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Comparison between EOR methods (Gas Injection,Water injection and WAG Processes) in One of Iranian Fractured Oil Reservoirs

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Abstract: In the common enhanced oil recovery methods, unsuitable mobility ratio within the injected fluid and the oil in the reservoir, leads to reduction of sweep efficiency especially in fractured reservoirs. In this work, gas injection, water flooding and WAG processes were applied in well configuration which called Dual-Five spot. Because this sector model was selected from a highly fracture reservoir. Dual-Five spot with 38.889% oil recoveries are the best EOR plans for this sector model. The main important point in using WAG process in this sector model is that the cycle of injected gas should be less than injected water.
Keywords: WAG, Well pattern, Simulation, Sweep efficiency, Optimizing,WAG Cycle,WAG Ratio

1. Introduction

For enhanced oil recovery purpose, miscible gas flooding and water alternating gas (WAG) process have been applied successfully in many hydrocarbon reservoirs [McGuire P.L., et al., 2003, Thomas F.B., 1994]. The attractiveness of miscibility is that it can reduce the interfacial tension. The reduction in the interfacial tension has a significant effect on relative permeabilities and residual saturation by increasing the trapping number, which has been formulated mathematically and tested by experiments [Qiliang, B., et al., 2003, Wagner, O.R., et al., 1996].

The WAG process is designed to improve the continuous gas injection EOR method, mainly by reducing gas mobility and thereby increasing sweep efficiency in the reservoir. For any hydrocarbon reservoir, all causes of inefficient oil recovery can be formally organized into just five factors:

1. Heterogeneity and gravity effects. 2. Fractional flow effects. 3. Local or displacement sweep efficiency. 4. Capillary trapping of residual oil--residual oil saturation. 5. Streamline effects.

To maximize the oil recovery, we need to enhance displacement sweep efficiency and the volumetric sweep efficiency, which is defined as the product of areal sweep efficiency E_A and vertical sweep efficiency E_I, or to reduce the residual oil saturation [X. WU., et al., 2004]. The reservoir sweep efficiency to be expected from a gas injection is to a large extent dominated by the degree of heterogeneity if the displacement is not fully miscible. Analysis of historical water injection performance data will typically indicate presence of high-perm streaks and fracture network, which would prove harmful to the microscopic sweep efficiency in a gas injection scenario buy causing gas channeling and premature breakthrough [K. Mogensen, et al., 2010]. It is fundamental to the study of different displacement processes in reservoir systems knowing how the multiphase mixtures flow in response to heterogeneity. Small-scale heterogeneities are particularly problematic for all secondary and tertiary recovery processes as they can cause distortion of fluid streamlines and deviation from the production profiles of equivalent homogenous systems [Y.M. Al-Wahaibi, et al., 2011]

This paper is one of the few quantitative studies of the gas injection, water injection and WAG process including evaluation of parameters affecting project design, selection of injection and production well location and optimization of production well controls at gas injection, water flooding and WAG processes.

2. Fluid Properties

This field is located in southwestern of Iran. Water cut and gas oil ratio was set 90% and 700 ft^3/scf respectively. The other fluid properties are listed in Table 1. Figure (1) illustrates the final matching of phase diagram of reservoir fluid. Reservoir temperature is 115°F.

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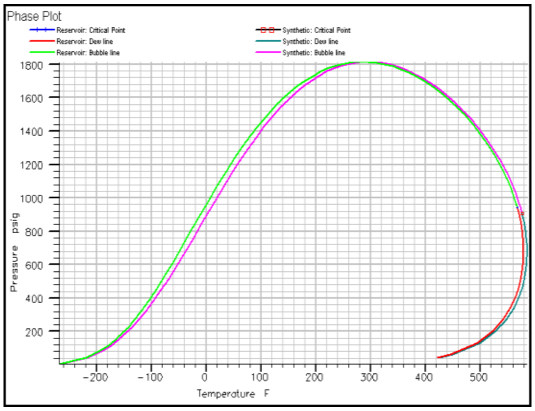

Figure (1): Phase diagram of reservoir fluid

3. Reservoir Rock Properties

Initially the oil reservoir was under saturated and initial reservoir pressure was equal to 2500 psia, Oil production causes to reduction in pressure. After reaching to saturation pressure gas cap stated to form gradually. Reservoir formations consist of grey and brown dolomitic and carbonate dolomitic rocks with oil field fissures and fractures. This zone can be divided into two subzones. Upper subzone which is carbonate has an average thickness of 53 meters. Lower subzone consists mostly of alternating carbonate and anhydrite rocks with average thickness of 16 meters. Fracture study implicated network is fairly distributed which includes most of the oil in place and these fracture networks are contributing to oil production which shows the reservoir is acting as dual porosity continuum.

4. Sector Model Properties

In this paper with regard to design the suitable well configuration and EOR method, the different injection scenarios with different well patterns were designed using commercial simulator. The properties of selected sector are listed in Table 1.

Table 1: Fluid and sector model properties

Fluid properties	API	39	Oil FVF, RBBL/STB	1.34
	GOR, ft3/scf	700	Water FVF,	1.01
	Water compressibility,1/psi	2.12E-06	Oil viscosity, cp	0.65
	Oil density, lbm/ft3	45	Gas viscosity, cp	0.019
	Gas density, lbm/ft3	0.049	Water viscosity, cp	0.18
Sector model properties	Type of porous medium	Fractured	X grid block size,ft	2180
	Number of cell in X-direction (N_x)	33	Y grid block size,ft	1130
	Number of cell in Y-direction (N_y)	31	Z grid block size,ft	116
	Number of cell in Z-direction (N_z)	7	Matrix porosity,%	7
	Number of cell	7161	Fracture permeability, md	5800
	Dual porosity matrix-fracture coupling,$1/ft^2$	0.6	Effective matrix block height for gravity drainage ,ft	20

Based on the Geological data, fracture media exists, so dual porosity model was chosen for simulation of reservoir. Then reservoir static data including porosity, absolute permeability and NTG were calculated for all grid blocks using geological model of reservoir and up scaling techniques and were used as input data to simulator. In order to classify reservoir rock, first using frequency diagram of initial classification of various kinds of rock-water saturation diagram, porosity and the results of special experiments and various kinds of rock were divided into four groups. Then by drawing water saturation diagram, porosity and applying water saturation and porosity sections, reservoir rock was divided into six types of rock. Figure 2(a) shows the selected sector.

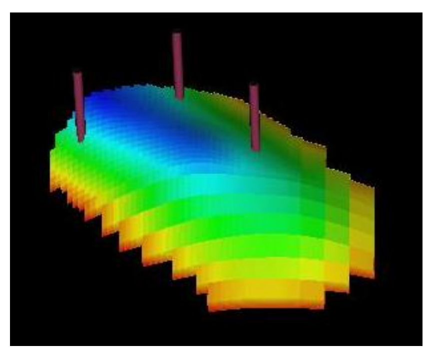

Figure 2 (a): Three dimension view of selected sector with three production wells

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5. Results

5.1. Natural Depletion

Selected sector model has three production wells; rate of field oil production was set at 6000 STB/DAY with divided between three wells. This natural depletion was called (Nd-DONO-6000). According to the result of do noting scenario, ultimate oil efficiency was obtained only 5/9%. After adding three other production wells with the same field oil production rate, efficiency reached to 27.24 %. Pay much attention to the location of infill drilled wells is necessary.

With regard to obtain the best location of injection wells, Dual-Five spot patterns have six production wells and two injection wells (figure 2(b)). Because of strong and dominate fracture network, the location of wells especially injection wells has a huge effect on recovering of fluid in place.

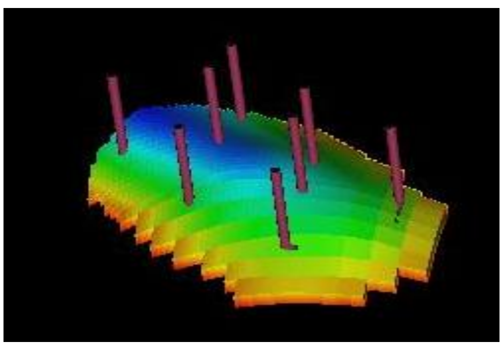

Figure 2(b): Three dimension view of selecte sector with six production wells & two injection wells

5.3. Gas Injection

In this part, several gas injection scenarios with different injected gas rate during 1.5 to 60 MMSCF were applied to reach the optimum gas rate. With increasing the rate of gas injection, field oil efficiency increased but there is no clear difference between higher rates.Figure 3 illustrates maximum oil recovery was obtained 32.003%.

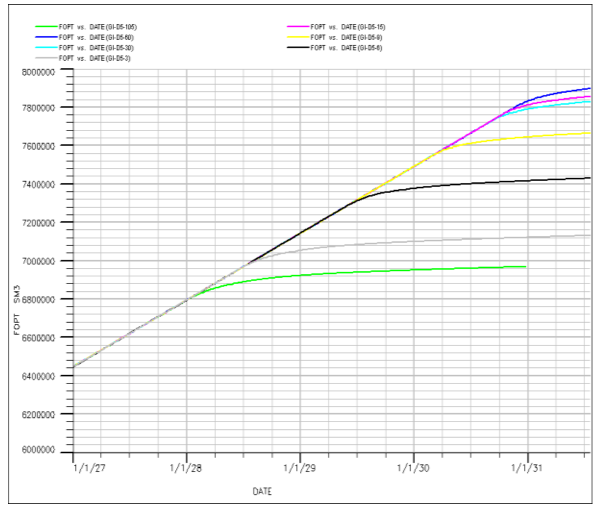

Figure 3: Field oil production total at gas injetion scenario at Dual-Five spot (D5)

5.4. Water Flooding

Figure 4 shows the effect of water injection rate (5000 to 30000 BBL/DAY) on field oil production of selected sector model. As it is seen scenario of water injection with 30000(bbl/day) has higher efficiency in this pattern.Beacouse of highly dencity of fracture in this sector,efficiency in water injection scenario is better than Gas injectuin scenario.

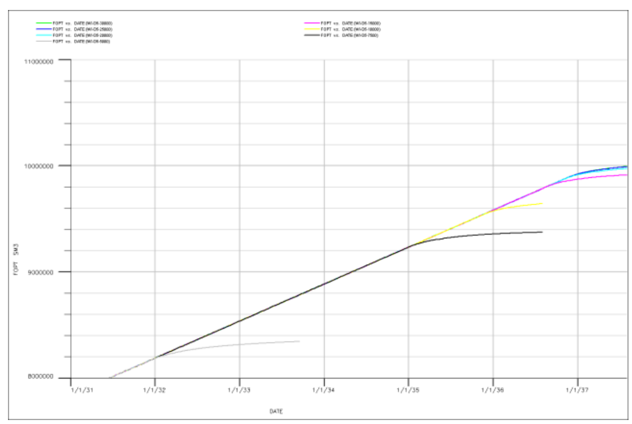

Figure 4: Field Oil Production at water injection scenario at Dual-Five spot pattern

5.5. WAG Flooding

In WAG process there are some important parameters which included WAG ratio and WAG cycle that planned WAG ratios are 1:1, 2:1, 3:1, 4:1, 1:2, 1:3.the first number of ratio correspond to water and the second number to gas. First two pore volume injections 0.1 PVI and 0.5 PVI were considered. The results of different WAG pore volumes

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injections and WAG ratios are listed in Table 2.

Table 2: Effect of pore volume injection and WAG ratios on Dual-Five spot pattern at WAG process

Name	Qw(bbl/day)	Qg(MMSCFD)	FOE%	FOPT(SM3)
WAG-0.1PV-31	22500	20	38.713	9556371
WAG-0.1PV-21	15000	20	38.581	9523566
WAG-0.1PV-13	7500	60	36.483	9017749
WAG-0.1PV-12	7500	40	36.539	9025493
WAG-0.1PV-11	7500	20	36.941	9134618
WAG-0.1PV-41	30000	20	38.733	9563569
WAG-0.2PV-41	40000	30	38.729	9560369
WAG-0.2PV-31	30000	30	38.608	9530676
WAG-0.2PV-22	20000	30	38.525	9522115
WAG-0.2PV-13	10000	90	37.05	9145539
WAG-0.2PV-12	10000	60	37.372	9213045
WAG-0.2PV-11	10000	30	37.628	9290653

First different pore volume injections and WAG ratios were optimized in designed patterns, in next step effect of WAG cycle on WAG process was investigated. Several WAG cycles (6, 10 and 12 month) were applied, each of WAG cycle time can divided to two parts which the first one is the amount of gas injection time and the other one corresponds to water injection time. According to Figure 5, the highest oil recovery at Dual-Five spot pattern, WAG-D5-0.1PV-41-210 (38.889%), also effect of WAG cycle at Dual-Five spot pattern with different ratios in Figure 5 was displayed. Comparison between all of scenarios at 0.1 and 0.2 pore volume injections at different cycles explains that 0.1 PVI is more suitable to reach higher oil recovery; the reason of this occurrence is function of network fracture. The greatest efficiencies, 38.889 % were achieved at WAG-D5-0.1PV-41-210 and 38.73 % at WAG-D5-0.2PV-41-210.

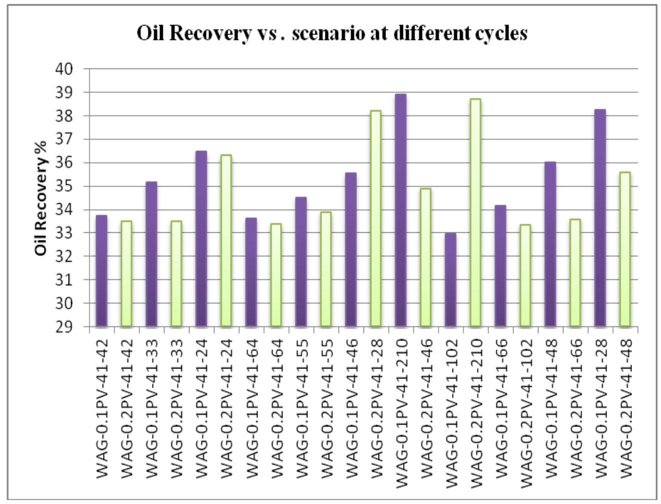

Figure 5: Comparison between WAG cycle with 0.2 and 0.1 PVI at Dual-Five spot pattern

With consider to Figures 5, all of implemented scenarios at 0.1 PVI have higher efficiency than 0.2 PVI totally. Figure 6 describes the total result of all of the best scenarios. The first part is included of gas injection scenarios, so selecting gas injection method lead to 32 % efficiency.

For applying WAG process, Dual-Five spot scenarios with 38.889 % oil recovery can select as the best method, But sensitivity analysis on location of injection and production wells shows the location of wells is more important in WAG rather than gas injection. At all of well configurations, water injection has the first rank. There are two injected wells, it is necessary to know that the cumulative of water injection is constant. Number of injection well clearly affects on oil recovery because cause to spread fluid in a stable movement especially infractured media.

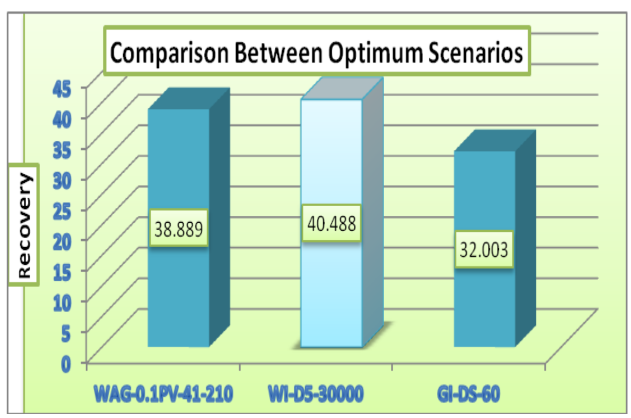

Figure 6: Comparison of oil recovery between Optimum EOR method (gas injection, water injection, WAG)

6. Conclusions

Base on the results, intensive network fracture has skirted the model and fracture veins have strong relation, therefore gas can move rapidly and easily inside the reservoir and lead to minor oil recovery. The main important point in using WAG process in this sector model is to adjust period of gas injection time. Whatever the cycle of injected gas is less than injected water, model will visit the limitation of GOR subsequent. The other significant part in WAG process is number of cycles. If the number of cycle would be less it tends to steady and suitable sweep efficiency for this reservoir.

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