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Gas Injection Development Scenarios and Forecasting for Tight Oil Energy

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ABSTRACT

Tight oil energy occupies an increasingly important position for petroleum energy in the world. At present, most tight oil reservoirs have the problems of low formation pressure and difficult exploitation. Therefore, it is important to make reasonable management scenarios and forecasting for tight oil energy. Current research shows that natural gas flooding (NGF) can improve oil recovery for tight reservoirs, meanwhile, the oil field usually has abundant associated gas, which is suitable for natural gas flooding.

This paper mainly investigates NGF development for tight oil reservoirs in Ordos Basin, aiming to recycle the associated natural gas that has little commercial value to enhance oil recovery, and formulates reasonable development plan and forecasting. The PVT experiment is conducted to provide support for numerical simulation, which includes three parts: Firstly, the numerical model of tight reservoir is established. Then, sensitivity production parameters are analyzed. Finally, oil recovery and gas storage are studied.

The phase diagram of crude oil is obtained by PVT experiments, and the saturation-pressure line is obtained by composition model is well matched with the experimental data. Sensitivity analyses demonstrate that the recommended injection rate of single well is 4000-4500 m^3/d and bottom hole pressure of production well is about 8 MPa. In the early stage of NGF, oil recovery is higher and gas storage effect is better, while oil recovery and gas storage effect are both poor in the later stage.

This paper is a combination of energy recycling and enhanced oil recovery. In this research, development scenarios and forecasting are applied in practical oil fields and provides support for subsequent development, which provides a reference for developing similar oil reservoirs. Meanwhile, it is expected that this research can be extended to the collaborative gas storage construction and oilfield development.

Keywords: Energy management, energy development, scenarios and forecasting, enhanced oil recovery, energy recycling

1. INTRODUCTION

With the reduction of conventional reservoir resources, unconventional oil and gas resources have become a hot spot for global oil and gas exploration and development [1-3]. Due to the use of multi-stage fracturing long horizontal well technology, the United States has achieved commercial-scale development of tight oil [4-6]. In 2019, the production of tight oil in the United States accounted for about 70% of the total annual crude oil production in the United States [7]. Although China has abundant tight oil resources, most tight sandstone reservoirs have the problems of insufficient natural energy and low pressure coefficient, which leads to rapid decline in production and low recovery in the process of depletion development [8-11]. Therefore, it is very important to make reasonable management scenarios and forecasting for tight oil energy.

High-efficiency gas injection development of tight oil reservoirs has become a key research field for the oil and gas industry. The commonly used gases for gas injection development are mainly carbon dioxide, natural gas and nitrogen, and many scholars have verified the feasibility of different gases for gas injection development in tight oil reservoirs [12-15]. Cheng and Liu [16] conducted experiments on formation oil high-pressure physical properties and displacement effect after gas injection under different formation conditions. The comparison of three gases proves that CO_2 displacement effect is the best, natural gas is the second, and N_2 is the lowest.

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Although CO_2 has the best oil increase effect, there are some problems in the tight oil reservoirs of Ordos Basin, such as insufficient CO_2 gas source, high purchase and transportation cost, corrosion of pipelines and so on. Natural gas (associated gas) can avoid the above-mentioned disadvantages, and has a good oil-increasing effect. Meanwhile, there is often a large amount of natural gas in the oilfield, which can be considered as an economic and effective injection medium.

Aiming at the low recovery ratio of tight oil reservoirs and lack of field experience for natural gas injection in Ordos Basin, it also refers to the experience of tight oil reservoir development in North America. This research uses a combination of experiments and numerical simulations to make development scenarios and forecasting. This article is expected to provide support for the field pilot of tight oil reservoirs in Ordos Basin and provide guidance for the development of similar tight oil reservoirs in the world.

2. RESERVOIR NUMERICAL MODEL

Accurate characterization of reservoir fluid phase characteristics is the basis for multi-phase and multi-component reservoir numerical simulation to accurately predict the performance of gas injection and production in oil fields. Meanwhile, it is very important for the change of phase characteristics in the dissolution and mass transfer process between injected gas and formation fluid. Based on PVT experiment, use the WINPROP component module of CMG simulation software to perform PVT fitting and pseudo-component splitting. The results are shown in Table 1 and Fig.1.

The target reservoir is a tight reservoir in Block L, with a buried depth of 1815 m, an effective thickness of 8 m, an average porosity of 8.9%, an average permeability of 0.25 mD, and the original formation pressure is 16 MPa. Based on the reservoir geological characteristics and block data, a numerical model of SRV zonal reservoir is established, including fracturing reconstruction areas and non-fracturing reconstruction areas. The specific simulation parameters are shown in Table 2.

Table 1 Pseudo-component data table of reservoir crude oil

Components	C_1	C_2-C_3	C_4-C_6	C_7-C_{10}	C_{11}-C_{20}	C_{20}^+	N_2
Content/%	30.75	16.47	11.79	12.97	19.99	7.16	0.89

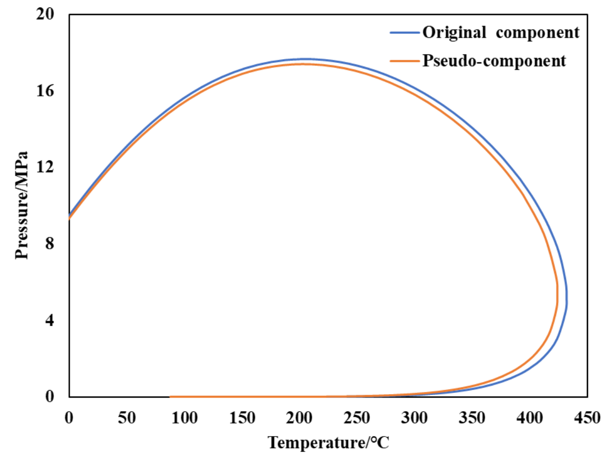


Fig. 1. Phase characteristics fitting diagram of crude oil

Table 2 Parameters of SRV zonal reservoir numerical model

Reservoir parameters	numerical value
Number of block grids, x×y×z	65×69×1
Grid size, x×y×z/m	25×20×8
Matrix permeability/mD	0.25
Natural fracture permeability/mD	1.25 (Non-fracturing) 2.5 (Fracturing area)
Matrix porosity/%	8.9
Natural fracture porosity/%	0.5 / 1
Natural fracture density/(m/ strip)	40 / 10
Initial formation pressure/MPa	16
Saturation pressure/MPa	12.8
Initial oil saturation/%	55
Reservoir temperature/℃	53.2
Horizontal well length well/m	380
Horizontal well spacing/m	400
Half length of fracture/m	162.5
Interval of fracturing section/m	20

3. OPTIMIZATION OF INJECTION-PRODUCTION PARAMETERS

3.1 Optimization of gas injection rate

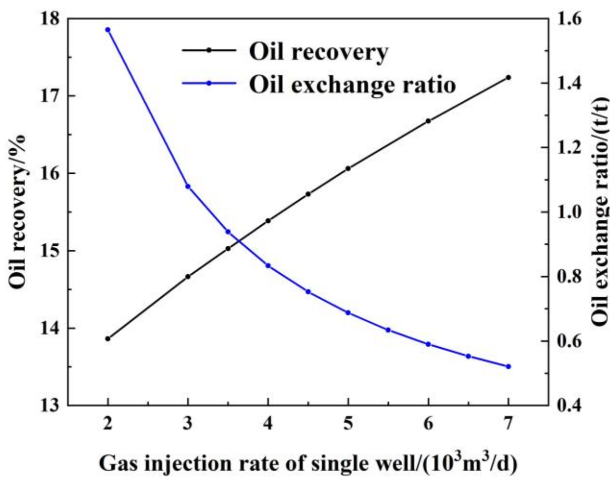
In order to study the impact of gas injection rate of single well on the development effect in the block, based on the experience of tight oil and gas injection development in North America and combined with the actual situation, eight different gas injection rate of single well between 2000 m^3/d and 7000 m^3/d are designed to simulate production and predict for 20 years, so as to select the best gas injection rate of single well.

As the daily gas injection rate of single well increases, tight oil recovery also increases. However, when the daily gas injection rate of single well exceeds 4000-4500 m^3/d, the increase rate of oil recovery slows down (Fig.2a).

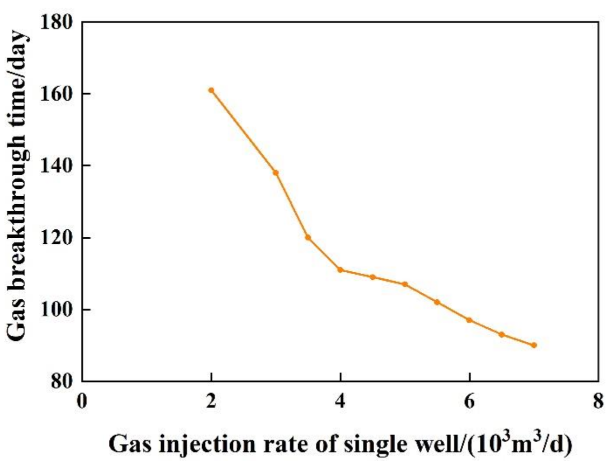
At the same time, combined with the relationship between gas injection rate and oil exchange ratio of single well (Fig.2a), it can be seen that the higher the gas injection rate of single well, the lower the oil exchange ratio, indicating that it is unreasonable to blindly increase the gas injection rate in pursuit of higher recovery.

The gas injection rate of single well is basically negatively correlated with gas breakthrough time, that is, the greater gas injection rate, the shorter gas breakthrough time. When gas injection rate of single well exceeds 4000-4500 m^3/d, the downward trend of relationship curve between gas injection rate and gas breakthrough time becomes slower (Fig.2b).

Therefore, comprehensively considering the optimization indicators such as oil recovery, oil exchange ratio and gas breakthrough time, the reasonable gas injection rate of single well for target block is determined as 4000-4500 m^3/d.



(a) Oil recovery and oil exchange ratio



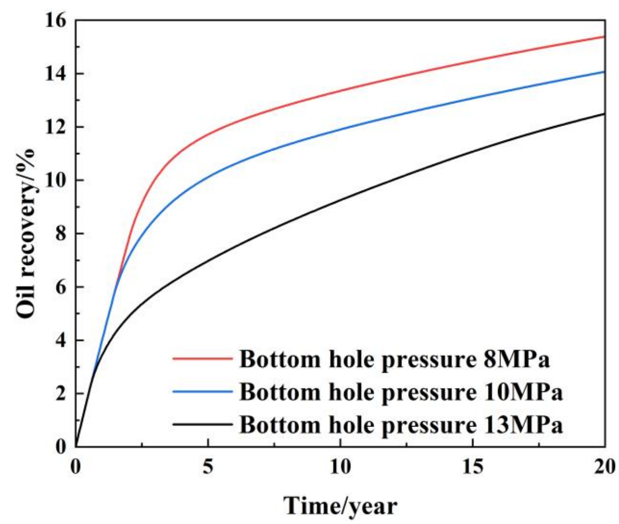
(b) Gas breakthrough time

Fig. 2. Development parameters of different gas injection rate

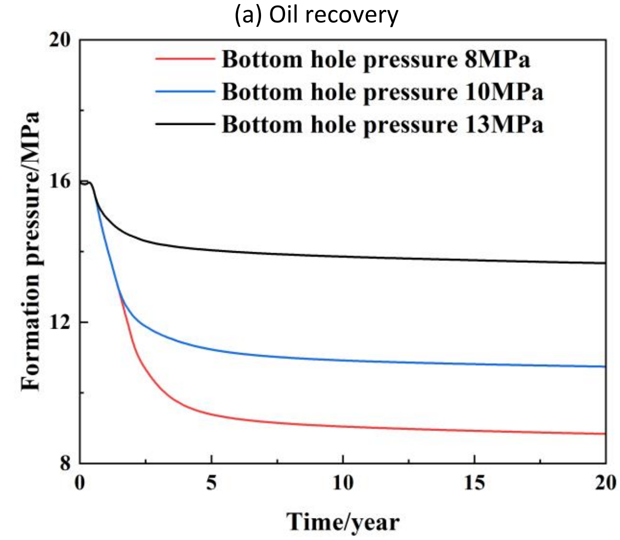
3.2 *Optimization of bottom hole pressure*

As an important production parameter of oil well, bottom hole pressure of producing well has a close influence on the oil production capacity. In order to study the influence of different bottom hole pressure on gas injection development in Block L, based on the reservoir saturation pressure of 12.8 MPa and field conditions, three sets of bottom hole pressure of 8 MPa, 10 MPa and 13 MPa are designed for comparison and optimization.

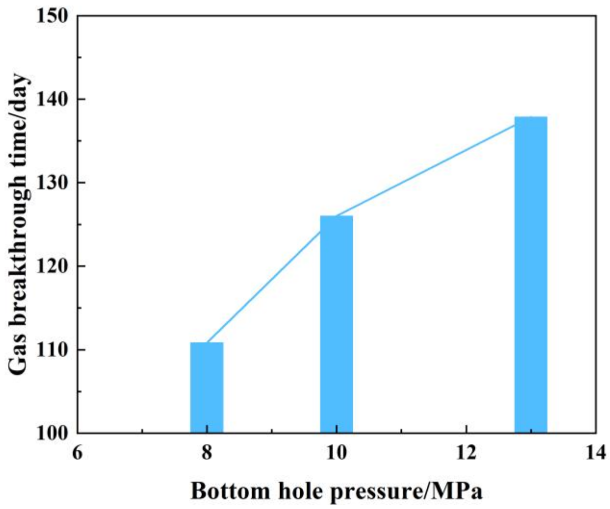
With the continuous decrease of bottom hole pressure in production wells, oil recovery increases continuously. The development effects of different bottom hole pressure show that oil recovery increases rapidly in the early stage and slows down in the later stage (Fig.3). Lower bottom hole pressure can obtain a longer high production period in the early stage. When bottom hole pressure is 13 MPa, although the average formation pressure maintains relatively high, it decreases rapidly after short-term high production in the early stage. However, the bottom hole pressure cannot



(a) Oil recovery



(b) Average formation pressure



(c) Gas breakthrough time

Fig. 3. Development parameters of different bottom hole pressure

be continuously reduced in the early stage. Lower bottom hole pressure leads to low average formation pressure and early gas breakthrough time, resulting in poor effect in the later stage of development.

By comparing oil recovery and oil exchange ratio for different bottom hole pressure at different times, the influence of bottom hole pressure on development effect of the block is further analyzed (Fig.4). When the bottom hole pressure is 8 MPa, oil recovery is higher than the bottom hole pressure of 10 MPa and 13 MPa for gas injection development, and the difference of oil recovery corresponding to different bottom hole pressure is the most obvious in the early stage (5 years). When the bottom hole pressure is 8 MPa, oil exchange ratio is higher than the bottom hole pressure of 10 MPa and 13 MPa in 5 years, 10 years, and 20 years. But, as the

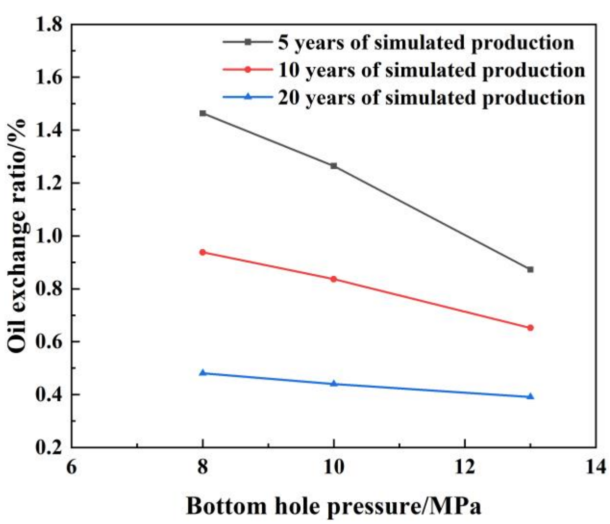


Fig. 4. Oil exchange ratio under different bottom hole pressure

development time increases, the difference of oil exchange ratio with different bottom hole pressure gradually decreases.

When the bottom hole pressure of production well is 8MPa, both oil recovery and oil exchange ratio are the highest, and the economic benefit is good. Therefore, 8MPa is selected as the reasonable bottom hole pressure of production well in the target block.

3.3 Analysis of oil recovery and gas storage

When gas injection is used to develop tight reservoirs, the injected gas can displace oil to improve oil recovery. At the same time, the injected gas also is stored underground or produced, which can play a role in gas storage and produced gas cyclic utilization. When natural gas is injected into the formation, the formation fluid undergoes three periods :(1) Before gas breakthrough in the production well (i.e., within 0.5 years of gas injection development), the oil recovery of natural gas flooding increases rapidly to 2.022% (Fig.5), and the oil exchange ratio is higher. In 0.5 years, the accumulative injection volume of natural gas is 5.792×10^6 m^3, the accumulative storage volume of natural gas is 3.29914×10^6 m^3, and the accumulative oil production is 14410.3 m^3. Most of the injected natural gas is stored in the formation due to pore space storage, which can be used as the reference for gas storage construction [17]. (2) In the early stage after gas breakthrough (0.5-3 years of gas injection development), the oil recovery increases rapidly in the early stage and slows down in the later stage. In 2.5 years, the accumulative gas injection volume is 2.928×10^7 m^3, the accumulative gas storage volume is 1.64×10^6 m^3, and the accumulative oil production is 57117 m^3. In this period, the oil recovery and storage capacity of natural gas flooding are high but begin to decline. (3) After the severe gas channeling (after 3 years of gas injection development), oil recovery increases by only 5% and cumulative storage volume is small in this stage. The production gas-oil ratio rises sharply from 1470.76 m^3/m^3 to 9876.94 m^3/m^3, indicating severe gas channeling and low oil exchange ratio, as shown in Fig.5. During this period, most of the injected gas is produced directly from the production well, resulting in little oil recovery and storage capacity. However, the produced natural gas can be injected back into the formation to achieve natural gas cyclic utilization. In the first and second periods of gas injection production, it plays a good storage role and is suitable for gas storage construction. In the third period, the gas storage capacity is poor, which is not conducive to gas storage construction due to severe gas channeling.

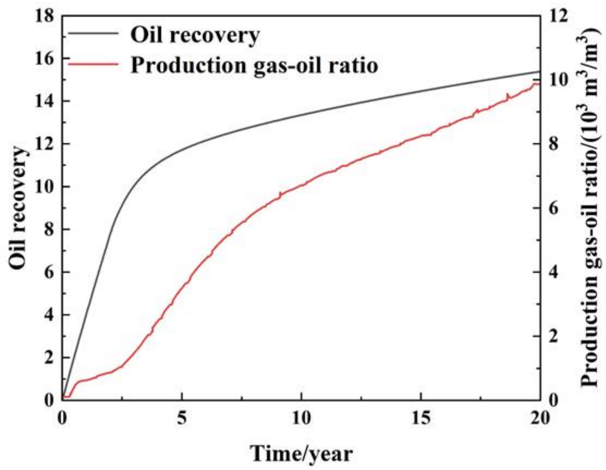


Fig. 5. Oil recovery and production gas-oil ratio for the block

4. CONCLUSIONS

This paper is a combination of energy recycling and enhanced oil recovery. Based on the reservoir scale model, the development performance is predicted and the reasonable development plan is formulated.

Sensitivity analyses demonstrate that the recommended gas injection rate of single well is 4000-4500 m^3/d and bottom hole pressure of production well is about 2/3 of bubble point pressure. In the early stage of NGF, oil recovery is higher and gas storage effect is better, while oil recovery and gas storage effect are both poor in the later stage. Meanwhile, it is expected that this research can be extended to the collaborative gas storage construction and oilfield development.

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