Experimental Investigation of Nature Gas Production Rate's Effect on the Reservoirs with Gas Cap

Liu Jia, Cheng Linsong, Huang Shijun, and Zhang Jian

***Abstract*—In order to study the effect of nature gas production rate on the reservoirs with gas cap, three-dimensional visualized gas-cap reservoir physical simulation device was established to simulate the processes of oil and gas development at different gas production rates. Monitoring and records of the interface migration law and well performance can be realized through visualization window. According to experimental result, it is shown that migration speed of oil-gas interface was reduced with increasing gas production rates while migration speeds of internal and external oil-gas interfaces gradually became close, which effectively slows down occurrence of gas channeling, reduces production gas oil ratio and increases the swept volume of gas drive, so as to improve its development effect. According to the optimization of collaborative development for gas-cap oil-rim reservoirs, the equivalence of accumulative production of oil and gas can reach the maximum value when the fixed period of reservoir exploitation is 50 years and the gas production rate is between 2% and 4%.**

***Index Terms*—Oil rim reservoir, coordinated development, indoor experiment, migration law of oil-gas interface, gas production rates.**

I. Introduction

Natural gas, as a kind of clean energy, will not only reduce the use of coal and oil consumption and improve environmental pollution greatly, but also reduce nearly 100% emission of sulfur dioxide and dust, 60% emission of carbon dioxide and 50% emission of oxynitride, so as to relieve global greenhouse effects and fundamentally improve environmental quality. In recent years, it catches great attention of many countries, resulting in increasing demand for natural gas in international market. As a result, a lot of gas-cap reservoirs need to be invested for development with the increasing demand on sales market. However, gas cap and oil ring in a same reservoir stay in a uniform hydrodynamic system, so they are in balance state of pressure before development. Once it is developed, pressure changes of any part will influence the other. MacDonald [1] and Addington [2] discussed gas coning and dipping in vertical wells with mathematical simulation, getting determination of the right position and length of perforation and the maximum critical oil rate which could provide the most profitable and permissible gas-free oil production. Onwukwe [3] and Kartoatmodjo [4] proposed a model for determining the optimum horizontal well placement in a thin oil rim reservoir in order to control coning tendencies effectively and optimize oil production. Delauretis [5] caculated the migration law of oil-gas interfaces in different development patterns using material balance method. Ezzam [6] pointed that both gas production and oil production would lead to changes of oil-gas interface and mutual displacement between oil ring and gas-cap. According to Nandalal [7] and Bayley [8], gas channeling into oil ring has little influence on ultimate recovery of natural gas, but oil reduction is inevitable and under some serious circumstance, only gas is produced without any oil in oil production wells. If crude oil enters gas cap, large amount of oil will be wasted and oil recovery will be influenced. Vo [9], [10] and Kabir [11] pointed out that the key concern is therefore obtaining economic and optimal operations despite the gas and water coning effects that could confine production below commercial rates and hinder recovery. Therefore, coordinated development of gas cap and oil ring has been an ideal way to recover resources in gas-cap reservoirs, Kuppe [12] have confirmed it by considering concurrent gas and oil production from the Virginia Hills Belloy field. Mohamed and Fayzullin [13] introduced intelligent well completion would significantly improve the overall cumulative production of gas and oil from a thin oil reservoir with a large gas cap. Travis [14] introduced experience of developing gas cap reservoir by injecting water at the gas-oil contact while simultaneously producing the gas cap and oil column. However, at present, few studies are focused on the effect of nature gas production rate on the reservoirs with gas cap, and the migration law of oil-gas interface in gas cap reservoir with coordinated development. Taking the Zanarol Oilfield in Kazakhstan as an example, this paper established three-dimensional visualized physical model to analyze the migration law of oil-gas interface of gas-cap reservoir through indoor experiment.

Manuscript received May 15, 2013; revised July 17, 2013. This work was financially supported by the National Natural Science Foundation of China and the technology Project is "The Coupling Percolation Mechanism and Model for Fractured Low Permeability and Ultra-low Permeability Reservoir" (51174215/E0403).

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II. Experimental Study on the Migration of Oil and Gas Interface

A. Experimental Condition

Three-dimensional visualized device was used for physical simulation experiment and sizes of experimental device were 1000mm×300mm×300mm. Thickness and dip angle of model can be regulated to meet geometric similarity condition of experiment. Experimental device can be connected with intermediate container filled with proper gas to simulate gas-cap reservoir of different gas-cap indexes, as is shown in Fig. 1.

DOI: 10.7763/JOCET.2014.V2.134

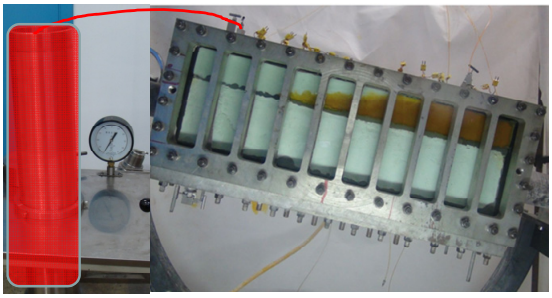


Fig. 1. Three-dimensional visualized physical simulation device

Based on oil production rate of 0.7%, gas production rates of 0.5%, 2%, 4% and 8% were adopted for coordinated development experiments of gas cap and oil ring. In the experiments, dynamic data of oil and gas wells were measured. At the same time, real time monitoring was carried out on migration law of oil-gas interface.

B. Migration Speed of Oil-Gas Interface

Through visualized window of physical model, migration of oil-gas interface at different production moments can be observed to calculate its migration speed. Taking gas production rates of 0% and 2% for example, influence of gas production rate on migration speed of oil-gas interface was analyzed. The location of oil-gas interface at the same production time (200min) is shown in Fig. 2. In the figure, black line refers to initial location of oil-gas interface and yellow line refers to its location after development.

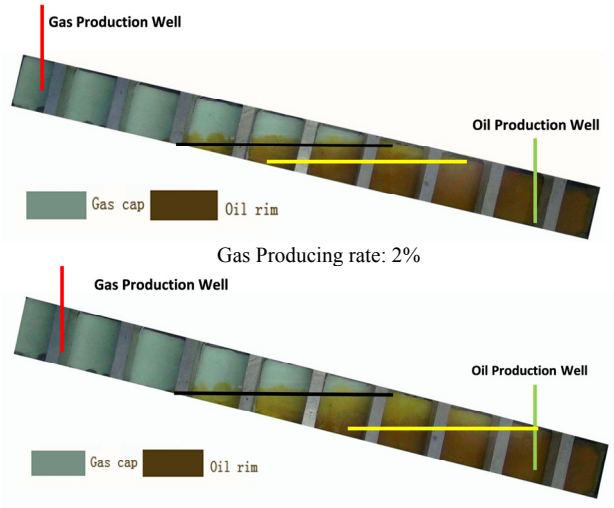


Fig. 2. Migration law of oil-gas interface at different gas producing rates

Visualized results show that at the same production moment, migration distance of oil-gas interface was larger and migration speed was fast when gas cap is not developed, which could cause gas channeling seriously and decline of oil output.

When oil production rate was 0.7% and gas production rate was 0%, 0.5% and 2% respectively, migration speed of oil-gas interface was measured as shown in Fig. 3. If gas production rate is 0%, migration speed of oil-gas interface will be the largest and it will be reduced with the increasing gas production rate, or migration speed of oil-gas interface can be reduced if coordinated development of gas-cap oil ring is carried out, but it helps keep the balance of oil-gas interface.

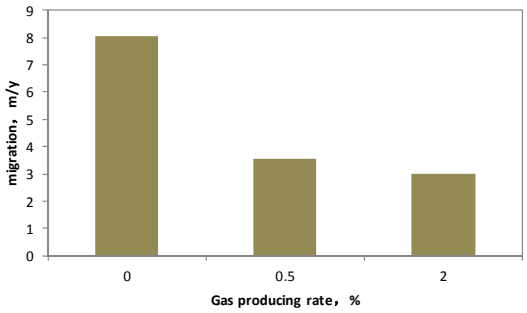


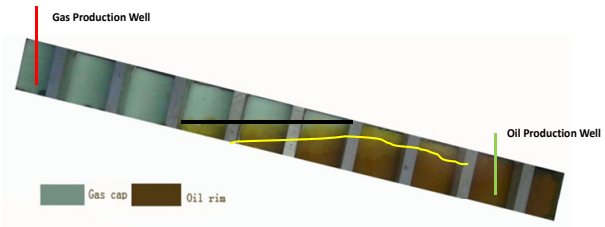
Fig. 3. Migration speed of oil-gas interface at different gas production rates

C. Migration Form of Oil-Gas Interface

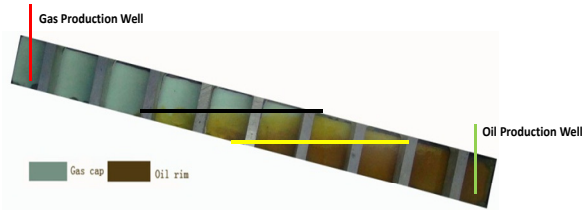
In order to study migration of oil-gas interface through visualized window and describe migration form clearly, interface at the nearby side of oil ring is defined as external oil-gas interface and the interface next to gas cap is defined as internal oil-gas interface.

If gas production rate is 0%, oil ring is produced alone till exhaustion while gas cap expand to displace oil ring. As viscosity of gas is small, fingering phenomenon occurs in displacement of crude oil. At the same time, gas is likely to migrate to top of stratum due to large difference of oil-gas density, resulting in faster migration speed of external oil-gas interface than that of internal oil-gas interface. Migration form is shown in Fig. 4(a).

If gas production rate is 4%, migration speed of oil-gas interface will slow down due to coordinated development and fingering phenomenon will be weakened. Moreover, oil-gas interface is kept nearly parallel to initial interface for down migration and migration speeds of internal and external oil-gas interfaces are almost the same. Its migration form is shown in Fig. 4(b).



(a). Migration form of oil-gas interface when oil producing rate is 0%



(b). Migration form of oil-gas interface when gas production rate is 4%

Fig. 4. Migration form of oil-gas interface with different gas production rate

In Fig. 5, red line refers to balance situation of migration speed of internal and external oil-gas interfaces. From the figure, it is clear that if migration speeds of internal and external oil-gas interfaces are close, oil-gas interface will be kept parallel to initial interface for down migration. At this moment, swept volume is the largest, recovery rate of oil ring is the highest and development effects are the best. So, migration of oil-gas interface at this moment is considered as stable migration.

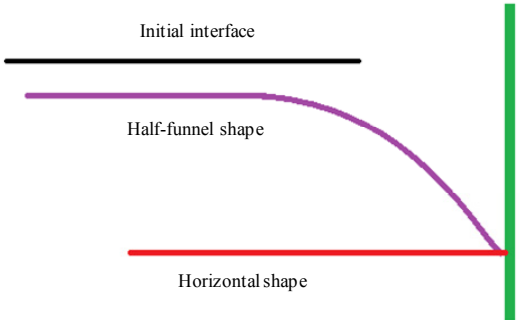


Fig. 5. Different migration forms of oil-gas interfaces

By numerical simulation of reservoir, full-size numerical model for indoor experiment was established and migration speeds of internal and external oil-gas interfaces at different gas production rates were calculated. As shown in Fig. 6, with the increase of gas production rate, migration speed of oil-gas interface will slow down. At the same time, migration speeds of internal and external oil-gas interface are likely to be equal. If coordinated development in stable regions is carried out, oil-gas interface will be kept stable.

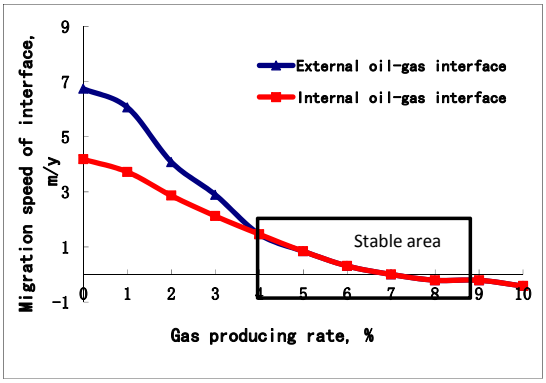


Fig. 6. Curves on relationship between gas production rate and migration speed of internal and external oil-gas interfaces

Fig. 7 shows the curve of gas-oil ratio when gas production rate is 0%, 0.5% and 4% respectively so as to study the influence of gas production rate on development effects of oil well.

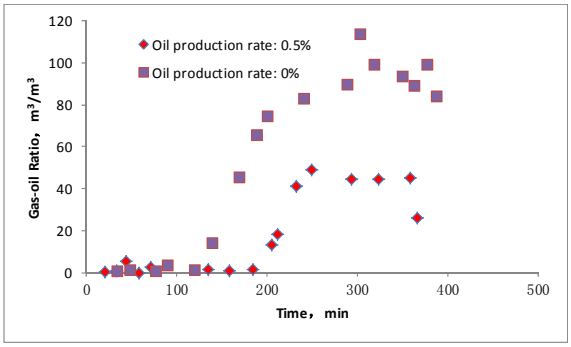


Fig. 7. Curve on gas-oil ratio at different gas producing rates

From the figure, we can see that with the increase of gas production rate, migration speed of oil-gas interface will slow down and gas breakthrough time will be postponed. If gas production rate is more than 4%, there is no gas breakthrough in oil well. At the same time, when gas production rate increases, expansion of gas cap will be weakened and production gas-oil ratio will be smaller so as to effectively reduce gas channeling phenomenon and improve its development effects.

III. Optimization of Coordinated Development of Gas-Cap Reservoir

Due to the limits of local development policy, the oil field has to be subject to definite years of development. At the same time, for the sake of the economic benefit of oilfield, the oil field will be shut down when gas channeling is found serious. This paper assumes that the fixed number development years of such kinds of gas-cap oil-rim reservoirs is 50 and the oilfield will be shut down when gas-oil ratio reaches 1800m3/m3 after the discovery of gas. Under such assumptions, the optimization of gas-cap oil-rim collaborative development is studied.

Curves of gas production rate, recovery percentage of gas cap and oil rim, and fuel-gas equivalence according to the simulation experiment in laboratory on the basis of similarity when the fixed development period of gas-cap oil-rim reservoirs is assumed as 50 year are shown below(Fig. 8).

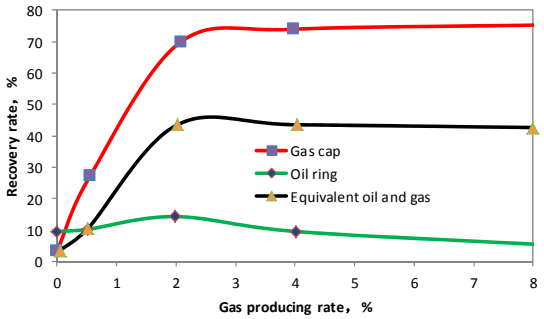


Fig. 8. Curve of gas production rate with gas-cap recovery, oil recovery and oil and gas equivalent recovery (considering development years and well closing)

(Oil rim development effect) When the gas cap is not be used, the oil gas interface migrates fast, the gas can be found earlier, and gas-oil ratio increases quickly, while the oilfield has to be shut down due to serious gas channeling, resulting in that the recovery percent of oil rim is relatively low. With the increasing of gas production rate, i.e. after the simultaneous exploitation of gas and oil, the migration of oil gas interface gradually becomes slow, the appearance time of gas is delayed, and the increasing of gas-oil ratio slows, resulting in that the development time of oil rim is prolonged and the recovery percentage of oil rim increases. After the gas production rate is over 2%, no gas is found in oilfield, while as the increasing of gas production rate, the descent rate of formation pressure speeds up, the development time is shortened and the recovery percent of oil rims drops as a result.

(Gas cap development effect) When the gas cap is not be used, as the oilfield is shut down due to serious gas channeling, the gas production volume is small, so that the recovery percent of gas cap is only around 1%. As is shown in the Figure, when the gas production rate is 0.5%, the recovery rate of gas cap can only be up to about 20% due to the limit of development years, and after the gas production rate exceeds 2%, it is hard to observe the changes of recovery percent of gas cap.

Upon overall consideration of the recovery percent of gas cap and oil rim, we can obtain a relation curve of oil gas equivalence and gas production rate. According to the curve, for such kinds of gas-cap oil-rim reservoirs, if the

development period is 50 years and the oil production rate is below 0.7%, with gas production rate increasing, the oil-gas equivalence will rise first and then descend, and when the gas production is around 2%, the oil-gas equivalence reaches to the peak and the development effect is the optimum.

IV. Conclusion

1)Three-dimensional visualized gas cap reservoir's physical simulation device can be established to analyze the influence of coordinated development on development effects of reservoir through indoor experiment. The experiment results showed that synergistic recovery of gas-cap oil ring is conductive to slow down migration speed of oil-gas interface and stabilize its migration form. At the same time, production gas-oil ratio will be lowered and development effects of reservoir will be improved.

2)Based on the material balance principle, determine the gas-cap oil-rim reservoir engineering method by collaborative development, and calculate the oil gas interface migration law under different development conditions. When the oil production rate is small and the gas production rate is big, the intrusion of oil gas interface into oil rim will slow down. Proper oil production rate and gas production rate can maintain the balance of oil gas interface.

3)For such kinds of gas-cap oil-rim reservoirs, if the development period is 50 years and the oil production rate is below 0.7%, with gas production rate increasing, the oilfield gas channeling extent decreases, meanwhile the decreasing rate of formation pressure picks up and the accumulative oil-gas equivalence tends to increase first and then descend. The optimum development effect will be obtained when the gas production rate is within the range from 2% to 4%.

Acknowledgment

This work was financially supported by the National Natural Science Foundation of China and the technology Project is "The Coupling Percolation Mechanism and Model for Fractured Low Permeability and Ultra-low Permeability Reservoir" (51174215/E0403).

This work was financially supported by the national major projects of 973 and the technology Project is "The seepage mechanics theory by CO2 flooding" (2011CB707305-005).

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