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Improving Oil Production from Fractured Reservoirs Using Simultaneous Water Alternative Gas (SWAG) Injection Scenario

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Abstract: Natural depletion of reservoir pressure is an unavoidable mechanism during oil production from fractured reservoirs. Due to this fact, several methods and strategies have been introduced for enhanced oil recovery (EOR). However, selection of the most efficient EOR technique is always a concern in the reservoir management. Alternative slugs of water and gas (WAG injection) were simultaneously injected to a carbonate reservoir of Iran to improve sweep efficiency. Injection of water slugs followed by gas that leads to triple region increase the contact level of injected fluid and reservoir, stable the movement front and finally increase the recovery. In the current study, scenario of simultaneous water alternative gas injection is simulated on a fractured reservoir of Iran, Ferdowsi Oilfield, to gain the ultimate oil recovery from this reservoir. The results show that an optimized SWAG process can increase the produced oil and recovery factor of the reservoir up to 58.909 and 37.94, respectively.

Key words: Oil production · Enhanced oil recovery · Fractured Reservoir · Water Alternating Gas Injection · Ferdowsi Oilfield

INTRODUCTION

Enhancing the recovery of an oil reservoir is one of the major roles of any oil company. Millions of oil barrels remain in reservoirs after primary and secondary recovery methods such as water flooding (WF) and gas injection (GI). Continuous growth of oil price has made great attention for recovering the remained oils through tertiary recovery methods water alternative gas (WAG), chemical flooding and even thermal methods. Difficulties and constraints of conventional EOR methods, like inappropriate mobility ratio and early fingering of injected fluid, have led to invention of WAG injection as combination of two methods of gas and water injection in the last decades [1]. The WAG process was first introduced to increase sweep efficiency during gas injection. Practically, the WAG process includes injection of alternative cycles of water and gas slugs for improving the sweep efficiency of water flooding and either miscible or immiscible gas flooding. During this process the impact of viscous fingering is reduced. The combination of higher microscopic displacement efficiency of gas and improved macroscopic sweep efficiency of water significantly increase the recovery over a plain water flood. The mobility ratio between injected gas and the displaced oil bank by CO_2 and N_2 and other miscible/immiscible gas displacement processes is typically very unfavorable because of low viscosity of the injected phase. The unfavorable mobility ratio refers to viscous fingering and consequently reduced sweep efficiency [2].

The WAG process is an injection technique developed to overcome this problem by injection of specified volumes, known as slug, of water and gas alternatively. The mobility of the injected gas, alternating with water, is less than the case in which gas injected alone; therefore, the mobility ratio of the process is improved [3]. The success of WAG injections, compare to simple water and gas injections, causes from two facts. Firstly, the residual oil in the flooded rock may be lowest when three phases of oil, water and gas have been injected to the reservoir. Secondly, simple water injection tends to sweep the lower parts of a reservoir and simple gas injection sweeps more of the upper parts of a reservoir owing to gravitational forces; however, WAG injection sweep both lower and upper parts of the

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reservoir [4]. Ma and Youngren [5] provided additional support to the benefits of the WAG process such as higher production rates, reduced water handling costs and better reservoir management. Several literatures have clarified the main technical and operational issues that should be considered during WAG method. Suitable operating condition and constraints, such as limitation of gas production rate, production and injection bottom hole pressure affect oil production rate and ultimate oil recovery. In addition, Identifying different types of mechanisms and the appropriate activation time for each mechanism are the most crucial parameters for studying the injection procedure in a fractured reservoir. Investigating the reservoir behavior in different conditions, predicting the future behavior of reservoir after different injection scenarios and comparing the performance of developed scenarios are the main goals of this research. Procedure for Paper Submission.

Reservoir Characteristics of Ferdowsi Oilfield: The studied oilfield is an asymmetrical anticline on Asmari group measuring 10 km length and 5 km width. This field is located in southwestern of Iran. The trapped hydrocarbon in the studied reservoir of the field is classified as a light hydrocarbon with 39° API gravity, gas oil ratio is 700 ft^3/scf and oil formation volume factor of 1.34 RBBL/STB. Table 1 represents the most important reservoir characteristics and fluid properties of the studied reservoir. At the beginning of production, the reservoir was under saturated, while fluid production has reduced the pressure and the reservoir converted to a saturated one with a free gas cap. Petrophysical and geological data suggest that the reservoir just includes Asmari Formation. Also, due to petrological and texture variations it has been divided into two zones, including a carbonate unite and a mixture of carbonate and anhydrate sediments. The present information indicates that the mean porosity of the upper carbonate part (Dolosparite) is about 15% which is an evidence for fair distribution of the fracture network. These fracture networks are contributing to oil production, which shows the reservoir is performing as a dual porosity continuum. Table 2 shows the mean values of petrophysical properties of the reservoir.

Model Description: In this study, different injection scenarios were simulated through commercial simulator (FloGrid Software-An Eclipce Module). A gridding network of the reservoir was designed using geological data. In this network, reservoir was divided into 38 and 34 grid blocks in longitudinal and latitudinal directions, respectively. Also, considering the rock type variations, 7 grid blocks were defined for the reservoir in vertical direction. Table 3 presents valuable information about sector model of the studied reservoir.

Designing Injection Scenarios: In this study, first natural depletion of the reservoir was simulated on the sector. The results of this simulation can be used as a standard and scale for studying the effects of different types of EOR injections.

Table 1: Fluid characteristics of the studied reservoir

°API	39
Total thickness, ft	226
GOR, ft^3/scf	700
Rock compressibility,1/psi	4/29e-6
Water compressibility,1/psi	2/12e-6
Oil density,lb_m/ft3	45
Gas density,lb_m/ft^3	0/049
Datum depth, ftss	2500
Average reservoir pressure @ datum depth, psi	1750
GOC, ftss	2500
WOC, ftss	2600
Reservoir temperature, °F	120
Average Matrix porosity,%	15
Oil FVF, Rbbl/stb	1/34
Water FVF,Rbbl/stb	1/01
Oil viscosity,cp	0/65
Gas viscosity,cp	0/019
Water viscosity,cp	0/854
Oil saturation,%	76
Water saturation,%	24

Table 2: Mean values of reservoir properties

	Oil Zone				
Zone	Öi %	Sw %	NTG	Bo rb/stb	Ave.Permeability
A	13/77	21/63	0/915	1/34	0/1126
B	3/6	55/06	10/94	1/34	0/1498

Table 3: Simulated sector model properties

Type of porous medium	Fractured
Number of cell in X-direction (N_x)	38
Number of cell in Y-direction (N_y)	34
Number of cell in Z-direction (N_z)	7
Number of cell	9044
Dual porosity matrix-fracture coupling,1/ft^2	0.13
X grid block size(Mean), ft	188
Y grid block size(Mean), ft	240
Z grid block size(Mean), ft	116
Matrix porosity,%	17
Fracture permeability, md	5800
Effective matrix block height for gravity drainage, ft	20

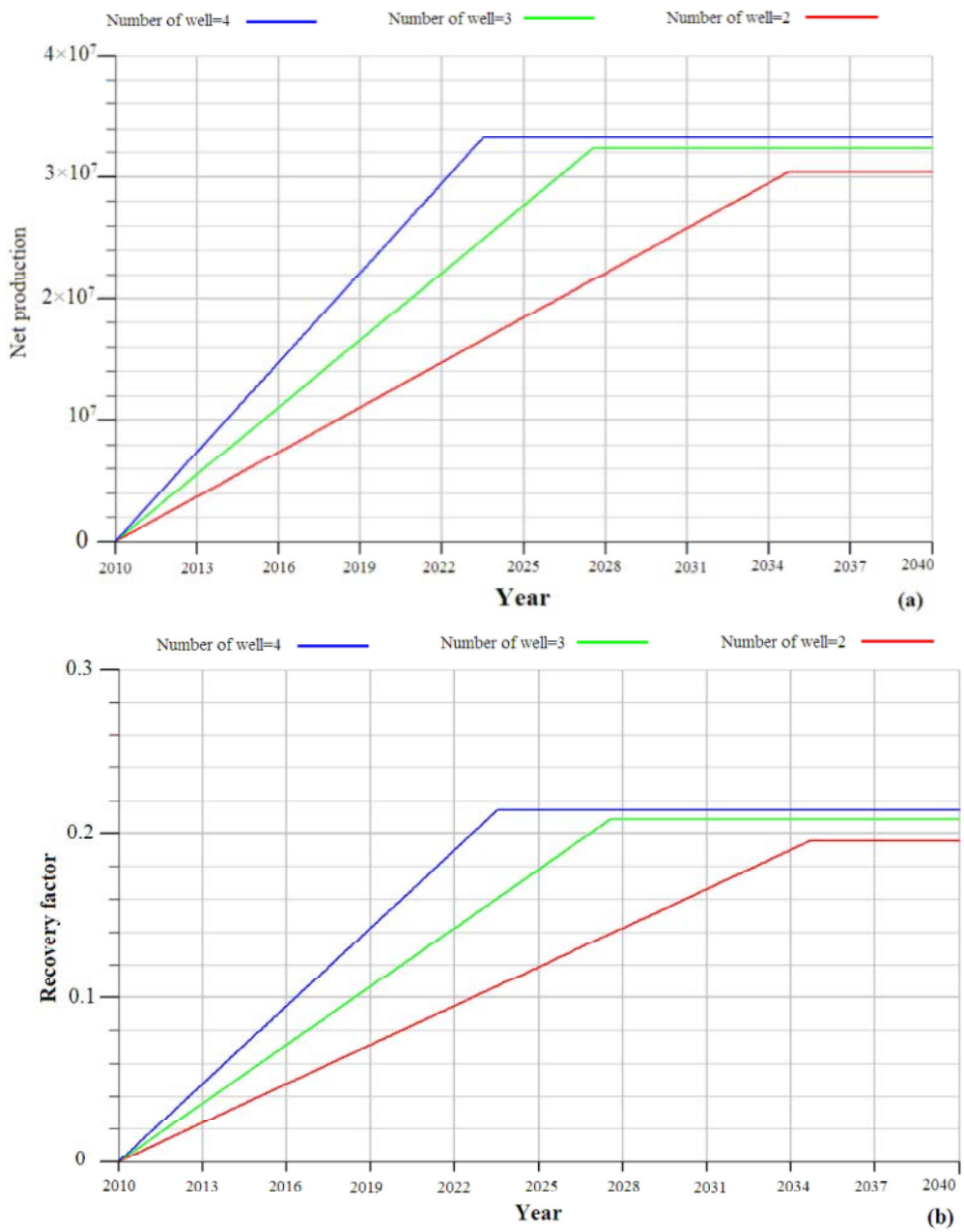

Fig. 1: Behavior of the reservoir for (a) net production and (b) recovery factor in three different scenarios

Natural Depletion: In this section, the natural depletion of the studied reservoir is simulated. Number of production wells is the only parameter that changes in natural depletion. Three scenarios are simulated based on 2, 3 and 4 production wells. The production rate of all scenarios is the same and considered 6733 stock tank barrel per day (STB/Day). Table 4 represents net production (NP) and recovery factor of simulated scenarios in a period of 30 years (From 2010 to 2040). Fig. 1 is a graphical illustration of the maximum amount of production and recovery factor of the reservoir in different scenarios. As illustrated in Fig. 1(a), 4-well scenarios produces maximum amount of oil compared to 2-well and 3-well scenarios, which is also equivalent to maximum recovery factor for this production strategy (Fig. 1(b)). However, the reservoir will be depleted in about 14 years if four wells are used for production, while 3-well and 2-well scenarios shows 18 and 24 years, respectively, as the effective productive age of the reservoir.

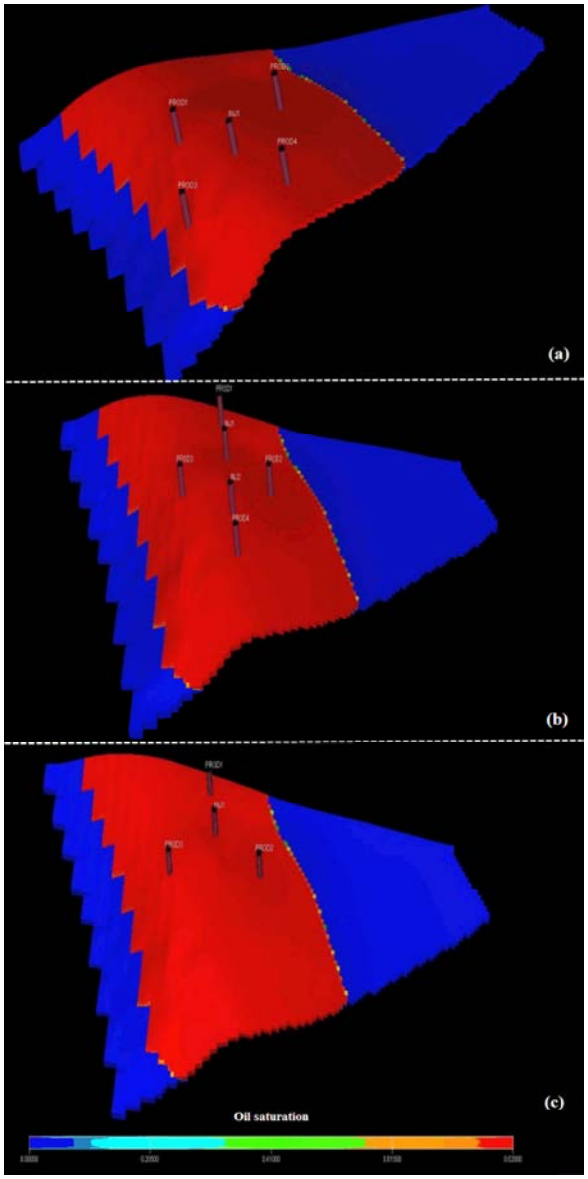

Fig. 2: Schematic graphical illustration of three different patterns of injection and production wells

Simultaneous Water Alternative Gas (SWAG) Injection: Simultaneous water alternative gas (SWAG) process is simulated to achieve the lowest residual oil in the sector. Studying the literatures shows that this method can perform more efficient compare to WAG process. Although the recovery methods improve the ultimate production and recovery factor of a reservoir, however, selecting the optimum and suitable parameters has undeniable impacts on outlines of an EOR project. Optimum pattern of injection and production wells, water to gas ratio and pore volume injection are the most important parameters of a SWAG process. Here, these parameters were optimized based on the conditions of the studied reservoir.

Optimum Pattern of Injection and Production Wells: In the first step the optimum distribution of injection and production wells in the studied reservoir should be investigated. Three different patterns of injection and production wells are analyzed and the best pattern is selected based on the maximum produced oil and recovery factor. Based on EOR theories these patterns are the most popular patterns of injection scenarios. Fig. 2 shows the distribution of production and injection well in the studied patterns. The results suggest the 4 spot-Dual as the optimum pattern in which two injection wells were surrounded by four production wells (Fig. 3). In the next sections, 4spot-dual pattern is considered for simulating and studying parameters affecting injection process.

Optimum Value of Pore Volume Injection: In this step three values are considered as the probable optimum value of pore volume injection (PVI), including 0.3, 0.5 and 0.7. the results of simulation demonstrates that 0.7 is the optimum value of pore volume since the amount of produced oil and recovery factor in the correspondence model is larger than other ones. It is worth mentioning that in all simulations of this step, the ratio of water to gas is considered equal.

Effect of Water to Gas Ratios: The ratio of water to gas is called WAG ratio. Large value of WAG ratio increases the water cut, while low value of WAG ratio increases the produced gas compare to oil; therefore, calculating the optimum WAG ratio is a crucial parameter affecting economic operating conditions of EOR process. The volume of injected fluid is equal to 0.7 plus space volume of the model (PV=0.7). The studied WAG ratios are 1:1, 1:2, 1:3, 2:3 and 3:4. The results show that the most suitable WAG ratio is 1:1 in which the maximum oil production and recovery factor is obtained. Due to this fact, this ratio is considered in the next calculations of this study. Table 5 shows the results of simulated models for the studied reservoir. Also, the net production and recovery factor of the reservoir are graphically compared in Fig. 4. If the WAG ratio is considered as 1:1, the maximum oil will be produced in almost 22 years, while other ratios not only shows lower recovery factor and production, but also they reduce the effective age of the reservoir. The maximum produced oil and recovery factor of the reservoir are 54.321 million stock tank barrel and 34.98%, respectively.

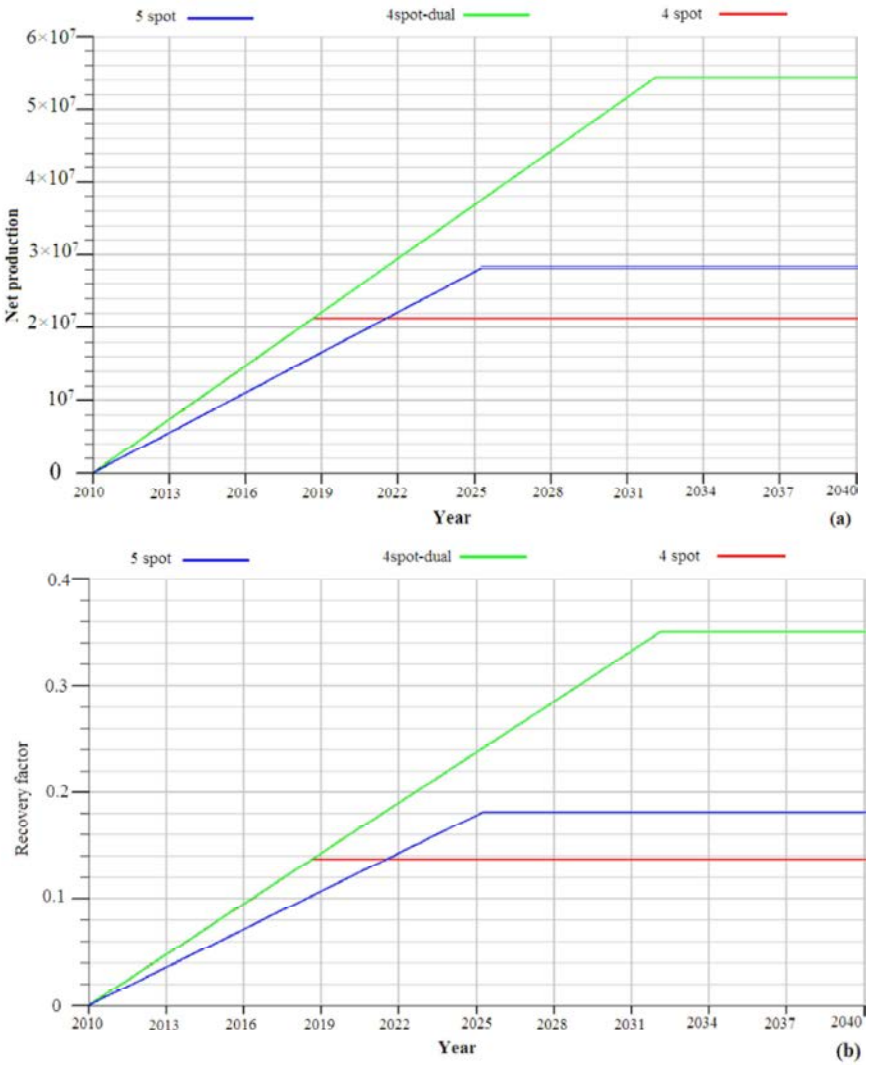

Fig. 3: Graphical behavior of the reservoir for (a) net production and (b) recovery factor in three different patterns of injection and production wells

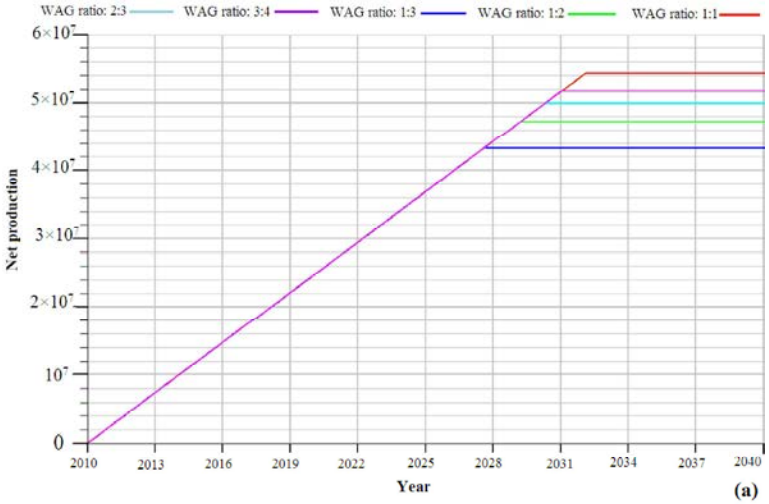

Fig. 4: Continued

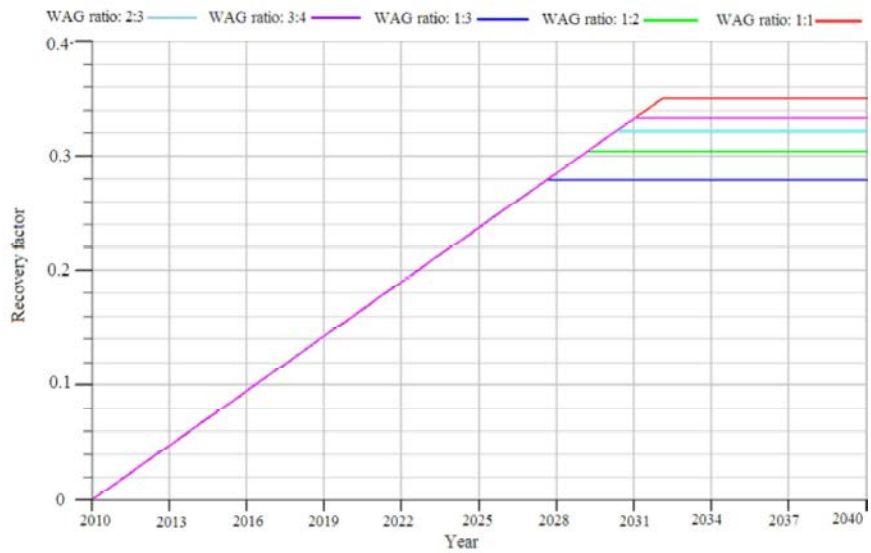

Fig. 4: Graphical illustration of (a) net production and (b) recovery factor in five WAG ratios (PV=0.7).

CONCLUSION

In the current study the performance of a relatively novel EOR method is analyzed on a fractured reservoir of Iran. First, the behavior of the reservoir is simulated in natural depletion condition over a period of 30 years. The results shows that the maximum amount of produced oil and recovery factor will not exceed 33.222 MMSTB and 21.4%, respectively. Therefore, a SWAG process is simulated and the most suitable parameters were optimized to gain the maximum amount of production. The results shows that a spot-dual pattern in which PV and WAG ratio are equal to 0.7 and 1:1, respectively, can improve the produced oil and recovery factor up to 58.909 and 37.94, respectively.

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