

Numerical Simulation Analysis of Interlayer Interference in Coal Measure "Three-gas Combined Production" Well

Xuemei Luo, Yanfei Ren, and Bingyue Han

School of Petroleum Engineering, Xi'an Shiyou University, Xi'an 710300, China

ABSTRACT

China has abundant reserves of coalbed methane, shale gas and tight gas, which are widely distributed and constitute an important part of China's unconventional oil and gas resources. If only a single gas is developed, it will be difficult to exploit, with low output and economic benefits. Therefore, the technology of "three-gas combined production" of coal measures is of great significance to increase the degree of reserve utilization, reduce the development layer size, and increase the gas production and mining life of a single well. In this paper, CMG numerical simulation software is used to numerically simulate and analyze the interlayer interference of coal measure "three-gas combined production" well, and the factors such as daily gas production and cumulative gas production, pressure field and gas saturation distribution of single-layer and three-gas combined production are respectively compared and analyzed, which provides reference for the knowledge of productivity law of "three-gas" combined production and the analysis of interlayer interference factors.

KEYWORDS

Three Gas Combined Production; Interlayer Interference; Numerical Simulation; Gas Production Comparison.

1. INTRODUCTION

Coalbed methane, shale gas and tight gas are called "three gases" in coal measure formation [1], and are the main components of unconventional gas in coal measure formation. At present, the understanding of "three gases" in coal measure strata is relatively weak, and the degree of exploration and development is low [2]. China's gas reservoir, shale gas and tight gas reserves are relatively rich and widely distributed, which is an important part of China's unconventional oil and gas resources. Most of the tight sandstone gas in China is coal gas, which is mainly divided into alkane gas, in which the methane content is the highest [3]. Moreover, tight sandstone gas reserves are abundant and widely distributed. The total explored geological resources are $17.4 \times 10^{12} \sim 25.1 \times 10^{12} \text{m}^3$, of which the total recoverable resources are $8.8 \times 10^{12} \sim 12.1 \times 10^{12} \text{m}^3$, among which the total coal measure tight sandstone gas resources are about $20 \times 10^{12} \text{m}^3$ [4]. In coal measure strata, the "three gases" of coal measure have a good basis of symbiosis and coexistence. With the continuous development of hydraulic fracturing and other technologies, the exploration and development of unconventional oil and gas resources has been promoted, and the "three gas combined production" of coal measures has also shown great development potential in recent years. The joint exploration and development of coalbed methane, shale gas and tight sandstone gas is a guide to the development of these unconventional natural gas resources by selecting suitable technology according to the characteristics of "three gas" symbiosis in different regions. Because if only for a single gas mining is bound to affect the efficiency of mining, and a single gas mining difficulty, low output, the most important is the high

development cost. If a single well can be used to exploit coalbed methane, shale gas and tight sandstone gas at the same time, it can improve the degree of reserve utilization, reduce the development layer size, and increase the gas production and mining life of a single well compared with a single gas exploitation [5].

1.1. Research Status of "Three-gas Co-production" Multi-layer Co-production of Coal Measures at Home and Abroad

A lot of research has been carried out at home and abroad on the problem of multilayer combined production of oil and gas reservoirs. Lefkovits (1961) [6] Firstly, the pressure solution of a combined production system with any layer number and no interlayer channeling is studied analytically. Kucuk (1986) [7] proposed a well test analysis method for connected reservoirs that comprehensively utilized wellbore pressure and flow. Fetkovich [8] has given relevant conclusions on productivity analysis of stratified combined mining systems. Aly et al. studied Agarwal's results in depth, and improved the combined production system under different pressures in each zone, and the theoretical method for solving the bottom hole pressure and the flow rate in each zone. Spivey studied the application of pressure data of multi-layer reservoir to analyze its seepage flow pattern and curve automatic fitting. Huang et al. established a multi-layer porous flow model with three external boundaries considering well reservoir and skin factor, and used the boundary element method to solve the bottom hole pressure solution. Sun Hedong et al. [9] applied the concept of maximum effective well diameter to establish the maximum well diameter model of the infinite three-layer overflowing reservoir, and obtained the accurate Laplace space solution of bottomhole pressure and stratified flow rate and the typical curve calculation method. Zhang Wangming et al. [10] analyzed the pressure dynamics of multilayer reservoirs, focusing on the difference of interlayer exhaustion and the seepage mechanism caused by interlayer channeling after shut-in. Xiong Qian, Li Shuang, Li Jinxiu et al. used numerical simulation method to study the equal division method of production in multi-layer combined mining, and also carried out a certain degree of research abroad.

1.2. Numerical Simulation of Interlayer Interference in Coal Measure "Three-gas Combined Production" Well

In order to explore the possibility of multi-layer coalbed methane combined mining, most scholars have studied the bottom-hole flow law and contribution of multi-layer coalbed combined mining. Based on the analysis of the influencing factors of multi-seam combined mining and the difference of seepage mechanism between coal seam and conventional oil and gas reservoir, the characteristics of the bottom-hole inflow dynamic curve of multi-seam combined mining are summarized [11]. In this paper, CMG numerical simulation software is used to establish a three-gas combined production model by using the component model, and the following mining modes are simulated respectively: (1) the shale gas is exploited separately, and the gas and tight gas are closed; (2) Coal-bed gas is exploited separately, and shale and tight gas reservoirs are closed; (3) The tight gas is exploited separately, and the shale and coal layers are closed; (4) Shale gas, coal bed gas, tight gas, simultaneously mined; (5) Three gas combined production, bottom hole flow pressure 5000Kpa; (6) Three gas combined production, bottom-hole flow pressure 2000Kpa; (7) Three gas combined production, bottom-hole flow pressure 500Kpa. The differences of "three-gas combined production" in coal measures are analyzed to provide reference for the understanding of production capacity law and the analysis of interlayer interference factors.

2. ESTABLISHMENT OF NUMERICAL MODEL OF INTERLAYER INTERFERENCE IN COAL MEASURE "THREE GAS COMBINED PRODUCTION"

CMG software is used to establish a three-gas combined production model by using the component model. The basic reservoir data is obtained by logging interpretation of well G6-6. The numerical and modular parameters are shown in Table 1. The grid model is 550m×550m plane, the number of grids in X, Y and Z directions is 27, 27 and 18 respectively, the length of a single grid in X and Y directions is 20m, and the length of a single grid in Z direction is 5m. The total number of grids is 27×27×18=13122. Fig.1 shows a tectonic grid model, and the reservoir is buried at an altitude of 2269~235.

Table 1. Digital modulus parameters

Parameters	Segment G6-6	Segment G6-6	Segment G6-6
Depth (m)	2269~2286.5	2305~2326	2327~2341
Mean matrix permeability (md)	0.00638	0.059	0.0237
Mean matrix porosity (%)	5.77	7.79	4.47
Mean fracture permeability (md)	0.01	0.8	0.01
Average fracture spacing (m)	15.24	0.4	15.24
Gas adsorption capacity (cm ³ /g)	11.246	19.08571	/
Fracture half length (m)	106.68	106.68	106.68
Existent state	Adsorbed gas, free gas	Adsorbed gas	Free gas

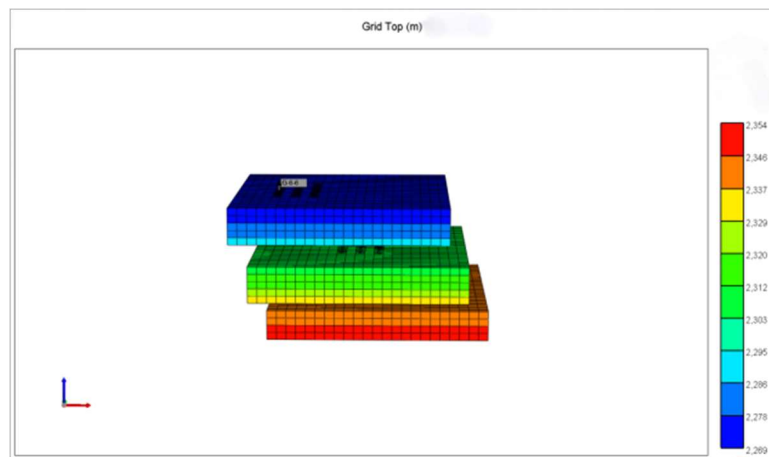


Fig. 1 Grid model

3. SINGLE ZONE GAS CORRELATION (SHALE GAS, COALBED METHANE, TIGHT GAS)

CMG numerical simulation software was used to simulate the daily gas production, cumulative gas production, pressure field and gas saturation distribution of shale gas, coalbed methane and tight gas respectively, and analyze the differences of the above parameters, laying a foundation for the understanding of the productivity law of "three gases" combined production.

3.1. Daily Gas Production and Cumulative Gas Production

The occurrence state of coalbed methane is mainly adsorbed gas, and its migration law and exploitation mechanism are different from conventional natural gas. As shown in Fig.2 and Fig.3, when the reservoir pressure is lower than the desorption pressure, coalbed gas desorbs from the surface of the coal matrix and diffuses into the cleaved pore system, migrates in the cleaved pore system, and then recovers from coalbed gas Wells, which undergoes a complex process of desorption, diffusion and seepage. After the opening of Wells, the daily oil production of coalbed gas has a rising stage. After reaching the top, production began to decline and reached a stable yield.

The exploitation of shale gas and tight gas is obviously different from that of coalbed methane. Because shale gas and tight gas contain a large amount of free gas, the output of shale gas decreases rapidly after reaching the peak after well production. Shale gas contains a small amount of adsorbed gas and also has a desorption process, so the daily output decreases slowly compared with tight gas. There is little difference in the output of shale gas and tight gas in the later stage of production, while the cumulative production and daily production of coalbed methane in the early stage are lower than shale gas and tight gas, and higher than shale gas and tight gas in the later stage.

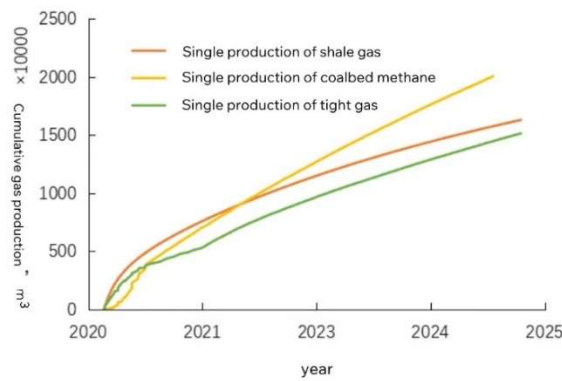


Fig. 2 Cumulative gas production curve of single-layer production

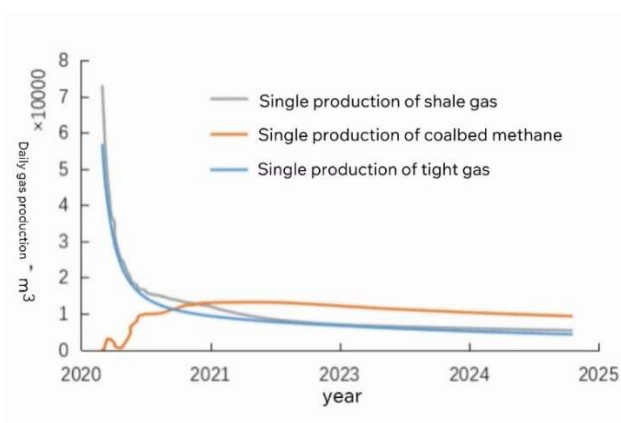


Fig. 3 Curve of daily gas production in single-layer production

3.2. Comparison of Pressure Field

The Fig.4 is the initial pressure field before mining, the left is the first layer pressure field plan, and the right is the longitudinal pressure distribution map of each layer. The Table 2 captures the plane pressure field distribution diagram and the longitudinal pressure field distribution diagram of each

experimental mining main layer after the first year, the third year and the fifth year of mining respectively.

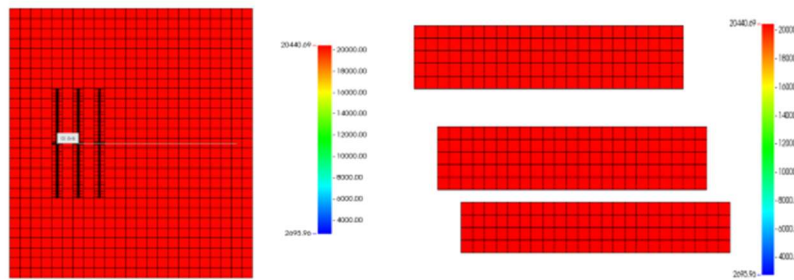


Fig. 4 Initial pressure field diagram (left plane diagram, right longitudinal diagram)

Table 2. Pressure field under different mining time of each single layer

Pressure field distribution after the fifth year of production	
Single production of shale gas	
Single production of coalbed methane	
Single production of tight gas	

As can be seen from the Table 2, the common feature of individual mining in each layer is that the pressure drops faster at the artificially fractured fracture, and the pressure drop area gradually spreads from the fracture to the surrounding area. Under the same production years, the accumulative production of gas reservoir single production is the largest, the pressure drops the fastest, and the pressure drops the slowest. From the longitudinal pressure field of each layer, it can be concluded that the pressure of other layers will also be affected during single-layer mining. When the pressure of gas production drops, the pressure of tight gas and shale gas also drops. When tight gas is produced separately, the pressure of both shale and tight gas reservoirs decreases. When shale gas is produced alone, it has little influence on the pressure of gas reservoir, but little influence on the pressure of tight gas reservoir.

3.3. Comparison of Gas Saturation Distribution

The following Fig.5 shows the initial gas saturation distribution diagram before exploitation, the left is the first layer gas saturation distribution diagram, and the right is the vertical gas saturation

distribution diagram of each layer. In the Table 3, the plane gas saturation distribution maps and the vertical gas saturation distribution maps of each experimental main layer after the first year, the third year and the fifth year of mining are respectively captured.

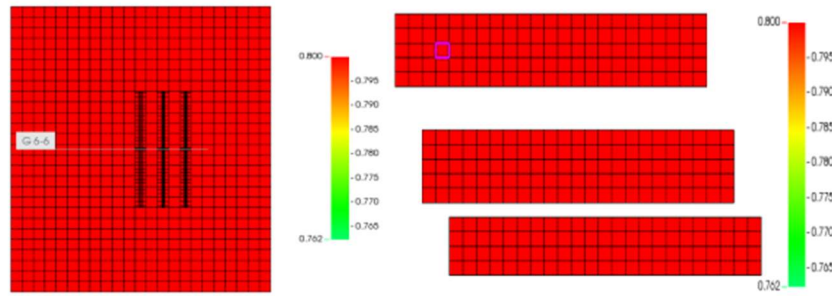
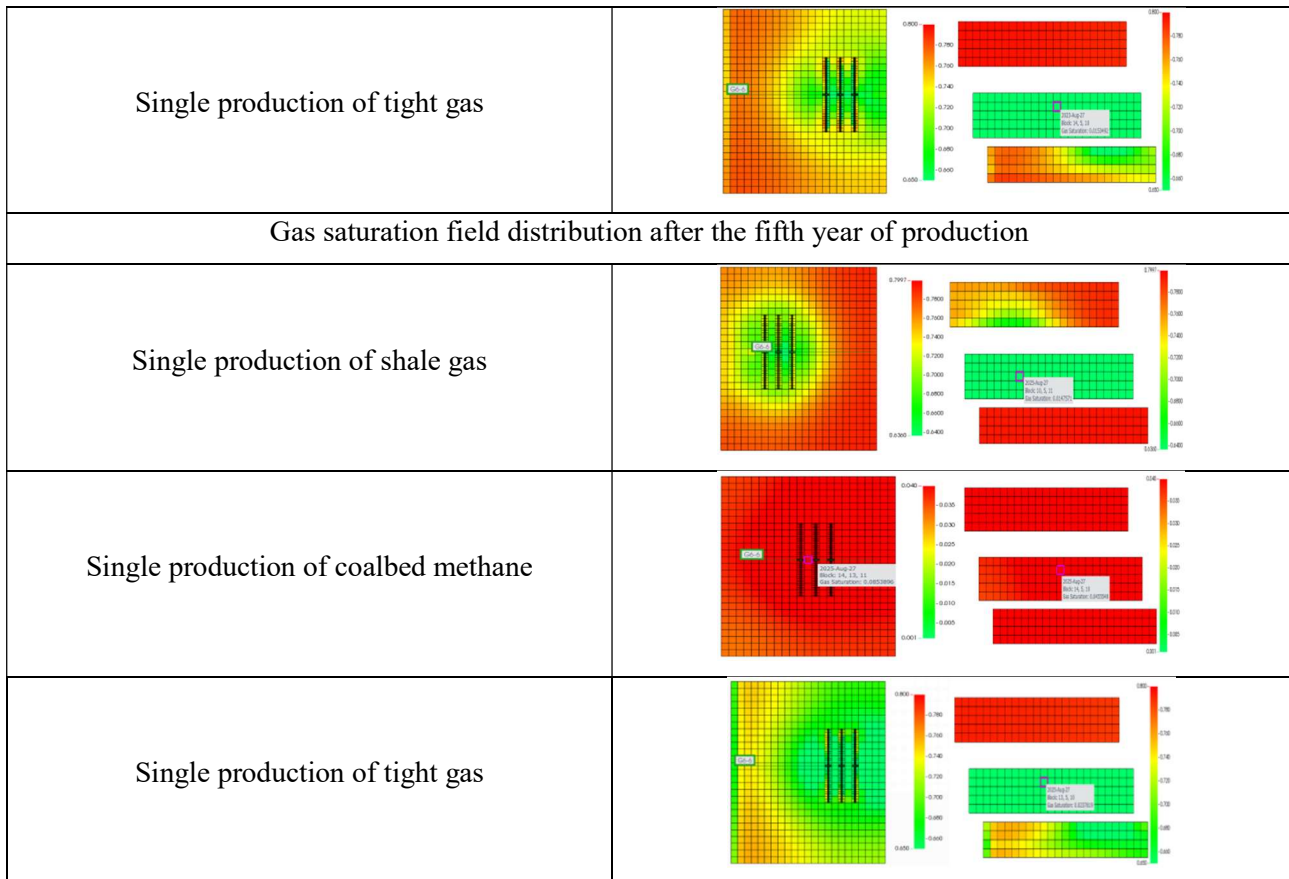


Fig. 5 Initial gas saturation field (left planar graph, right longitudinal graph)

Table 3. Distribution of gas saturation in each single layer under different production times

Gas saturation field distribution after the first year of production	
Single production of shale gas	
Single production of coalbed methane	
Single production of tight gas	
Gas saturation field distribution after the third year of production	
Single production of shale gas	
Single production of coalbed methane	



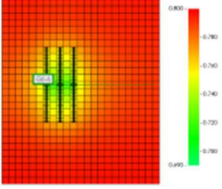
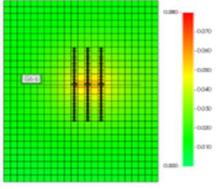
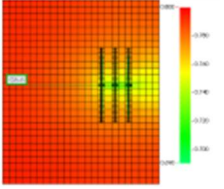
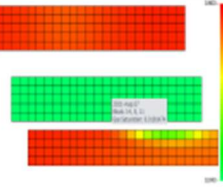
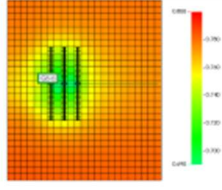
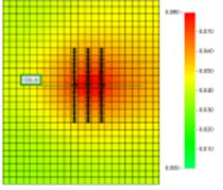
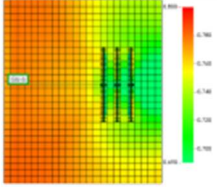
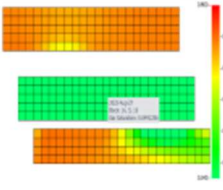
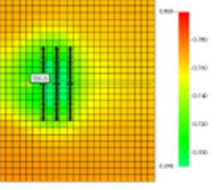
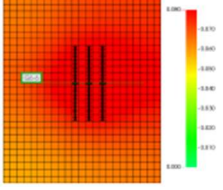
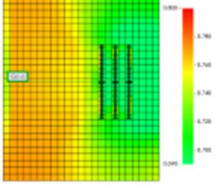
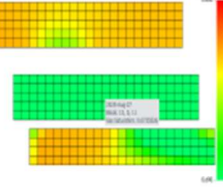
It can be seen from the Table 3 that the occurrence state of coalbed methane is mainly adsorbed gas. When the well is opened again for production, it can be seen that the gas saturation without free gas in the reservoir is 0. When the reservoir pressure drops below the desorption pressure, the gas saturation of free gas begins to rise from the surface of the coal matrix. Coalbed methane desorption appears first in the artificially fractured fracture due to the fastest pressure reduction, and the gas saturation rises the fastest. In the fifth year of mining, coalbed methane desorption has spread throughout the region.

The occurrence state of shale gas and tight gas is mainly free gas, the gas saturation decreases the fastest in artificial fracture, and the gas saturation decreases gradually from the fracture to the surrounding area. When shale gas and tight gas are exploited, the reservoir pressure drops, the adsorbed gas in the gas layer starts to desorption, and the gas saturation rises accordingly.

4. "THREE GAS COMBINED PRODUCTION" OF COAL MEASURES

It can be seen from the Table 4 that in the artificially fractured fracture, the gas saturation drops rapidly, and the gas saturation decline area gradually spreads from the fracture to the surrounding area. Under the same production years, the gas saturation of each layer decreases the fastest, and the gas saturation decreases the fastest in the spread area. The pressure of the tight gas layer drops the fastest. It can be seen from the longitudinal gas saturation diagram that when the gas saturation decreases in the two-layer combined production, the gas saturation also has a great influence on the gas saturation of the other reservoir, and the gas saturation also decreases and increases. For example, when shale gas and tight gas are produced together for five years, the gas saturation of coalbed methane rises from 0% to 7%, and when gas and tight gas are produced together for five years, the gas saturation of shale gas drops from 80% to 78.3%.

Table 4. Gas saturation distribution map under different production time

"Three gas combined production" of coal measures	Shale gas surface (65%~80%)	Coalbed methane surface (0~8%)	Tight gas surface (65%~80%)	Vertical (65%~80%)
The first year				
The third year				
The fifth year				

4.1. Bottom-hole Flow Pressure Comparison

The lower the bottom-hole flow pressure is, the larger the production pressure difference is. As can be seen from Fig. 6 and Fig. 7, the larger the production pressure difference is, the larger the daily gas production and cumulative gas production are. The daily gas production and cumulative gas production when the bottom-hole flow pressure is 500Kpa are significantly larger than the daily gas production and cumulative gas production when the bottom-hole flow pressure is 2000Kpa and 5000Kpa.

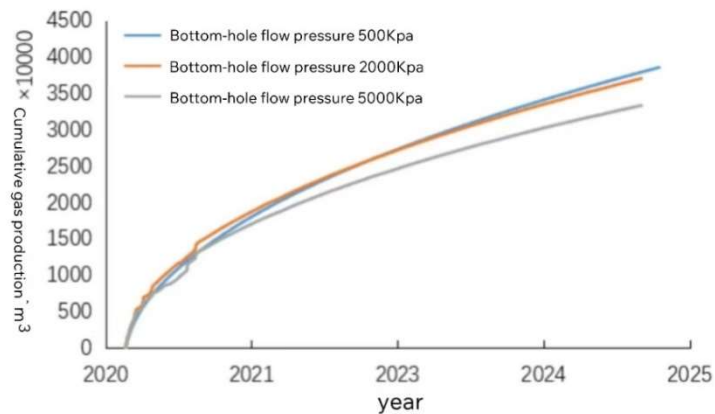


Fig. 6 Cumulative gas production curve of combined formation

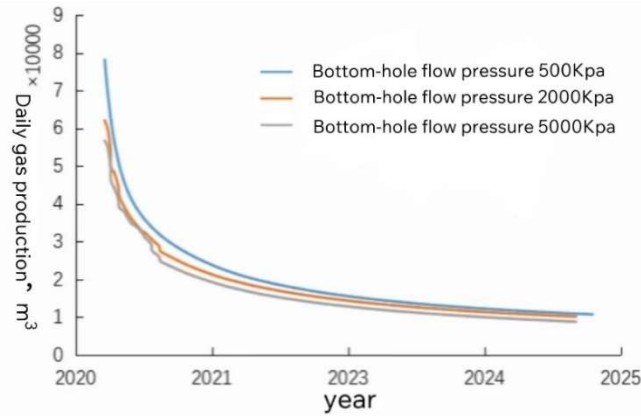


Fig. 7 Cumulative gas production curve of combined formation production

4.2. Comparison of Pressure Field

It can be seen from the Table 5 that the lower the bottom-hole flow pressure, the larger the production pressure difference, and the larger the production pressure difference, the faster the pressure drop of each layer pressure field. From the pressure field distribution diagram after the fifth year of production, it can be seen that the pressure drops of each layer when the bottom-hole pressure is 500Kpa is significantly greater than that when the bottom-hole pressure is 5000Kpa.

Table 5. Pressure field distribution after the fifth year of production

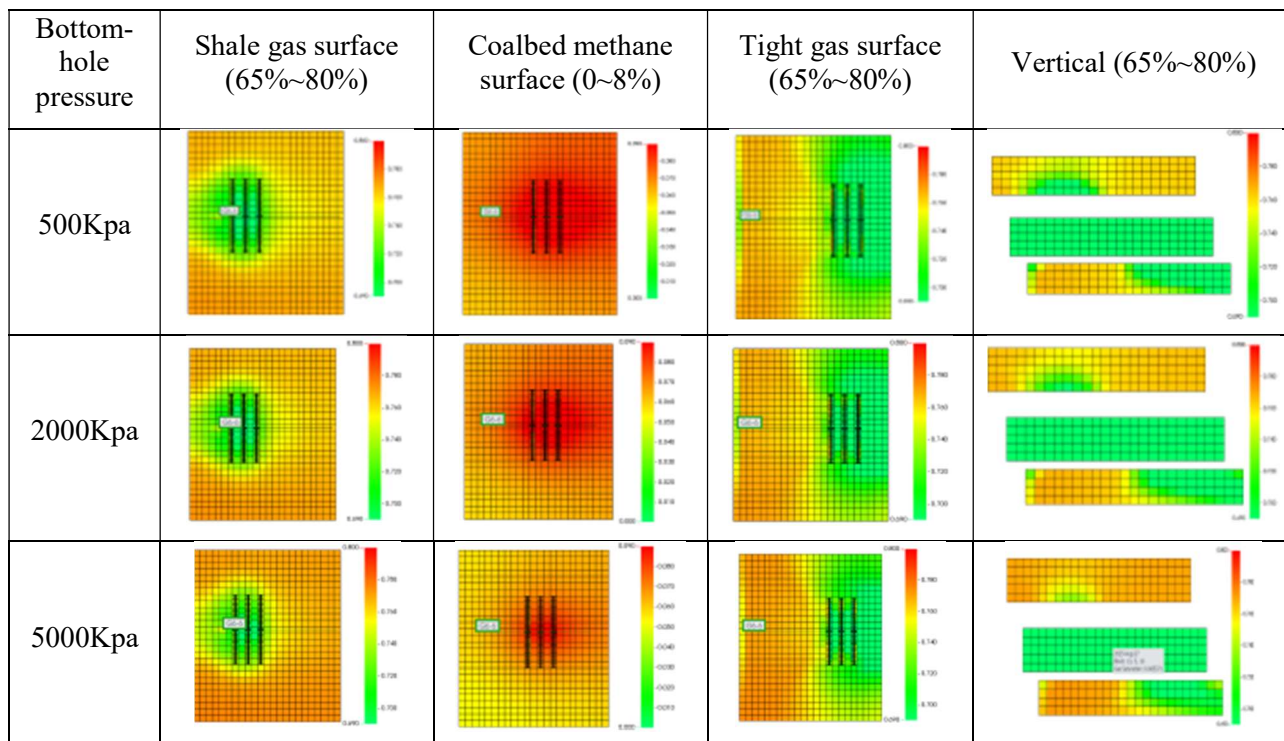
Bottom-hole pressure	Shale gas surface (65%~80%)	Coalbed methane surface (0~8%)	Tight gas surface (65%~80%)	Vertical (65%~80%)
500Kpa				
2000Kpa				
5000Kpa				

4.3. Gas Saturation Distribution Diagram

It can be seen from the Table 6 that the lower the bottom-hole flow pressure, the larger the production pressure difference, and the larger the production pressure difference, the faster the gas saturation field of each layer drops or rises. From the gas saturation distribution after the fifth year of production, it can be clearly seen that the gas saturation of shale and tight layer decreases significantly more when

the bottom-hole pressure is 500Kpa than when the bottom-hole pressure is 5000Kpa. The desorption degree of coalbed methane is greater than that of the bottom hole pressure of 5000Kpa.

Table 6. Gas saturation distribution after the fifth year of production



5. SUMMARY

The technology of "three gas combined production" in coal measures is of great significance to increase the degree of reserve utilization, reduce the development layer size, and increase the gas production and mining life of a single well. In this paper, CMG numerical simulation software is used to numerically simulate and analyze the interlayer interference of coal measure "three-gas combined production" well, and the factors such as daily gas production and cumulative gas production, pressure field and gas saturation distribution of single-layer and three-gas combined production are respectively compared and analyzed, which provides reference for the knowledge of productivity law of "three-gas" combined production and the analysis of interlayer interference factors.

REFERENCES

- [1] Bing Liang, Yingshuang Shi, Weiji Sun, et al. "Three of China's coal gas" accumulation characteristics and mining possibility [J]. Journal of coal science, 2016, 9 (01): 167-173. The DOI: 10.13225 / j. carol carroll nki JCCS. 2015.9016.
- [2] Jinkui Hu, Wenfeng Du. Analysis on feasibility of "Three-gas combined mining" in coal measure formation [J]. Evaluation of geological theory, 2017 tobacco (S1): 83-84. The DOI: 10.16509 / j.g eoreview. 2017. S1.041.
- [3] Mao Zheng, Jun Zhao. Feasibility and Technical Research on the Unified Extraction of "Three Gases" from Coal Series. Contemporary Chemical Industry, 2018, 47(11): 2430-2434. DOI: 10.13840/j.cnki.cn21-1457/tq.2018.11. 048.
- [4] Chengzao Jia, Min Zheng, Yongfeng Zhang. Unconventional oil and gas resources and exploration and development prospects in China [J]. Petroleum Exploration and Development, 2012, 39(02): 129-136.
- [5] Shangzhi Meng, Rihe Mo, Fenna Zhang, et al. Analysis of current situation and key technologies of coalbed methane, tight gas and shale gas Co-production process equipment [C]// Coalbed Methane Professional Committee of China Coal Society, Petroleum Geology Professional Committee of China Petroleum Society, and Strategic Alliance for

Technological Innovation of Coalbed Gas Industry. Proceedings of the 2016 Coalbed Methane Academic Symposium. China United Coalbed Methane Co., LTD.; School of Mechanical and Electrical Engineering, China University of Petroleum (East China); 2016:5.

- [6] Hedong Sun, Lei Liu, Fangde Zhou, et al. Infinite three layers, the more accurate solution of bottom hole pressure and flow reservoir characteristic curve [J]. Journal of minerals, rocks, 2003, (01): 101-104. The DOI: 10.19719 / j. carol carroll nki. 1001-6872.2003.01.021.
- [7] Wangming Zhang, Qixiang Lian, Dakuang Han, et al. Well test analysis of multilayer reservoir [J]. Petroleum Exploration and Development,2001,28(3):63-66.
- [8] Yixing Zhu. Research and Application of stratified oil production technology of mechanical production Wells in Jiangsu Oilfield [D]. China University of Petroleum (East China),2012.
- [9] Pengcheng Liu. Study on inflow performance of multi-seam Combined production well [D]. China University of Petroleum (East China),2013.
- [10] Longshi Peng, Qiao Lan, Gong Min, et al.Factors affecting productivity of coalbed methane Wells with multiple production zones [J]. Coal science, 2014, 33 (10) 6:2060-2067. The DOI: 10.13225 / j. carol carroll nki JCCS. 2014.0541.
- [11] Yong Li, Shangzhi Meng, Peng Wu, et al.Numerical Simulation of gas production in coal measures [J]. Lancet coal science, 2018 (6): 1728-1737. The DOI: 10.13225 / j. carol carroll nki JCCS. 2018.4032.