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A new workflow for optimization of WAG injection process in an Iranian oil reservoir

Hamed Panjalizadeh*, Hamed Jafari, Ali Beitsaeed, Alireza safari, Mohammad hadi Fatehi
Mehran Engineering and well services company, Mehran Dead End, One Block Northward from Emdad-Sharghi St, Sheikh Bahaie Lane North Molla-Sadra Ave,Tehran, Iran.
**Corresponding Author's E-mail: h.panjalizadeh@mehranservices.com*

Abstract

Availability of hydrocarbon gases at the field makes it attractive for gas-based EOR methods such as WAG Injection. Optimization of EOR methods requires too many simulation runs which are time-consuming and expensive. Therefore, developing a proxy model, which emulates simulator outputs, is considered as an appropriate alternative technique. In this work effects of composition changes of injection gas, WAG ratio, and slug size on produced oil and water are investigated. In addition, the optimum value of the above parameters, including some constrains, are presented using response surface methodology. Experimental design is also applied to construct different polynomial regression models as proxy models for a sector of an Iranian oil reservoir under WAG injection scenario. A new work flow is introduced for optimization of the WAG parameters, which all effecting parameters are changing simultaneously.

Keyword : WAG injection method, WAG ratio, polynomial regression, experimental design, response surface methodology

Research Highlights

- Despite previous studies, in this study all WAG optimization parameters change simultaneously
- This study demonestrates the application of response surface methodology and experimental design for optimization of WAG injection process in a time-effective and economical way.
- High injection rates with small slug sizes and WAG ratio of 1:1 are optimum conditions obtained in this study.

1. Introduction

The first idea leading to WAG injection was to gain both positive aspects of water flooding and gas injection. The poor mobility ratios in gas injections can be compensated by either increasing the viscosity of gas or by decreasing its relative permeability [1]. There is always an optimum WAG Ratio in the experiments, Jafari et al. concluded that it depends on rock wettability and fluid properties, for their work 2 is obtained as optimum WAG ratio [2]. The experimental investigating of the WAG process using methane-carbon dioxide mixture as injection gas on a sand stone rock is carried out by Alizadeh et al. and the optimum WAG ratio is found 1:1 [3].

Optimization of WAG process is necessary in order to find optimum injection conditions. Stochastic optimization algorithms such as genetic algorithm can be one of the optimization procedures. They have been used extensively to determine optimum conditions in different reservoir development problems. Using these algorithms requires a lot of simulation runs. Thus, stochastic optimization is time-consuming and expensive procedures. Alternatively, developing a proxy or response surface such as a polynomial regression model, which gives outputs close to the simulation results, seems to be appropriate techniques. Panjalizadeh et al. worked on risk analysis and optimization of steam flooding scenario using various proxy models in heavy oil reservoirs [4]. In this study a new workflow is introduced for optimization of the WAG parameters such as WAG ratio, slug size and injection gas composition which are in good agreement with the experiments (A.Alizadeh and M.H.Ghazanfari). Despite previous works in this area, in this study all optimization parameters of WAG process, such as injection rates, injection times, and injection gas composition change simultaneously.

1. Objectives and Selection of Optimization Parameters

Field oil production total (FOPT), field water production total (FWPT) are important production parameters in any WAG injection process. Numerical optimization was done to maximize FOPT and minimize FWPT. We assumed 5 for FOPT's importance weight and 1 for FWPT's. Optimization parameters and the possible range of each parameter are shown in Table 1. The range of WAG ratio (volume of injected water/volume of injected gas) will be from 0.2 to 5 and slug size (%PV) will be in range of 10% up to 60% injected pore volume.

Table 1 Optimization parameters and their range

Uncertain parameter	**Minimum value**	**Maximum value**
CO_2 Mole Percent in Injected Gas	0	75
Water Injection Rate (bbl/d)	50	250
Gas Injection Rate (cft/d)	25	1405
Gas Injection Time (days)	120	360
Water Injection Time (days)	120	360

2. Dataset Sampling Using Response Surface Designs

More informative input dataset samples will lead to more accurate proxy models. Different response surface designs are used in this section including: Quadratic Box-Behnken (BB), quadratic Inscribed Centered Central composite (CCI), a combination of BB and CCI and, a combination of BB and CCI.

2. Proxy Model Construction

We use previously mentioned response surface designs to construct proxy models to emulate our desirable production outputs, FOPT and FWPT. Eclipse 300 simulator is used as reservoir simulator and, rock and fluid properties of an iranian oil reservoir is inserted as input of simulations.

5.1. Polynomial Regression Model (PR)

PR models are constructed using Least Squares Method. PR models are constructed up to 2 PV injections. Ten extra cases are designed by a random number generator to validate constructed PR models. Relative prediction Errors (RE) of each PR model are calculated. The maximum and average relative error of PR models for final FOPT and FWPT for each design, are shown in Table 2.

Table 2 Maximum and average relative errors of PR models for different designs

Response	**Design**	**Polynomial Type**	**Fitting Error %**		**Validation Error %**	
			Ave. RE	**Max RE**	**Ave.RE**	**Max RE**
FOPT	**BB**	Quadratic	0.47	1.96	0.44	1.33
	CCI	Quadratic	0.21	0.85	0.55	1.88
	BB+CCI	Quadratic	0.40	2.32	0.46	1.09
	BB+CCI	Cubic	0.31	0.83	0.23	0.65
FWPT	**BB**	Quadratic	4.99	21.33	8.23	25.29
	CCI	Quadratic	3.33	19.51	9.87	25.61
	BB+CCI	Quadratic	5.2	26.67	5.98	17.66
	BB+CCI	Cubic	2.44	10.86	2.86	12.50

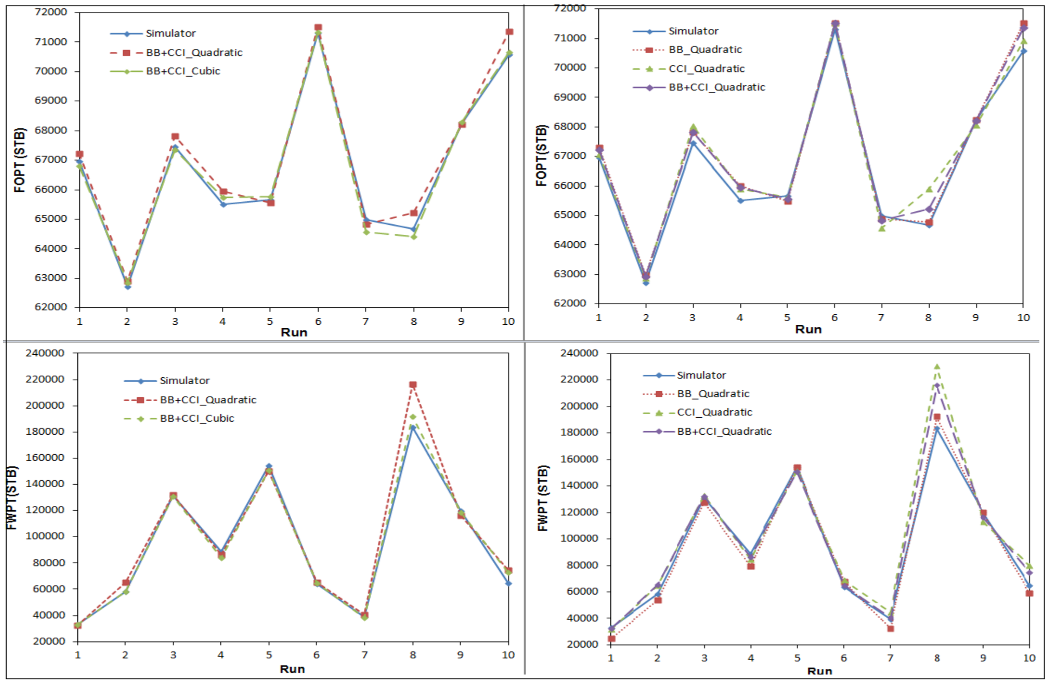

Figure 1 Results of simulation and different proxy models of FOPT and FWPT for 10 randomly selected runs

As per Table 2, constructing cubic models with a combination of BB and CCI design is led to the best fit for both FWPT and FOPT. Therefore, this model is chosen for the optimizing of objectives. It should be noted that CCI+BB provides 5 level for each factor and has enough data points for constructing cubic models. Figure 1 shows the results of simulation and different proxy models of FOPT and FWPT for 10 randomly selected runs.

3. *Result and discussions*

The results shown in Figure 2 clearly indicate the positive effect of increasing CO_2 content of injection gas on final oil production with no important effect on the produced water. Presence of CO_2 helps to reduce the MMP of CH_4 which is the major reason to increasing produced oil. The CO_2 mole fraction is limited to 75% to preventing facility corrosion, transportation and storage costs. As shown in Figure 2a, increasing in CO_2 content in injection gas, will increase the FOPT value, also at the high rates of the injected water the produced oil will increase, but this is neither applicable nor economical since the water production is increased so rapidly and it will increase surface operation costs. Note that increasing in CO_2 content of the injected gas has not any sensible effect on FWPT. The CO_2 is soluble in the water, so in the reservoir and at the high pressure conditions it will be solve in the water and at the surface condition it goes out, so the volume of the water will not change any more in each constant injection rates.

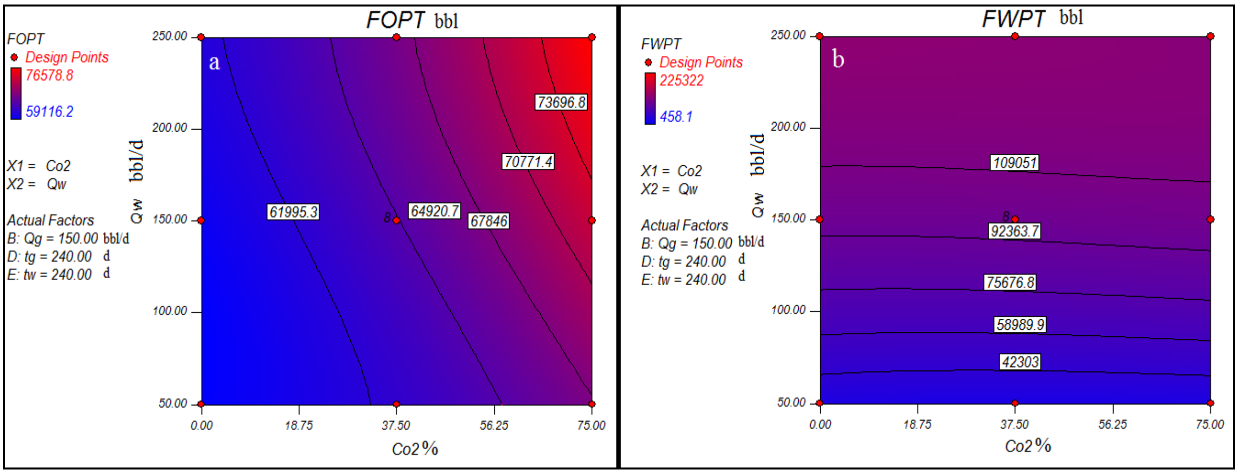

Figure 2 Effect of CO_2 content and rate of water injection after 2PV injection on (a) FOPT, (b) FWPT

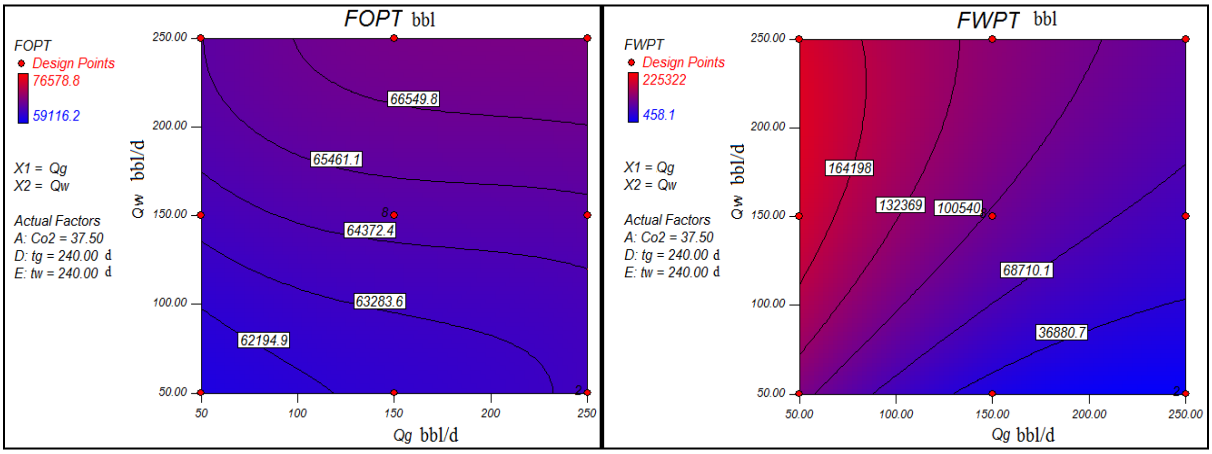

Figure 3 Effect of injected rates after 2PV injection and CO2 content of 37.5% on (a) FOPT (b) FWPT

Figure 3 shows that increasing in water injection will increase in the FOPT amount and FWPT, the higher shear rate exerted on oil from high velocities in pores can move the oil. Note that increasing in water injection rate will increase produced water amount more than produced oil, which is not favorable. On the other hand, the increasing of the gas injection rate can reduce produced water and have a minor effect on FOPT increase, which is not suitable. Thus, here we should select an optimum rate of both water and gas.

According to Figure 4, increasing in slug size of the gas will decrease the FOPT because of breakthrough of gas, and increasing of injected water slug size will increase the FOPT and also FWPT. It should be noted that increasing in FWPT is not favorable. In this figure, water injection time (days) versus gas injection time (days) are plotted at constant rate, so the slug size which is product of rate in time is proportional to time of injection. WAG ratio which is an important factor in WAG process is also investigated in this study. There is always an optimum WAG ratio in any WAG process which depends on rock and fluid properties, so it will be different for each reservoir.

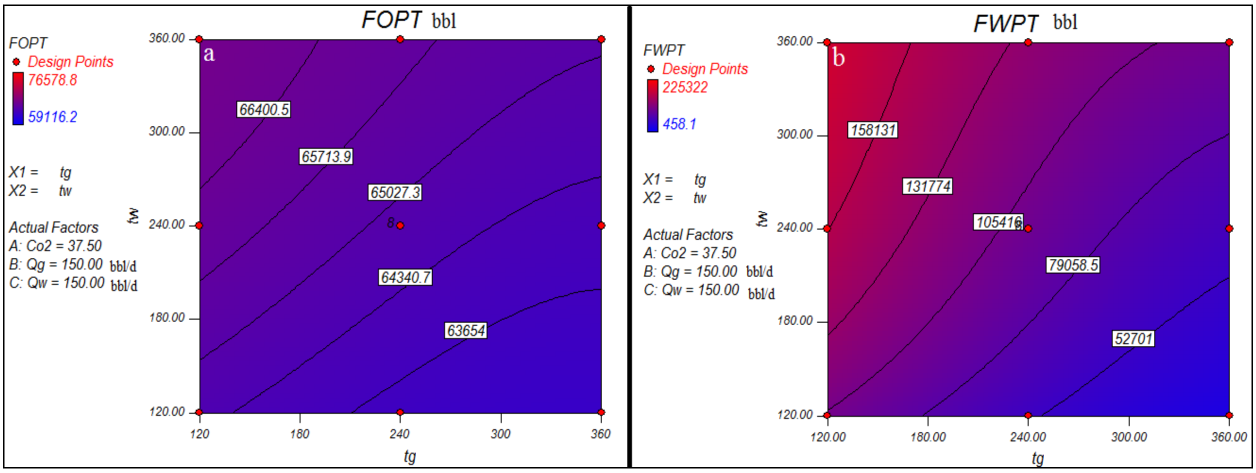

Figure 4 Effect of injected slug sizes with CO_2 content of 37.5% on (a) FOPT (b) FWPT

Choosing optimum values of the WAG parameters will lead to maximum produced oil and minimum water amount in produced fluid. As per first row of Table 3, which shows the optimum results of this study, we can observe that WAG ratio of near 1 is the optimum value. Total injection is 2 pore volumes (2PV) and in the optimum condition the desirability is near 1.00. Note that in the experiments for this reservoir which were conducted (A.Alizadeh, M.H.Ghazanfari) the optimum WAG ratio is 1:1 also.

Table 3 Optimum WAG parameters obtained from proxy model

Optimum Case	CO_2 %	Q_g cf/d	Q_w bbl/d	t_g days	t_w days	FOPT bbl	FWPT bbl	Gas slug size	Water slug size	WAG ratio	Desirability
1	75	1403	250	120.1	135.1	78625.37	102727.6	0.17PV	0.18PV	1.05	0.9035339
2	75	1403	250	120	160.4	78612.57	105045.5	0.17PV	0.22PV	1.30	0.9002092
3	75	1400	246.5	120	161.5	78625.29	105836.7	0.16PV	0.21PV	1.32	0.8996722
4	75	1403	250	120.4	148.9	78356.45	99688.12	0.16PV	0.20PV	1.25	0.8975745
5	75	1246	250	120	160.2	78625.26	108314.5	0.14PV	0.22PV	1.57	0.8965344

Results of this study show that optimum conditions occur when both gas and water is injected with maximum rates. Additionally, the slug sizes of injected water and gas should be about 0.18 and 0.17 of pore volume, respectively. This results show that high injection rates with small slug sizes are favorable in this reservoir.

5. Conclusions

In this case study polynomial regression models are utilized to construct different proxy models for a sector of an Iranian oil reservoir under WAG injection scenario. Below conclusions can be drawn from the results of this study:

- This work demonstrates the application of response surface methodology for optimization of WAG process using CH_4 and CO_2 mixture as injection gas.
- Decreasing the mole percent of CO_2 in injecting gas decreases the ultimate oil production. Changing in CO2 content of injected gas has no sensible effect on the ultimate produced water amount.
- Optimum WAG ratio for this oil reservoir is approximately 1:1. The optimum conditions are achieved at maximum produced oil and the minimum produced water.
- Optimum injection rate are the maximum rates applied, and optimum water and gas slug sizes are 0.18PV and 0.17PV respectively.
- Although increasing in injection water rate increases the produced oil and water due to high shear stress on the pore walls, excessive amount of water produced is not desirable.
- Increasing in slug size of the gas will decrease the total produced oil because of breakthrough of gas, and increasing water slug size increases the total produced oil and also total produced water.

Acknowledgements:

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6. References

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