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RESEARCH AND SIMULATION STUDY OF DIFFERENT TECHNOLOGICAL PROCESSES OF MISCIBLE CO_2 WATER ALTERNATING GAS INJECTION

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A B S T R A C T

One of the most commonly used methods for EOR in recent years is the water-alternating-gas (WAG) method, WAG injection is an oil recovery method aiming to improve displacement ratio, sweep efficiency and adjust the alignment of displacement in different layers to improve oil recovery and pressure maintenance. The main mechanism of it is 1) bettering the mobility control, 2) improvement of sweep efficiency (comparing to gas methods) and 3) the displacement efficiency (comparing to waterflooding). Many studies have been done in the past, but due to the increasing hard-to-recover field and facing difficulties during the production, the traditional WAG is facing problems that need to be coupled with. Implementation of new combinational methods and changes in the injection process to meet the needs have been developed during the last two decades. In this study, a simulation investigation has been done to compare proposed changes in the injection process to find the optimal injection scheme for the high heterogeneity - low permeability field. After analyzing the output of the simulation, the results show that each of the technologies has its advantages and disadvantages, and need to be applied according to the field constraints and requirement.

Keywords: water alternating gas (WAG); enhanced oil recovery; reservoir simulation; injection scheme; heterogeneity; permeability.

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Introduction

Currently EOR is one of the most important areas in the oil and gas industry since most of the discovered oilfield has only an average of 40% of recovery factor and the remained reserve is hard to recover. The main purpose of EOR application is to increase the recovery factor, there are three main methods for EOR: thermal, chemical injection, and gas injection[1, 2].

Gas injection is one promising method since 1) it can be used in most scenarios (low permeability, high water cut, etc.), 2) easy to access, 3) low capital and operating cost. But it has the disadvantage of the early breakthrough (fingering) and low sweep efficiency. Thus, the water alternating gas (WAG) technique has been introduced and proven to be a good way to increase the sweep efficiency and lower the fingering effect by injecting water along the way. The simplified conventional WAG scheme is shown in figure 1. Generally, the WAG process combined the advantages of waterflooding (WF) and gas injection (GI). Hence the displacement ratio is better than WF and sweeping efficiency is better than GI and overall increasing the recovery factor.

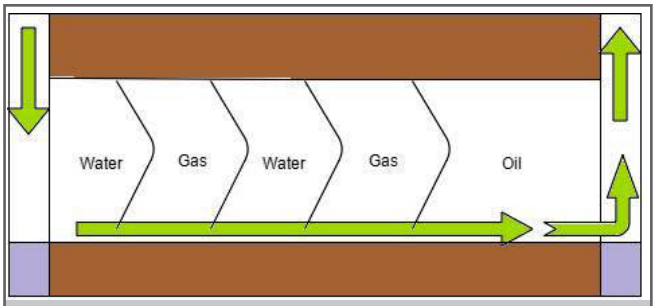

Fig. 1. Simplified conventional WAG scheme [3]

The performance is highly affected by injection strategies such as well pattern, the number of cycles, volume of each cycle, injection rate and pressure, and reservoir properties such as heterogeneity, fluid properties, miscibility condition, and rock wettability. So, to meet different requirements and difficulties, many variations of WAG injection methods have been proposed (fig. 1).

Based on the previous studies, the simulation studies were carried out for the different types of the WAG injection scheme on a synthetic reservoir and the analysis has been done on the result of the simulation [3, 4].

The classification of the different WAG variations can is shown below in figure 2:

The main focus of this study is on the process part of the classification. Thus, 7 types of injection schemes have been studied [3-12]:

1. Natural drive
2. Water flooding
3. Water alternating gas (WAG): For WAG, the gas and water are injected periodically and the slug size injected for each cycle are the same and according to the reservoir characteristic.
4. Gas alternating water (GAW): the GAW method is similar to traditional WAG, the difference is the gas is

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injected first, rather than water. The main focus of this technology is the rapid response of the frontal displacement by the gas phase and the production rate will increase earlier than a traditional WAG.

5. Hybrid WAG (HWAG): Hybrid WAG refers to the injection of a large slug of gas before the traditional WAG.

6. Tapered WAG (TWAG): The TWAG technique is used to adopt different WAG injecting ratios in different production stages. Compared with constant WAG, the TWAG could change the water gas ratio based on the actual production stage flexibly and regulate the oilfield production work system and delay the gas breakthrough. At the same time, production response speed could be accelerated or delayed artificially based on the bearing capability of the field apparatuses and pipelines.

7. Selective simultaneous injection (SSWAG): Gas and water are injected together through a single wellbore, but no mixing takes place at the surface. Two phases are pumped separately using a dual completion injector and are selectively injected into the formation. Where the water phase is from the upper side of the reservoir and the gas phase is from the downside of the reservoir. By time and gravity forces, the gas phase will move upward and water move downward, which will increase the overall sweep efficiency.

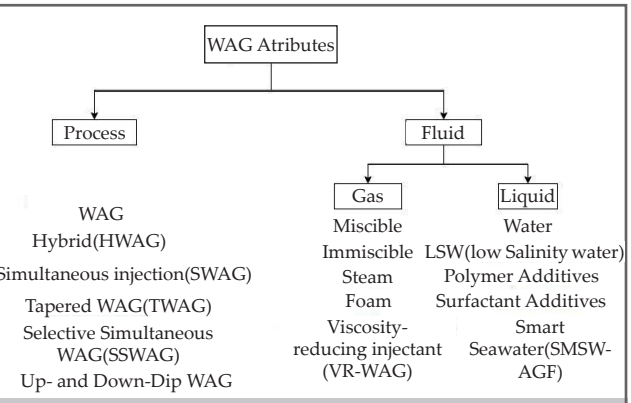

Fig. 2. Classification of WAG methods [3]

Materials and methods

Reservoir simulation. This study aims to analyze different variations of WAG injection methods by changing the injection scheme and study its effect on the final result. For this study, commercial software CMG-GEM has been chosen to simulate the development process.

The permeability has been randomly generated using Gaussian distribution between 0-20 md, then to increase the difficulty of the flow process, 20% of the block permeability has been set to 0 (no permeability), the 3D model is presented in figure 3.

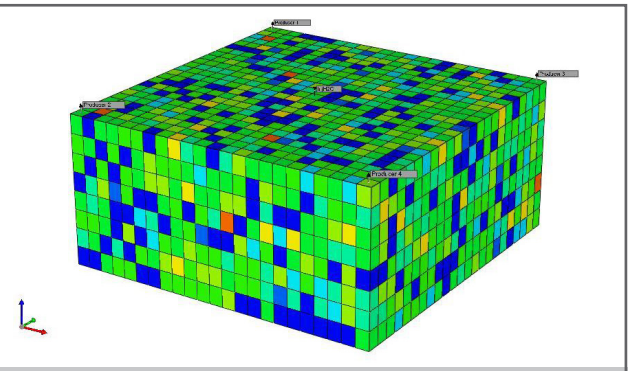

Fig. 3. 3D model of the reservoir and Permeability distribution

The simulation development time has been set to 50 years, the overall properties are shown in table 1.

Minimum miscible pressure

The implementation of conditions of miscible displacement in the reservoir ensures the achievement of high efficiency of oil displacement from the reservoir pore system. The scope of application of miscible displacement of oil by high-pressure gas is mainly associated with deep-lying light oil deposits confined to low-permeability reservoirs, where it is possible to maintain high reservoir pressure (about 30-40 MPa or more) necessary to achieve conditions of complete mutual miscibility of oil and gas.

When describing the mode of miscible displacement, such a concept as minimum miscibility pressure of reservoir oil and injected gas (MMP) is used. The minimum miscibility pressure depends on such factors as [13]:

- reservoir temperature;
- reservoir pressure;
- the composition of the displacing agent (gas) and the displaced fluid (oil).

As the study is based on the CO_2 miscible injection, another important parameter that needs to be verified is the minimum miscible pressure (MMP) of the reservoir. A neural network model has been developed using an adaptive neuro-fuzzy inference system (ANFIS) and the model has been used to determine the MMP for the synthetic reservoir. molecular weight for C^{5+}, oil volatile and intermediate as input data, and MMP as the output. The data is divided into training Zand test set (75% / 25%), then 5 type of membership function has been applied in ANFIS neural network methods with 2

Table 1
Reservoir and simulation properties of synthetic field

№	Properties	Unit	Values
1	Reservoir temperature	C	85.3
2	Total thickness	m	24
3	Reservoir depth	m	1800
4	Porosity	-	0.24
5	Number of cells in X and Y direction	-	23
6	Number of cells in Z direction	-	8
7	Number of an oil layer	-	8
8	Total cell number	-	4232
9	X and Y grid block size	m	29
10	Z grid block size	m	3
11	Reservoir pressure	MPa	18
12	Oil viscosity	mPa·c	5
13	Oil density	g/cm^3	0.85
14	Rock compressibility	1/MPa·10^{-6}	5.4

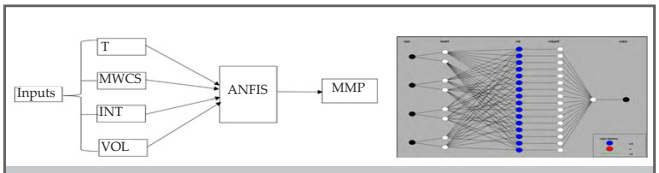

Fig. 4. ANFIS model scheme

input variable and 5 layers, and 100 epochs (fig. 4). The result then is compared with correlations (Alston, Lee) using Mean Absolute Error (MAE) and Root mean squared error (RMSE) as of measurement.

Results and discussion

Before the simulation, the MMP value needs to be determined, after creating the ANFIS model and compare with the empirical formulas, we can see that our model with Psig function has a better result than the correlation formulas, thus, by using our model and the properties from the reservoir, the MMP is set to 19 MPa. The results of the comparison are shown in table 2.

The reservoir simulation results are shown below, as we can see from table 3 and figures 5-7, all the WAG variation

Table 2

Summary of validation values

Method	RMSE	MAE
ANFIS-Psig	6.276	1.522
ANFIS-Gaus	9.521	2.309
ANFIS-Tri	8.411	2.040
ANFIS-Trap	13.067	3.169
ANFIS-Pi	8.438	2.046
Alston	33.729	8.181
Lee	15.722	3.813

has shown a better result than natural drive production and waterflooding (base case), wherein in a few cases the final recovery factor has increased for around 10%, from 47.6% to 57.3%. While traditional WAG injection still shows the highest result for the recovery factor, HWAG and GAW also have a similar result of 57.3%, which can provide us with some other advantages:

- For GAW, all of the important parameters are alike, but the oil production rate at the beginning is higher than WAG, which can be beneficial according to the practical and economical situation. But need to keep in mind that the oil production rate will decrease at a later stage.
- For HWAG, although a large slug is injected at the beginning, the total gas injected volume is a bit lower than WAG (4%) with similar RF, and the initial boost in production rate is also observed at the beginning. And by injecting the CO_2 at the initial stage, the wettability has changed to a more favorable state.
- TWAG and SSWAG have lower final oil recovery, but these methods have also their advantages:
- For TWAG, the gas injection volume is ~5.5 times lesser than traditional WAG, which is a big plus since, at the current stage, the source for CO_2 is not enough, and carbon capture technologies are still rather expensive, so if the oil price is low, from the economical point of view, the TWAG is more efficient than WAG; the GOR is almost constant around 50 m^3/m^3, while GOR for WAG has reached around 2000 m^3/m^3 at the end of the production, which need bigger and more expensive separators.
- For SSWAG, the gas injection volume is a few times lesser than traditional WAG, which is more favorable in the current stage; this technology is also more suitable than WAG in the more angular reservoir where the effect of gravity can be maximized; like TWAG, the GOR is lower than WAG; the water cut has reduced to 86% where for WAG is 92%. The overall sweep zone area is better than the WAG and the injectivity in the wellbore will not decrease due to periodic changes in water-phase and gas-phase injection.

Table 3

Summary of final results

	RF, %	WC, %	Cumulative gas injection, m^3
ND	6.4	1.6	0
WF	47.6	95.6	0
WAG	57.3	92.1	212 300 000
GAW	57.3	92.1	208 000 000
HWAG	57.2	92.5	205 000 000
TWAG	52.8	96.7	38 700 000
SSWAG	51.9	86.1	72 700 000

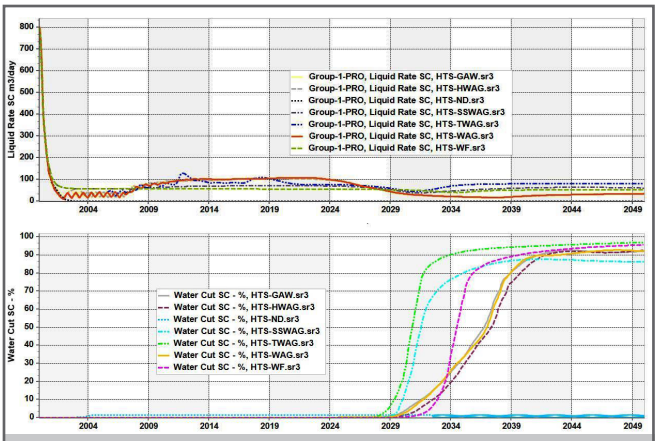

Fig.5. Liquid production rate (a) and water-cut (b)

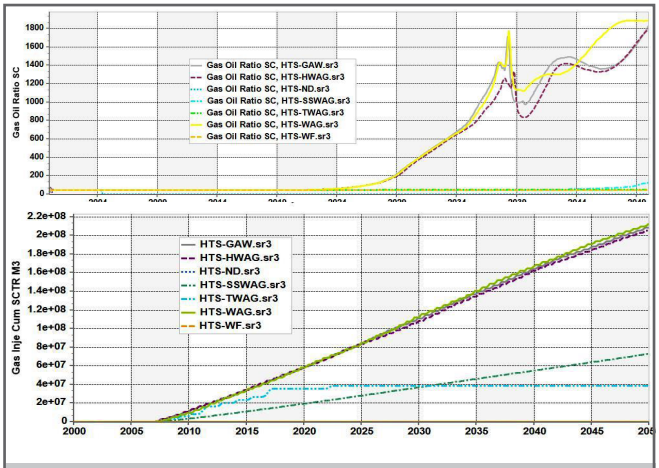

Fig.6. Gas oil ratio (a) and (b) cumulative gas injection (m^3)

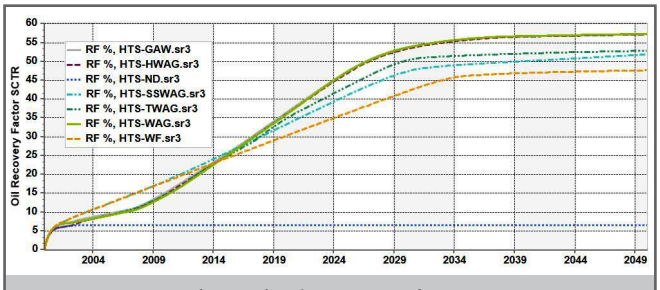

Fig.7. Final recovery factor

Conclusion

- Due to the complexity of hard to recover field, many new variations have been proposed, and 4 of them have been modeled in this study.
- An ANFIS model has been developed to predict the MMP of the CO_2, which showed a better result than empirical correlation. The MMP has been determined to be 19 MPa in the current reservoir.
- Results of four variations of WAG have been studied (GAW, HWAG, TWAG, SSWAG). Each of them has its advantages and disadvantages, which need to be evaluated according to practical and real situations.
- The combinational method between the process and chemical enhanced methods can be investigated as a future study area.

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Исследование и моделирование различных технологических процессов водогазового воздействия со смешивающимся CO_2

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Реферат

Одним из наиболее часто используемых методов увеличения нефтеотдачи в настоящим время является метод водогазового воздействия (WAG). Метод WAG — это метод извлечения нефти, направленный на улучшение коэффициента вытеснения, коэффициента охвата и регулирования фронта вытеснения в разных слоях для улучшения извлечения нефти и поддержания давления. Основным механизмом этого метода является: 1) улучшение подвижности, 2) повышение коэффициента охвата (по сравнению с газовыми методами) и 3) повышение коэффициента вытеснения (по сравнению с заводнением). В прошлом было проведено много исследований, но из-за увеличения доли месторождений с трудноизвлекаемыми запасами и возникновения трудностей во время добычи традиционная WAG сталкивается с проблемами, которые должны решены. В течение последних двух десятилетий были разработаны новые комбинированные методы и изменения в процессе закачки для удовлетворения потребностей. В этом исследовании было проведено моделирование и исследование для сравнения предлагаемых изменений в процессе закачки, для того чтобы найти оптимальную схему закачки для месторождения с высокой неоднородностью и низкой проницаемостью. Анализ результатов моделирования показал, что каждая из технологий имеет свои преимущества и недостатки, и их необходимо применять в соответствии с ограничениями и требованиями отрасли.

Ключевые слова: водогазовое воздействие (ВГВ); повышение нефтеотдачи; моделирование пласта; схема закачки; неоднородность; проницаемость.

Qarışıq CO_2 ilə su-qaz təsirinin müxtəlif texnoloji proseslərinin tədqiqi və modelləşdirilməsi

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Xülasə

Neft hasilatının artırılması üçün ən çox istifadə olunan üsullardan biri su-qaz təsiri üsuludur (WAG). WAG üsulu, sıxışdırma əmsalını, neft hasilatını yaxşılaşdırmağa və təzyiqi saxlamaq üçün müxtəlif təbəqələrdə sıxışdırmanın ön xəttinin tənzimlənməsinə və əhatə olunma əmsalını yaxşılaşdırmağa yönəlmiş neft çıxarma üsuludur. Üsulun əsas mexanizmi: 1) hərəkətliliyin yaxşılaşdırılması, 2) əhatə olunma əmsalının artması (qaz üsulları ilə müqayisədə) və 3) sıxışdırma əmsalının artması (sulaşma ilə müqayisədə). Keçmişdə bir çox araşdırmalar aparılmışdır, lakin çətin çıxarılan ehtiyatlara malik olan yataqların payının artması və hasilat zamanı çətinliklərin yaranması səbəbindən ənənəvi WAG həll olunmalı problemlərlə üzləşir. Son iyirmi ildə ehtiyacları ödəmək üçün suvurma prosesində yeni kombinə edilmiş üsullar və dəyişikliklər işlənmışdır. Bu tədqiqat, yüksək geyribircinsliyi və aşağı keçiriciliyi olan bir sahə üçün optimal suvurma sxemini tapmaq üçün suvurma prosesində təklif olunan dəyişiklikləri müqayisə etmək üçün modelləşdirmə və tədqiqat aparmışdır. Modelləşdirmə nəticələrinin təhlili göstərdi ki, texnologiyaların hər birinin öz üstünlükləri və mənfi cəhətləri var və bunlar sənayenin məhdudiyyətlərinə və tələblərinə uyğun olaraq tətbiq olunmalıdır.

Açar sözlər: su-qaz təsiri (SQT); neftveriminin artırılması; layın modelləşdirilməsi; suvurmanın sxemi; qeyri-bircinslilik; keçiricilik.