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Sequestration of Carbon Dioxide to Improve the Performance of Water Drive-Gas Reservoirs by Controlling the Effect of Aquifer

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Abstract: Due to high mobility of gas, the recovery of volumetric gas reservoirs are high. However, in some gas reservoirs aquifer activity is the prominent cause of low efficiency. High amount of residual gas saturation behind the water front is a major problem to these gas reservoirs. To date, various methods have been developed and introduced to alleviate the effect of water encroachment such as blow-down, co-production and re-perforation techniques. Although, these methods were encountered some difficulties. This study seeks to solve the mentioned problems of water drive gas reservoir with the intention of carbon dioxide (CO_2) sequestration which is one of the most noteworthy discussions these days. In this study, injection of CO_2 was performed nearby the edge aquifer and CO_2 plume was propagated in contact area of gas and water. In comparison with conventional methods the amount of gas and condensate production were increased 14 and 23 percent and negligible amount of injected CO_2 was recovered at the end of 112 years prediction. In addition to sequestration of CO_2, production of hazardous water was decreased which is important from environmental point of view.

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1 Introduction

The efficiency of volumetric gas reservoirs are usually high due to high mobility of gas (near to 90 percent). While, aquifer activity have been identified as a main influencing factor for the recovery decline in water drive gas reservoirs [1,2]. Water influx is not as efficient a drive mechanism such as gas expansion. As a result, recovery from water drive reservoirs is typically much lower than depletion drive recovery [3,4,5]. Recoveries of water-drive gas reservoirs vary between 35-75 percent [1]. High amount of residual gas saturation behind the water front and sometimes consequent water coning are key obstacle to these type of gas reservoirs. If the aquifer is strong, the residual gas saturation can be permanently trapped at a high pressure [6].

Earlier, three techniques have been used for increasing recovery in gas reservoir with contributing aquifer. One of these methods, is the blow-down technique. In this method, gas is produced with high rate for exceed the rate of water invasion into the gas zone, so pressure drop rate in gas zone should be increase before aquifer response it. Ineffective application in weak aquifer, water coning and sand production are disadvantages of this method [7]. In addition to these operational concerns, once the gas rate is accelerated it cannot be curtailed without a significant loss in recovery [5].

The second method for increasing gas recovery is co-production technique. In this method, water is produced separately from downdip wells while producing gas from up-dip. When sufficient water is produced the water influx can be effectively halted or at least slowed down, allowing up-dip wells more time to deplete the reservoir. However, when the aquifer is strong; increasing water production cannot greatly lower the reservoir pressure and low incremental recovery should be expected. The most crucial disadvantage of this method is producing of hazardous water which is not acceptable from the environmental point of view [7]. The third method is re-completion of existing wells to avoid water production [5].

2 Problem Definition and Methodology

This study seeks to solve the problem of water drive-gas reservoir type with the intention of CO_2 sequestration which is one of the most noteworthy discussions these days [8,9]. Injection of CO_2 was performed nearby the edge aquifer and CO_2 plume was propagated in contact area of gas and water. Injection was implemented in a way that pressure was remained below the 90 percent of reservoir initial pressure [10]. Decreasing aquifer influx due to dissolution and accumulation of CO_2 toward the aquifer and also, sweeping more gas toward the production well are two important mechanism occurred in this process.

In the first case (Case I) the effect of aquifer on reservoir was suspended by deactivating it. The only aim of implementing this case was determining the effect of aquifer on reservoir performance. In the second case (Case II) the production process by depletion scenario was simulated with companion of the aquifer. Comparison of the cases I and II can illustrates the effect of aquifer activity on water, condensate and gas production. The production condition of this case is same as the first case. This case can show the Base Case of the production in the reservoir. In the third case (Case III) co-production technique was applied. Water production was started at the first years at the optimized well production rate of 6 MSCM. Water was separately produced from a horizontal well near to the aquifer. Finally in the last case (Case IV), a proposed method of near gas–water contact sequestration of CO_2 was simulated.

It should be noted that due to numerical dispersion, the simulation of blow-down technique was not applicable. One of the important phenomenon which effects on the process of CO_2 sequestration is dissolution of this gas in reservoir water which can change the operational and thermodynamic condition [11,12].

3 Model Description

For this objective, a real compositional model was considered. This model was located in East – North of Iran. Previous studies on this field showed that aquifer activity weakened the performance of the reservoir.

The composition of reservoir fluid is represented in Table 1. Table 2 shows some static and dynamic properties of model for Base Case.

Table 1. Composition of reservoirs fluid

Component	Mole Fraction (%)
CO_2	2.6
C1	95.86
C_3C_4	0.71
C_5C_6	0.33
$C_{7+}(1)$	0.3952
$C_{7+}(2)$	0.1048

Table 2: Static and dynamic properties of model for Base Case (Case II)

Property	Unit	Value
Reservoir Length	m	48196
Reservoir Width	m	45627
Average Thickness	m	50.05
Temperature	°C	127
Initial Pressure	bar	350
Average Porosity	%	3.3
Water/Gas Contact Depth	m	2930
Average Vertical Permeability	md	1.6
Average Horizontal Permeability	md	16
Model Dimension	-	60×45×8
No. of Production Well	-	4
No. of Injection Well	-	3
Total CO_2 Injection Rate	MMSCMD	3.1
Simulation Time	Year	112
Maximum Water Cut	%	20
Total CO_2 Injected	MMMSCM	126
Aquifer Permeability	md	220
Aquifer Porosity	%	20
Angle of Influence	Degree	-
Bottom hole Pressure	bar	90

Figure 1 depicts a 3D view of whole reservoir model and it wells. CO_2 injection and water producing wells both consisted of a vertical main well and horizontal side track. Other producing wells were vertical.

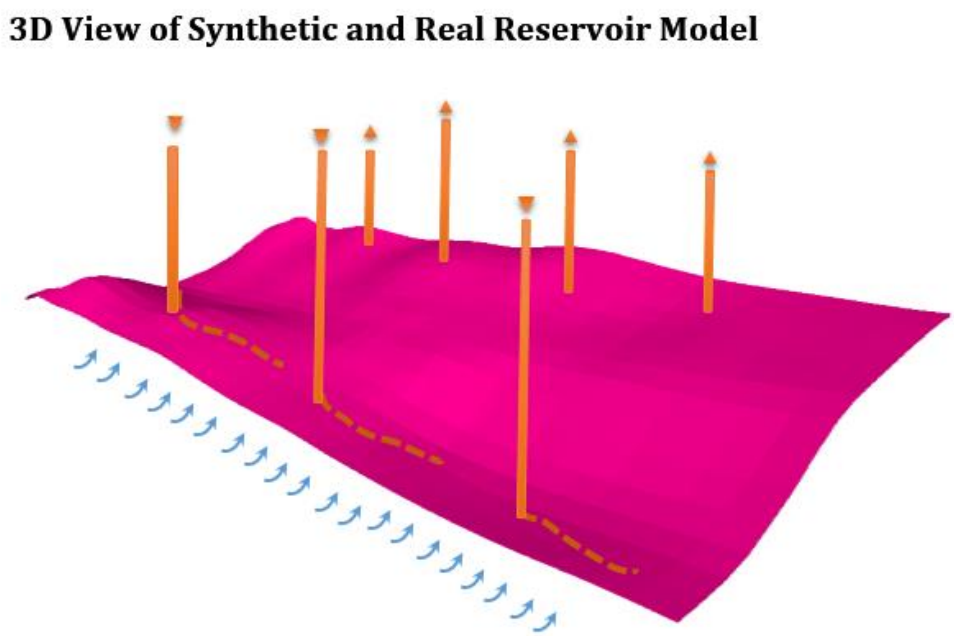

Figure 1: 3D view of reservoir model and it wells

4 Results and Discussion

In this study a method was proposed to control the effect of aquifer. Four cases were implemented to investigate the influence of aquifer on performance of the water drive gas reservoir.

Figure 2 shows the cumulative gas production for studied cases. As can be seen, injecting CO_2 in the reservoir (Case IV) increases cumulative gas production about 14 percent in comparison to the base case (Case II). By controlling the aquifer water influx the performance was almost improved to the level of hypothetical case of de-active aquifer (Case I). Also, a noticeable volume of CO_2 was sequestered.

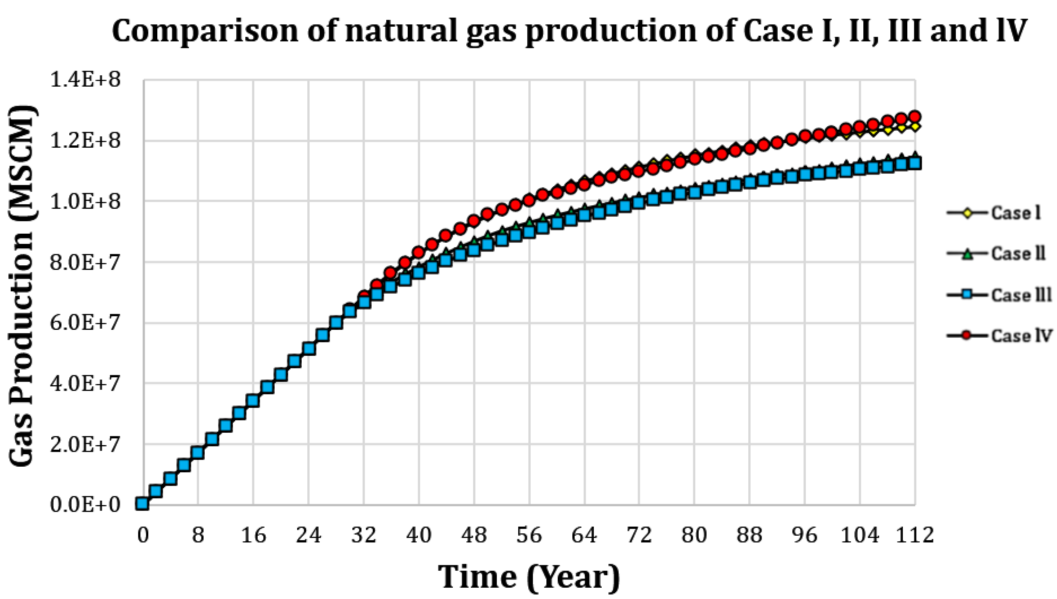

Figure 2: Comparison of gas production of Case I, II, III and lV

Figure 3 depicts the propagation of CO_2 plume in front of aquifer. Injection of CO_2 sweeps more gas to the produced well, while dissolution and accumulation of CO_2 leads to decrease in reservoir area invaded by aquifer. Results reveal that the amount of CO_2 production of the reservoir is low till the 112th years. Cumulative CO_2 production of Case IV is only 0.006 percent of injected CO_2 at the end of the process. In other words, almost all of injected CO_2 was sequestered.

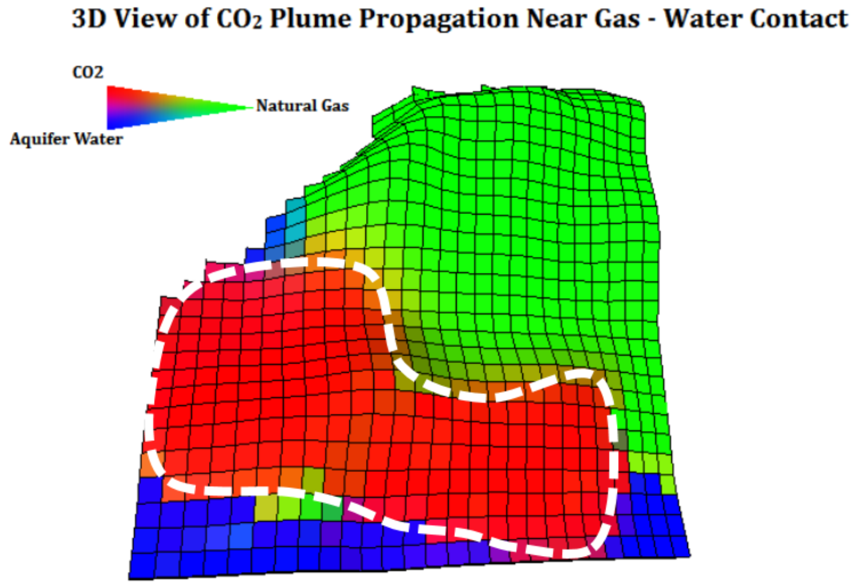

Figure 3: Part of reservoir that CO_2 plume was propagated to alleviate the effect of aquifer activity on reservoir performance

Figure 4 depicts the comparison of water production for cases. In addition to lower gas production, conventional method (Case III) leads to huge production of water. Formation water contains heavy metals, solids, production chemicals, hydrocarbons, benzene, PAHs, and on. High amount of water production in Case III is not acceptable from environmental point of view.

In comparison to the Case II, due to heterogeneity and complexity, injection of CO_2 results in sweeping some water toward production wells. To avoid this, using optimized injection well trajectory is important. However, production of some water can be expected.

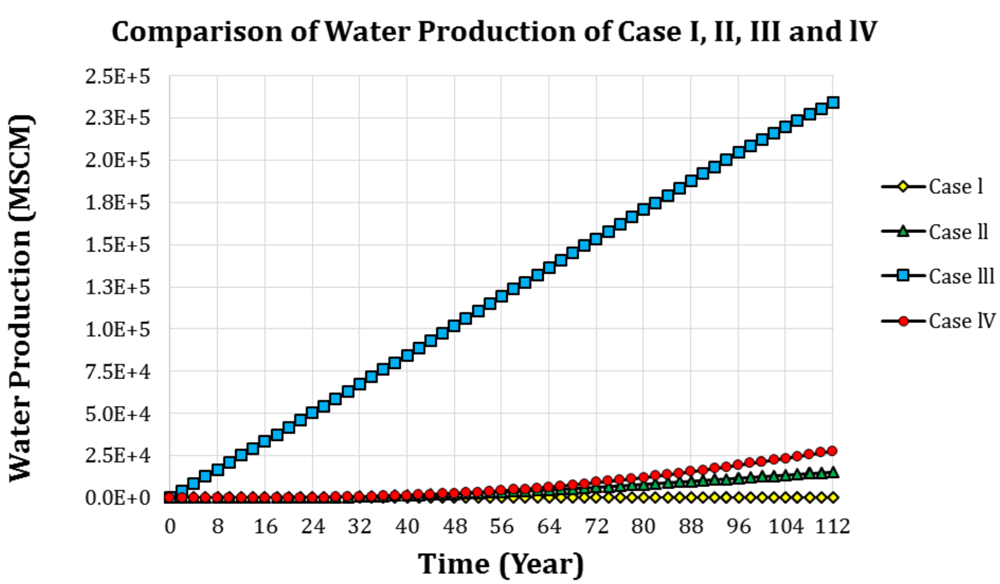

Figure 4: Comparison of water production of Case I, II, III and lV

Figure 5 shows the pressure responses for studied cases. Reservoir pressure is an important controlling parameter to avoid fracturing. Final pressure responses for cases I to IV are 109, 180, 123 and 307 bar, respectively. Maximum pressure allowed during CO_2 injection process is 0.90 of initial pressure which is controlled by total injection rate of CO_2.

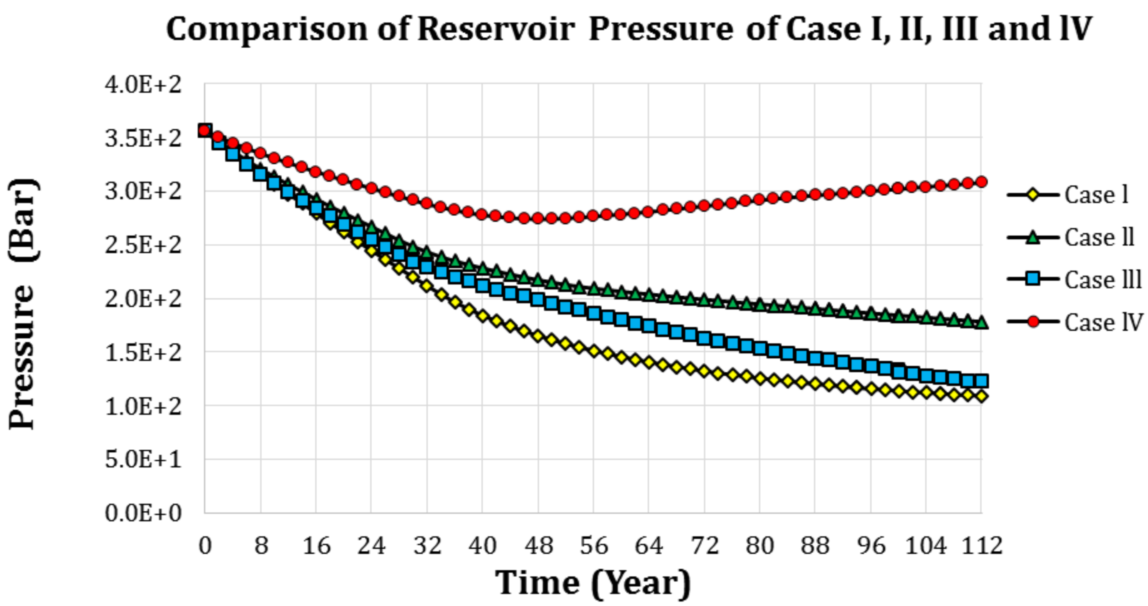

Figure 5: Comparison of reservoir pressure of Case I, II, III and lV

Figure 6 illustrates the comparison of produced condensate. Application of Miscible CO_2 in sweeping condensate was studied before. Injection of CO_2 in Case IV increases the condensate production volume by 23 percent in comparison with Case II.

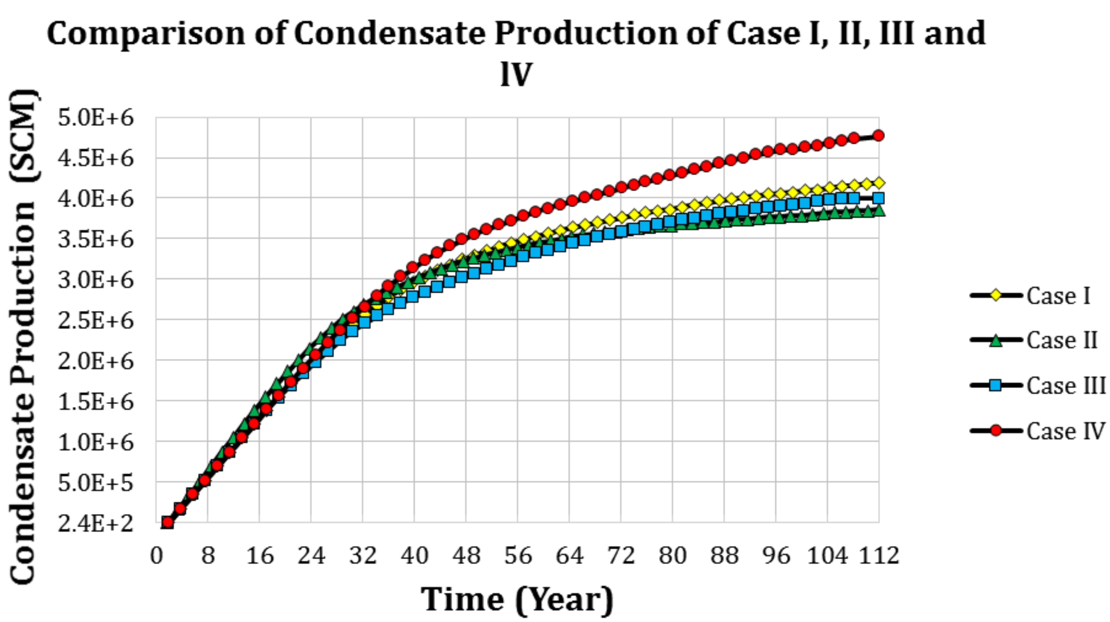

Figure 6: Comparison of condensate production of Case I, II, III and lV

For case of CO_2, considering important phenomenon of dissolution (correlations given by Chang et al) has no major effects on cumulative gas production. Also, water production decreased by 9.5%.

Result demonstrates that CO_2 dissolution decreases the cumulative CO_2 production, considerably (about 23 percent) and final reservoir pressure decreased by 3%. During CO_2 injection, part of the injected CO_2 is dissolved in the aqueous phase and not in direct contact with hydrocarbon, which can be defined as the CO_2 lost to the aqueous phase. Although dissolution trapping of CO_2 reduces the risk of CO_2 leakage and the security of the trapping, consequently.

5 Conclusions

The main issues addressed in this paper are improving gas recovery from water drive - gas reservoir and avoiding both CO_2 emission to the atmosphere and hazardous water production. Decreasing aquifer influx due to dissolution and accumulation of CO_2 toward the aquifer and also, sweeping more gas toward the production well are two important mechanism occurred in this process.

In comparison with conventional method the amount of gas and condensate production were increased by 14 and 22 percent, respectively. Negligible amount of injected CO_2 was recovered at the end of 112 years prediction. In contrast to co-production method, sequestration of CO_2 at least, supports the cost of injection facility and decreases the production of hazardous water strongly.

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