure is part of the Asmari Formation. The studied sector is selected from the desired reservoir with an approximate length of 19.2 km and an approximate width of 13 km, and 12 layers have an approximate thickness of 300 meters. This sector includes different production and injection wells in different scenarios and has a very strong discharge. Figure 2 shows the general schematic of the model. The dark part is the active block grid of the tank model [11-13].

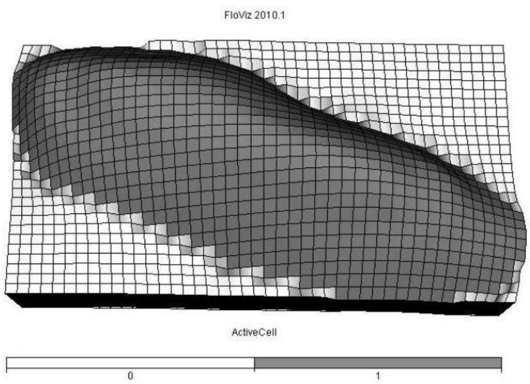

Figure 2. A general illustration of the studied reservoir.

Table 1. Reservoir model properties.

Characteristic	amount
Grid size in the X direction	427 m
Grid size in Y direction	366 m
Grid size in the Z direction	13 m
Number of grades in the X direction	44 pieces
Number of grades in Y direction	27 pieces
Number of grades in the Z direction	24 pieces

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Table 2. General characteristics of the formation.

Property	**amount**
Medium porosity	**12 percent**
Horizontal permeability	**24 mD**
Vertical permeability	**4.5 mD**
Water-oil contact surface	**1900 m**
Depth of base	**1354 m**
The pressure at the base depth	**219 bar**

According to the model structure and parameters under control, the number of wells, the wells' distance, the creation of horizontal wells, and periodic injection have been investigated among the various parameters affecting this study's storage. The overall purpose of this study is to eliminate carbon dioxide (standard 3e+11 cubic meters) for 30 years [14]. The studied reservoir, the specifications are given in Table 1, is connected to a water flow with the Fatquij model at a depth of 1920 meters and a pressure of 345 bar inside the reservoir section. The studied model is a sector of Asmari Formation, the general characteristics of which are expressed in Table 2. The combination simulation and fluid model are prepared by the improved Sao-Redlich-Quang equation [15, 16]. Figure 3 shows the model used in this research and the current wells' location in the study section.

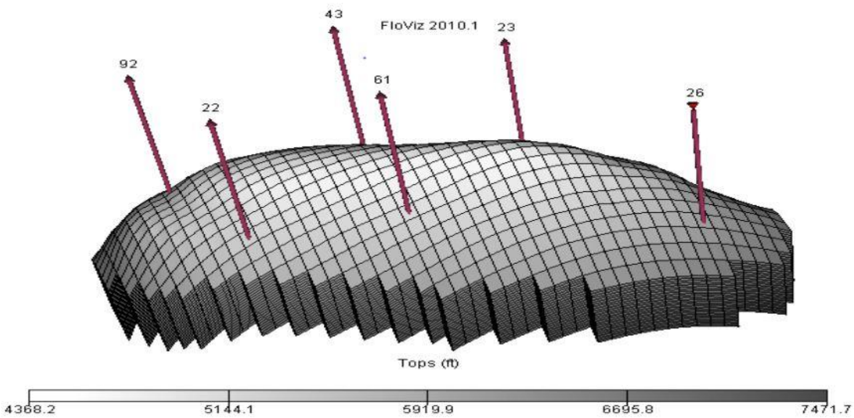

Figure 3. Reservoir model and location of its wells.

The infiltration of water into the reservoir and how it is connected to the reservoir are shown in Figure 3. The water of the reservoir is simulated with the Fatkovich model at a depth of 1920 meters. The water pressure at the base depth is 345 bar, and the initial volume of water in the water is equal to 6e+12 barrels. The reservoir fluid model consists of 17 components [17-20]. The tank temperature is 88 degrees Celsius.

2.2. Investigation parameters.

In this study, as mentioned, the controlled parameters such as injection method, good horizontal creation, and several wells on the reservoir sector were studied, and for each of these parameters to achieve the desired goal of storage of 2.8e+8 cubic meters of carbon dioxide gas was built in a maximum of 30 years depending on the conditions of the models [21, 22]. The models created to study each parameter is as follows:

2.3. Production and injection conditions of wells.

To ensure that the formation is not damaged due to the injection of the desired gas, the maximum injection pressure in the production wells is equal to the formation's failure pressure, i.e., 552 times. Therefore, as long as the bottom pressure of the production wells is lower than this value, the injection can be done according to the injection potential of the well, and when the bottom pressure reaches this level, the rate of injection gas gradually decreases so that it can always reduce the bottom pressure control according to the defined limit. The simulation scenarios are as follows [23, 24]: -Injection of carbon dioxide by vertical wells; -Injection of carbon dioxide by a horizontal well; -Periodic injection; -Investigation of increasing the distance between wells.

3. Results and Discussion

3.1. Scenario 1-injection by a vertical wall.

In this scenario, to perform sensitivity analysis, four different modes have been compared, in which the number of wells is equal to 1, 2, 4, and 6 injection wells, respectively, with the names of mode 1, mode 2, mode 3, respectively And mode 4 are named. The injection wells' location is selected based on the petrophysical structure of the formation and the status of the discharge. All these injection wells are completed in Abdeh, and the injection of gas, carbon monoxide is done only in Abdeh.

3.2. Scenario 2-injection by horizontal well.

In this scenario, horizontal wells have been used to increase the carbon dioxide injection potential. Although drilling horizontal wells requires higher costs, simulation studies are a way to prove that building such wells can greatly increase production or injection capacity. In this scenario, two cases are considered to investigate this issue, which is different in terms of the number of wells.

3.3. Scenario 3-periodic injection.

According to the injection potential of the mentioned cases in the predetermined basis and purpose and the injection flow behavior, injecting wells was defined periodically. In this case, a method was studied. The study includes an injection well. The injection method is that the total duration of 30 years is divided into 6 equal parts and each well is opened and closed in 5 years. This closing time gives the water a chance to reach equilibrium in terms of carbon dioxide concentration and pressure, and for the next injection, period to have more potential to trap carbon dioxide.

3.4. Scenario 4-well distance.

Here, according to the results of simulations, it was assumed that in this reservoir sector, increasing the distance of wells can help us achieve the desired goal. For this purpose, taking into account the reservoir's initial conditions and the joint surface of water and oil, four vertical wells are defined in the reservoir to have even the maximum distance between them. The reason for this choice is that by injecting gas, there is a gradual increase in pressure in the abyss. This increase in pressure reduces the injection potential of the wells. When the distance between the wells is large enough, the impact of the wells is less—injected more gas according to the good control conditions. On the other hand, this section's results can be compared with the results of mode 3 of the base method, where the number of wells is equal to 4 but with a shorter distance.

3.5. Discussion.

In the first scenario, where carbon dioxide is injected into the stream by vertical wells, the gas injection increases the flow pressure and strengthens it. Figure 4a shows the time-injected flow rate in each of the four simulated cases. As the number of injection wells increases, the injection rate increases, and the volume of carbon dioxide injected into the aquifer increases. Figure 4b shows the amount of total injected carbon dioxide over time for each of the four simulated items. As the number of injection wells increases, the injection rate increases, and the volume of carbon dioxide injected into the aquifer increases. Figure 4b shows the amount of total injected carbon dioxide over time for each of the four simulated items.

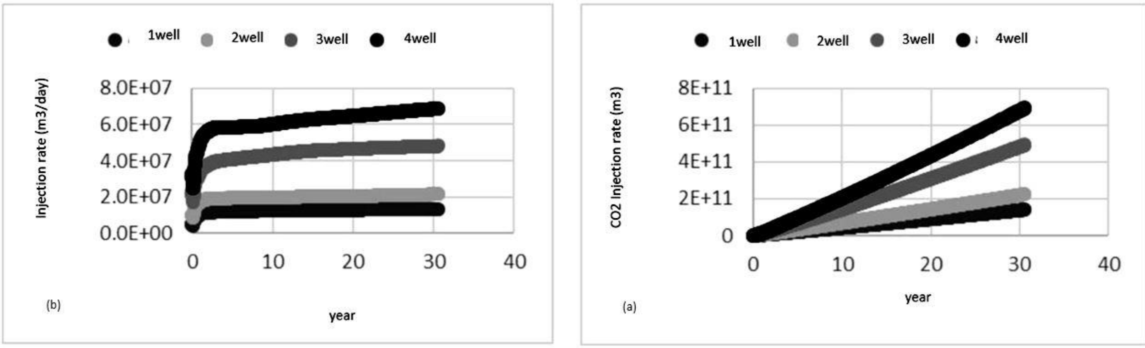

Figure 4. (a) Injection rate plot in vertical injection wells scenario (b) Cumulative injection rate VS. year with the vertical injection wells.

In this section, the results of the carbon dioxide injection scenario with a horizontal well are described. One way to increase production and injection potential in geological reservoirs and formations is to convert vertical wells to horizontal ones. In this study, two horizontal wells in the reservoir model were selected for carbon dioxide gas injection in water. In the first case, which has only one horizontal well, the amount of injected gas does not reach our target volume. Therefore, more wells need to be drilled, and in case two, carbon dioxide injection with two horizontal wells is investigated. According to Figure 5a, the injection flow of this well and its comparison with the vertical well's injection flow will notice a different behavior. In horizontal wells, the discharge starts from a maximum value and is fixed at a certain value, which indicates that in the case of carbon dioxide injection into this particular model, the injection can be done with a constant flow and using a horizontal well. Figure 5b shows the comparison of carbon dioxide injection flow in terms of time in the injection mode with a horizontal well and a comparison with the condition of a vertical well.

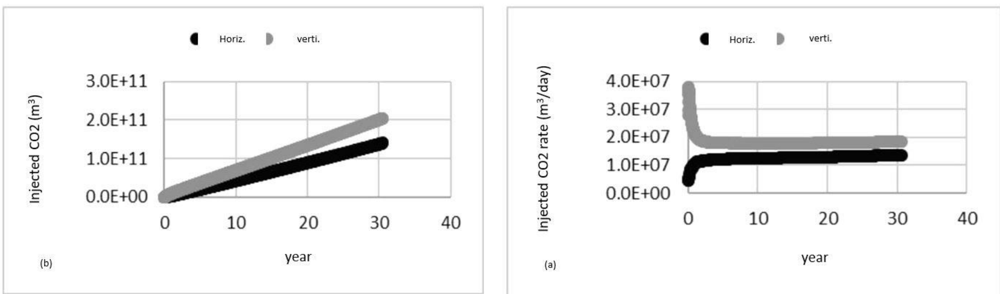

Figure 5. (a) Comparing Horizontal and vertical Injection rate (b) Comparing Cumulative injection rate of a horizontal well and vertical injection rate.

The second case consists of two horizontal injection wells in the reservoir water for simulated carbon dioxide injection. As it is known, creating two horizontal wells is enough to inject the desired amount of gas, and two horizontal wells can be used instead of 4 vertical wells. In the vertical well scenario, the well is latticed in all sections of the catchment, but in the horizontal well scenario, the well is latticed in the upper and lower sections of the catchment to investigate the grid's effect location.

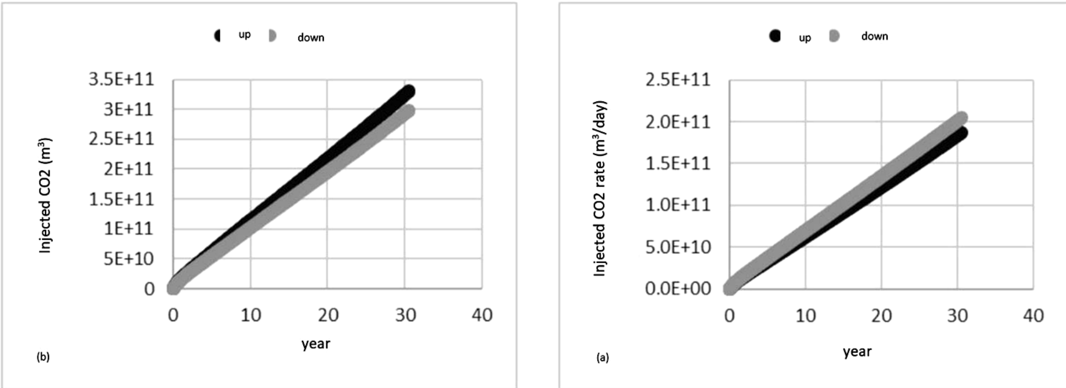

Figure 6. (a) Injection in different good completion cases with one injection well (b) Injection between different cases of good completion with two injection wells.

Figure 6a shows a gray diagram for completing the well in the aquifer's upper part and a black diagram to complete the well in the aquifer's lower part. The difference in height along the axis (Z) for the lattice is about 164 feet, the effect of which is quite clear on the amount of storage.

Figure 6b shows a black graph for the amount of carbon dioxide injected by the well completed in the upper part of the aquifer and a gray graph for the amount of injection with the well's completion in the lower part of the aqueduct. The water is more.

When carbon dioxide enters the aquifer near the upper impermeable part, it is likely to continue migrating to the high-slope parts for long distances and may eventually find its way out. In contrast, when injected into the lower half of the aquifer, gravity-driven flow continuously reduces the amount of associated gas before the gas can migrate to the aquifer's top.

In the third scenario, there is only one vertical injection well to store carbon dioxide. As can be seen from Figure 7a, after the injection of the first period and the closure of the well and after that, the flow in the injection period has increased sharply, which is due to the reduction of reservoir pressure during the closure of the well and the provision of time. Therefore, it is suitable and sufficient for the transverse distribution of carbon dioxide gas injected into the body. According to the observations, the final injection flow is close to the continuous state's final injection flow. Figure 7a shows the total injection flow rate compared to the baseline model of continuous injection of carbon dioxide into a well. Figure 7b shows the total amount of gas injected over time in this case.

In the last part, the fourth scenario, the main purpose is to investigate the distance factor's effect between the wells on the injection potential. This choice is the number of wells and the possibility of achieving the desired goal. By selecting this item based on the sector's position and the discharge status, the wells' distances were selected to have the maximum acceptable distance.

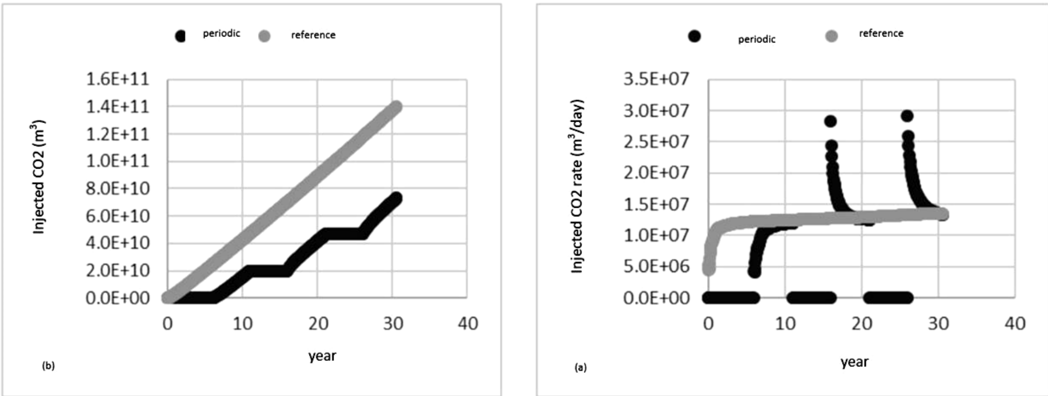

Figure 7. (a) Comparing total injection rate with one injection well (b) Amount of total gas injection VS. time.

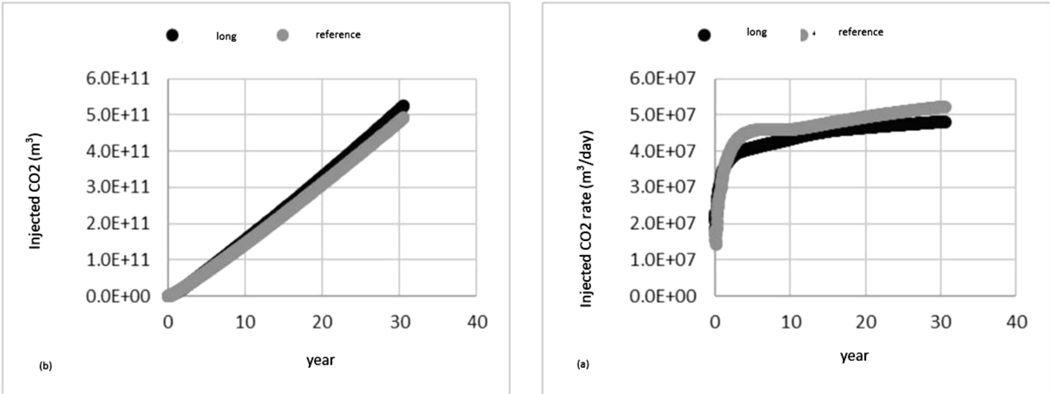

Figure 8. (a) Total gas injection rate in comparison injection rate with case 3 (b) Total amount of injected gas compared with case 3.

As shown in Figure 8a, increasing the wells' distance does not significantly change the injection flow. Figure 8b shows the total amount of injected gas to the sector, and according to the figure, with increasing the distance of wells in this case, the amount of total injected gas has increased by only 6%. The results of different injection methods for storing carbon dioxide gas are compared in Table 3.

Table 3. Amount of injected CO_2 for 4 cases.

Scenario	**Well 6**	**Well 4**	**Well 2**	**Well 1**
reference	9.6e+11	9.4e+11	3.2e+11	**4.1e+11**
vertical	-	-	3.3e+11	**2.0e+11**
periodic	-	-	-	**3.7e+11**
distance	-	3.5e+11	-	**-**

4. Conclusions

Environmental studies show that carbon dioxide accounts for about 64% of all greenhouse gases and is a major cause of global warming and climate change. Efforts to reduce greenhouse gas emissions are among the most important issues in many industries, including the oil and gas industry. The process of storing carbon dioxide in oil and gas reservoirs is a suitable solution to manage this gas's emission and prevent it from entering the atmosphere. On the other hand, due to the decrease in oil wells' efficiency in recent years, protection of these reservoirs and injection into When all kinds of gas have become essential to them. In this study, continuous injection of carbon dioxide to optimize stored carbon dioxide and recycling of oil produced in one of Iran's oil reservoirs using Eclipse 300 software is used to optimize the genetic algorithm. The most important question raised in this project is how the location of injection wells, the location, and the length of their meshwork on the rate of overdraft and excretion of carbon dioxide gas. The problem of location on injection well No. (9) has been done, and the effect of this factor and length and grid location was determined on the amount of gas storage and increase in oil extraction. The maximum amount of oil extracted was obtained per grid (24.7). After several performances, the best lattice location with the highest oil production efficiency was found to be the first layer. The lattice distance was approximately 77 feet. In this research, the simulation of injection and storage of a certain amount of carbon dioxide gas in a limited time to the discharge of one of the oil reservoirs was investigated. For this purpose, the reservoir model sector of the Asmari Formation, which includes the Abdeh, was selected, and the simulations were performed by a combined method using the Eclipse 300 commercial simulator. According to the study and simulation, the following results can be inferred for the storage of carbon dioxide in the reservoir water, according to the reservoir's structure and intended purpose, the wells' appropriate position must be selected first. Optimal selection of a good position is very effective in achieving the desired goal. To study simulation, many parameters are introduced as software input. For example, in this case, one of these parameters is the dissolution rate of carbon dioxide in water. Before performing simulations, these uncertainties must first be minimized. According to the simulation results, creating two horizontal wells (standard 3.3e+11 cubic meters) compared to two vertical wells (standard 2.3e+11 cubic meters) can greatly increase the injection potential. In this case, by creating two horizontal wells, a predetermined goal can be achieved, and increasing the number of wells in the horizontal position is not cost-effective due to the high costs of this drilling model. Completing the well plays an important role in deciding carbon dioxide's fate after injection. According to the results, completion in the upper part has higher efficiency, but due to the possibility of gas leakage to the upper part of the tank and due to the importance of gas retention in the tank, completion is recommended in the lower part. One of the ways to increase the injection flow is periodic injection. In this study, periodic injection increased the injection flow during the injection periods, but fewer results were observed in the final storage amount (7.3e+10 cubic meters standard). In general, using two horizontal wells or creating four vertical wells, the desired goal can be achieved: the amount (3e+11 cubic meters of standard) of carbon dioxide storage over 30 years. The durability of injected carbon dioxide in the abyss and the high solubility of this gas in the water inside the abyss. The formation of reservoirs under suitable pressure and temperature conditions is one of the best carbon dioxide disposal options and storage options.

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Conflicts of Interest

The authors declare no conflict of interest.

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