



# Experimental study on interlayer interference of coalbed methane reservoir under different reservoir physical properties and pressure systems

Lingli Liu<sup>1</sup> · Jianjun Wang<sup>1</sup> · Penghui Su<sup>1</sup> · Wensong Huang<sup>1</sup> · Bin Zhang<sup>2,3</sup> · Xianmin Zhang<sup>2,3</sup> · Zehong Cui<sup>1</sup> · Xiaoyi Wei<sup>1</sup> · Lijiang Duan<sup>1</sup> · Ming Li<sup>1</sup>

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## Abstract

Multilayer commingled production is the most efficient development technique of coalbed methane under the condition of multiple coal seams. However, due to the differences in physical properties between multilayer superimposed gas-bearing systems, interlayer interference severely limits coalbed methane development in commingled production. To achieve multilayer-commingled production, interlayer interference must be reduced and the combination of production layers must be optimized. Physical simulations are an effective measure to achieve this goal. According to the characteristics of multiple thin interbeds, strong reservoir heterogeneity and interlayer pressure difference in the Surat basin, a physical model is established to simulate the multilayer-commingled production process of coalbed methane reservoirs and the gas production contribution, and a pressure change of each layer is analyzed. The greater the interlayer pressure difference, the more obvious the early backflow phenomenon of the low-pressure layer, the more obvious the difference of layered production contribution in the later stage, the lower the degree of commingled production and recovery, and the stronger the interlayer interference. In view of these, this study proposes a new experimental method named the succession production. The novelty of this method is to control the commingled production time, that is, the high-pressure layer is produced first, and the low-pressure layer is combined when the interlayer pressure is consistent. The results show that this method can eliminate the early backflow phenomenon of the low-pressure layer and reduce interlayer interference. Furthermore, the characteristics of interlayer interference and the change law of multilayer-commingled production capacity of succession and commingled production are clarified, providing theoretical and technical support for reducing interlayer interference and optimizing production layer combination to promote the efficient development of multiple thin interbedded coalbed methane reservoirs.

**Keywords** Coalbed methane reservoir · Multilayer-commingled production · Succession-commingled production · Interlayer interference · Multilayer stacked gas-bearing system

## Introduction

Coalbed methane (CBM), a high-quality green energy source, has high calorific value, produces no pollutants and is relatively safe (Xue 2015; Zhao 2018). It is one of the most important aspects of unconventional gas exploration and development (Schmoker 2002; Ratner and Tiemann 2014; Jia 2017; Zheng et al. 2018; Nurudeen et al. 2018; Chen et al. 2019; Zhang et al. 2020; Ashraf et al. 2021). Low-rank CBM accounts for a very high proportion of the global production (Mangi et al. 2020, 2022), which predominantly comes from Jurassic-Cretaceous-Paleogene coal seams such as Surat in Australia, Fanhe in the United States, and Alberta in Canada (Ayers 2002; Scott et al. 2004;

✉ Penghui Su  
suhui317@petrochina.com.cn

<sup>1</sup> PetroChina Research Institute of Petroleum Exploration and Development, Beijing 100083, China

<sup>2</sup> Key Laboratory of Unconventional Oil & Gas Development (China University of Petroleum (East China)), Ministry of Education, Qingdao 266580, China

<sup>3</sup> School of Petroleum Engineering, China University of Petroleum (East China), Qingdao 266580, China

Pashin 2010; Ryan et al. 2012; Wang et al. 2020;). The Surat basin is rich in CBM resources and has huge development potential among them. It has become the basin with the highest CBM development efficiency globally (As et al. 2017). The main coal-bearing strata in the Surat basin is the Walloon subgroup of the middle Jurassic, mainly composed of siltstone, mudstone, and coal. The basin is a typical multi-thin interbedded and low-rank coal group characterized by a multi-thin coal seam, largely accumulated thickness, and frequent interbedded between the thin coal seam and sand/mudstone layer (Martin et al. 2013; Li 2016). The coal seams have low gas content, generally 4–6 m<sup>3</sup>/t, and are generally saturated or supersaturated. The permeability of coal seams can reach 100 mD. Still the heterogeneity is strong, so the development strategy of “vertical well + open hole completion + multilayer commingled production” is generally used (Clarkson 1998; Chaffee et al. 2010; Hamilton et al. 2012; Yu et al. 2014). However, due to the interlayer differences of reservoir pressure and physical properties in the multilayer-commingled production, interlayer interference will cause formation damage (Zhao et al. 2015), which will adversely affect the CBM production. Therefore, the research on multilayer-commingled production capacity based on the CBM occurrence conditions in this area is critical for promoting CBM development in the Surat basin.

Many attempts have been made to investigate the multilayer-commingled CBM production (Liu 2018), including well-testing analysis, numerical simulation and experimental methods (Liu et al. 2019; He and Mei 2019; Wei and Duan 2019). The well-testing analysis and numerical simulation methods (Ei-Banbi and Robert 1996; Jiang et al. 2016; Cheng et al. 2007; Zhao and Wang 2018) are based on theoretical derivation and numerical calculation. The fundamental assumptions are frequently simplified, which is difficult to reflect the physical properties under the reservoir conditions (Zhang et al. 2020; Guo et al. 2021). While the experimental approach is more intuitive and reliable for studying the production characteristics of CBM reservoirs, and the core-scale experiments have been frequently used in comprehensive production studies, that guide field operation (Song and Yang 2017; Zhao et al. 2018). Currently, many researchers have studied multilayer-commingled production by experiments. Using sandstone samples with different physical properties, Liu et al. evaluated the commingled production performance of gas reservoirs under various differential pressure conditions. They indicated that the interlayer interference would be aggravated by a well shut-in operation (Liu et al. 2019). Based on the geological conditions of the Laochang area in China, Wang et al. conducted studies on bilayer commingled gas production under different permeabilities and pressures. The results show that the effects of permeability range, interlayer pressure difference, and interlayer spacing of coal seams should be considered in the reservoir combination and drainage system to eliminate

interlayer interference and improve gas production (Wang and Quin 2019). Xu et al. developed a mixed drainage device for a multilayer-commingled system based on the special reservoir formation characteristics of a “multilayer superimposed CBM system.” The progressive drainage test is adopted to effectively avoid inversion between different coal seams by optimizing the production time, thus improving CBM recovery (Xu et al. 2018).

Most of the physical simulation test devices are mainly small-size parallel cylinder specimens. Most studies mainly focus on the commingled production of tight sandstone gas and shale gas, while there is little research on CBM reservoirs (Xu et al. 2018). However, most mathematical studies only characterized the interlayer interference phenomena of a CBM commingled production system without further investigation to reduce the interlayer interference and improve the CBM recovery. Therefore, in this study, we first innovate the coal sample processing method. Screened pulverized coal is selected as the experimental material instead of the cylindrical specimens used in previous studies. This method weakens the boundary effect and greatly reduces the adsorption equilibrium time of coal samples, which is less time-consuming and reduces the cost. Furthermore, we propose a new approach for commingled production of multilayer superimposed CBM system (succession-commingled production). The uniqueness of this method is to control the timing of commingled production. When multilayer coal seams are produced with vertical pressure difference, the high-pressure layer is produced first, and the commingled production is performed when the pressure of the high-pressure layer drops to the same level as that of the low-pressure layer. This method can effectively avoid the interlayer interference caused by the pressure difference of coal seams.

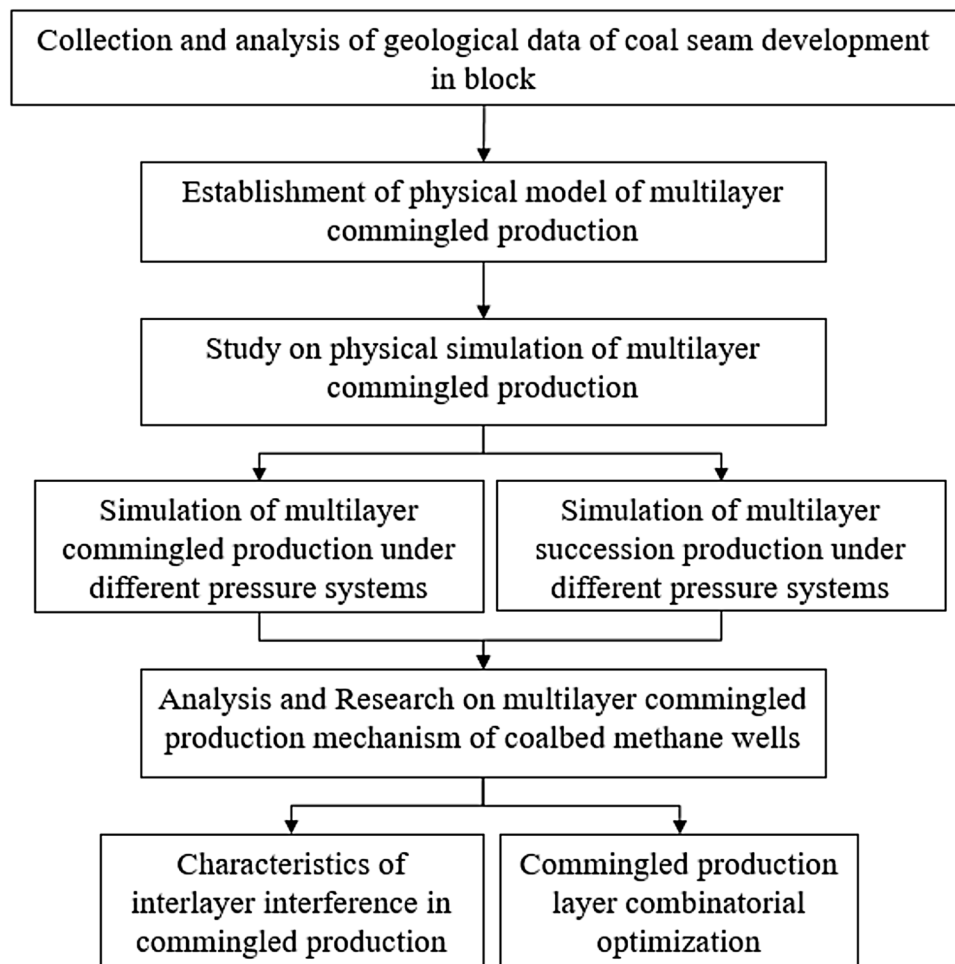
Figure 1 shows the technical route used in this study. First, a physical model is developed based on the occurrence conditions and geological characteristics of the CBM reservoir in the Surat basin. The proposed experimental scheme is then used to conduct a physical simulation experiment of multilayer-commingled production. Then, the change in stratified gas production is analyzed to determine the multilayer-commingled production capacity and interlayer interference characteristics. Finally, the commingled production effect under different conditions is compared to reduce interlayer interference, optimize production combination, and promote efficient development of CBM (Guo et al. 2021).

## Experiment

### Materials

The Walloon coal formation is located in the Middle Jurassic, and  $R_o$  is generally 0.30–0.60%, most of which are less

Fig. 1 Technology roadmap



than 0.50%. The pyrolysis experiments show that the atomic ratio of Walloon coal is 1.10–1.28, which is significantly greater than that of ordinary coals. Based on the above characteristic data, the coal samples used in the experiment were collected from the Shanhou minefield in China. The coal in this area belongs to the long-flame coal with  $R_{\text{omax}} < 0.5\%$ , which is closest to the coal quality of the target area. The coal samples were subjected to a series of preparatory treatments (Fig. 2), which included three steps: crushing the selected lump coal, screening the pulverized coal, and finally loading the pulverized coal into the sand pack models.

### Experimental methods and principles

A multi coal seam co-production simulation experiment method is designed to simulate the difference in physical properties and reservoir pressure simultaneously using the CBM adsorption and experimental desorption equipment and the multilayer gas production experimental device (Shi et al. 2019). This method considers the effect of percolation capacity on the productivity of each layer, and the parameters such as the production difference of each layer

and stratified gas supply capacities were analyzed. Figures 3 and 4 show the experimental system diagram and the experimental schematic, respectively. The experimental system comprises a gas source supply system, reservoir simulation system, and a measurement system. The gas source supply system consists of a gas cylinder, a pressure gage, and a pressure reducing valve, and it is used to provide methane gas for each sand pack model. The reservoir simulation system is composed of one reference cylinder (500 mL) and two sand pack models ( $\Phi 25 \times 400$ ), whose function is to simulate the process of coal adsorption/desorption and co-production by injecting methane into the gas source supply system. The measuring system consists of three high-scale pressure gauges, two mass-flow gas meters, a gas flow controller, and a data acquisition device. The pressure gauges  $P_1$ ,  $P_2$ ,  $P_3$  are used to record the pressure data of the reference cylinder, the upper sand filling pipe, and the lower sand filling pipe, respectively. Meanwhile, the upstream flow meter and the downstream flowmeter are separately used to record the lower sand filling pipe's gas production. The computer can accomplish



(a) Crushing

(b) Screening

(c) Filling sand

Fig. 2 Coal sample treatment process

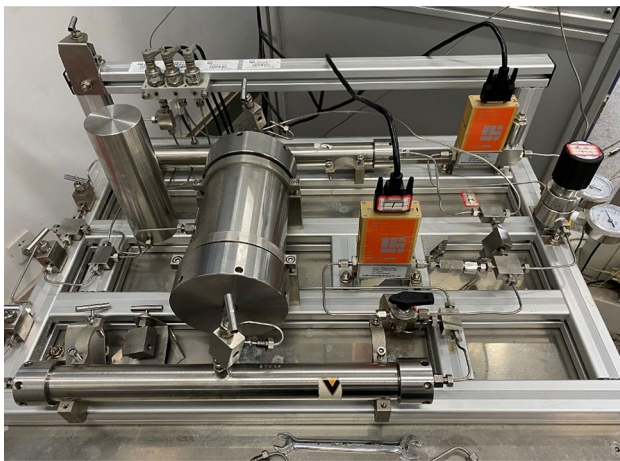


Fig. 3 Experimental system

all the data collection, thus minimizing the experimental error caused by manual operation (Liu et al. 2019).

### Experimental process

Three schemes are designed on the principle of similarity, considering the differences of reservoir properties and pressures between coal seams in the target block: (1) multilayer co-production simulation experiments under different permeability conditions. (2) multilayer co-production simulation experiments under different pressure systems. (3) Succession development simulation experiments of coal seams with the different pressure systems.

- (1) The sand filling simulation layers with different permeabilities are selected for the physical simulation test

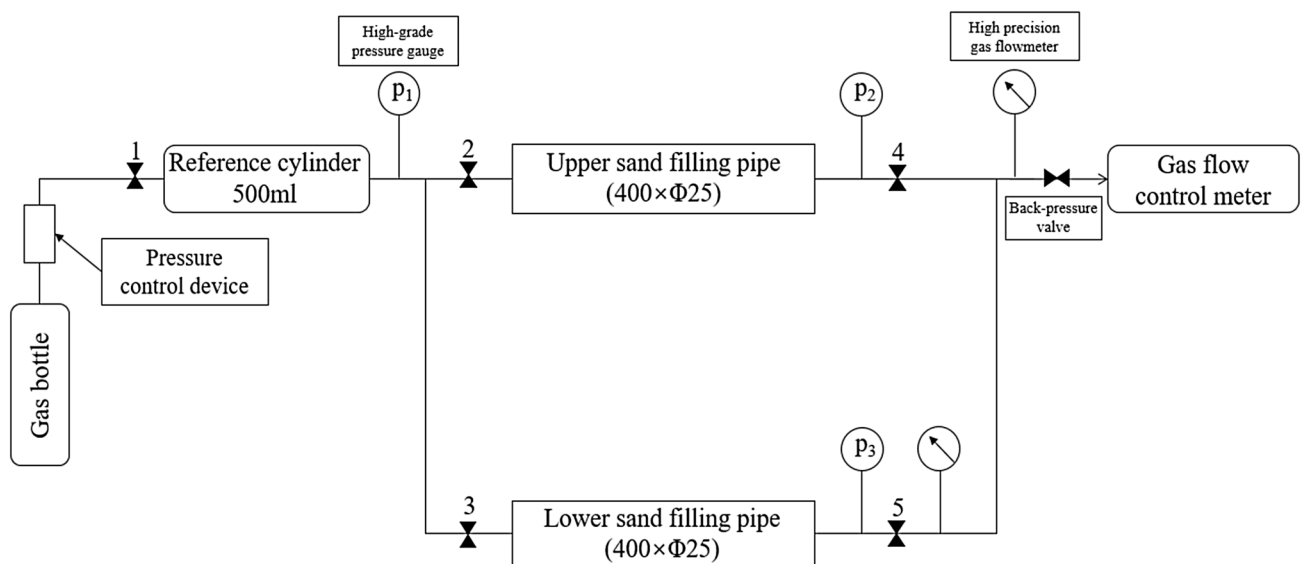


Fig. 4 Experimental schematic diagram

to elucidate the characteristics of productivity change and interlayer interference under different permeability conditions, and the experimental steps are as follows: first, the permeabilities of two sand filling simulation layers are measured by the steady-state method, which are separately 420 mD for the lower sand filling pipe and 91 mD for the upper sand filling pipe. The initial pressures of the two sand filling simulation layers are all set to 5 MPa when the gas supply system is opened. Then, the maximum outlet speed is set to 750 mL/min through the flow controller, controlling the outlet back pressure simultaneously. The outlet valve is opened to realize the synchronous gas production of two simulation layers, and the pressure, instantaneous, and cumulative gas production of each simulation layer are recorded regularly.

- (2) Physical simulation experiments are performed to simulate the commingled gas-bearing simulation conditions of different interlayer permeability and pressure systems to elucidate the law of productivity change and the interlayer interference characteristics. The experimental steps are as follows: first, keep the permeabilities of upper and lower simulation layers constant, and then set different initial pressures for the two sand filling pipes. The initial pressure of the lower sand filling pipe is set to 5 MPa, while that of the upper sand filling pipe is set to 4.3, 3.6, and 2.9 MPa, respectively (Table 1). The outlet back pressure is controlled, and the gas flow controller sets the maximum outlet speed to 750 mL/min. The pressure, instantaneous, and cumulative gas production of each simulation layer are recorded regularly basis once valves 4 and 5 are opened to realize the synchronous gas production of two simulation layers.
- (3) In view of the difference of reservoir pressure and physical properties in co-production, the interlayer interference phenomenon will cause reservoir damage, which will seriously affect the CBM production. This study innovates a test method and performs succession production simulations under different pressure systems based on multilayer co-production simulations. This method effectively reduces interlayer interference

in the co-production system to clarify the law of productivity change and the interlayer interference characteristics during succession production. The experimental steps are as follows: keep the permeabilities of upper and lower layers unchanged, set the pressure of the lower sand filling pipe to 5 MPa, and the pressure of the upper sand filling pipe to 4.3, 3.6, and 2.9 MPa in turn (Table 2). The outlet back pressure is controlled, and the maximum outlet speed is set to 750 mL/min through the flow controller. First, open valve 5 to achieve a separate gas production in the lower layer, and when the pressure in both lower and upper layers are the same, open valve 4 to realize a commingled gas production of the two layers, and regularly record the pressure, instantaneous gas production and cumulative gas production in each simulated layer.

## Results and discussion

Physical simulation experiments can obtain the parameters such as pressure, instantaneous gas production, and production contribution rate at each time point. The pressure change law, instantaneous gas production, production contribution rate, recovery degree, and interlayer interference of multilayer-commingled production can be thoroughly studied by a comprehensive treatment and analysis of these parameters, resulting in a technical basis for the formulation of multilayer-commingled production development technology strategy.

### Multilayer co-production under different permeability (upper layer permeability 91 mD, lower layer permeability 420 mD)

The instantaneous production changes of the two layers differ in different periods. The main gas-producing layer at the beginning of the experiment was the high-permeability layer. The gas production rate of the high-permeability

**Table 1** Experimental scheme of multilayer co-production under different interlayer pressure differences

Serial number	Reservoir pressure of different coal seams (MPa)		Set the output (mL/min)
	420 mD	91 mD	
1	5.0	4.3	750
2	5.0	3.6	750
3	5.0	2.9	750

**Table 2** Experimental scheme of succession-commingled production under different interlayer pressure differences

Serial number	Reservoir pressure of different coal seams (MPa)			Outlet flow (mL/min)
	420 mD	Replace production	91 mD	
1	5.0	4.3	4.3	750
2	5.0	3.6	3.6	750
3	5.0	2.9	2.9	750

layer was 742 mL/min, which was much higher than that of the low-permeability layer. When the high-permeability layer cannot satisfy the stable gas production rate, the instantaneous gas production rate decreases. At this time, a large amount of adsorbed gas is desorbed in the low-permeability layer. The gas production rate begins to increase to keep the total gas production rate unchanged. When the co-production system cannot maintain stable production, the co-production rate decreases. At this moment, the gas production rate of the low-permeability layer reaches the maximum, and then the total commingled gas production rate decreases. At 490 s, there is an intersection of gas production rate curves between high- and low-permeability layers. Then, the gas production rate of low-permeability layer surpasses that of high-permeability layer and becomes the main gas supply layer (Fig. 5). Therefore, when co-production is conducted in gas reservoirs with great differences in physical properties, the early production data in gas well production performance analysis and reserve evaluation mainly reflect the production situation of relatively high-permeability layers, and relatively low-permeability layers are less used. However, in the later production stage (depletion period), the production data mainly reflect the production situation of relatively low-permeability layers (Zhu et al. 2013).

The production contribution of each coal seam is an important index to evaluate the CBM co-production efficiency. It is defined as the ratio of CBM produced by each layer to the total co-production CBM (Guo et al. 2021). As shown in Eq. (1).

$$C_n = \frac{P_n}{P} (n = 1, 2, \dots) \quad (1)$$

where  $C_n$  is the CBM production contribution by each layer, %;  $P_n$  is CBM production rate of each layer, mL/min;  $P$  is

the total CBM co-production rate, mL/min;  $n$  is the concrete production layer.

Therefore, we calculate the CBM production contribution of each layer using flow data, and then study the CBM production characteristics and interlayer interference in multilayer co-production.

Ideally, the CBM production contribution in multilayer co-production is calculated by KH splitting method; that is, when the effective thickness of the formations is the same, the production contribution should be split according to the permeability of each layer. In the early stage, comparing the change of the CBM production contribution rate under different permeabilities (Fig. 6) its difference between the high-permeability and low-permeability layers is the largest. The contribution rate of the high-permeability layer is 98%, which is much higher than that of the low-permeability layer and is the main CBM-producing layer. The CBM production contribution of each layer gets closer as the experiment progresses, and the CBM production contribution curve crosses at 490 s. Previously, the CBM production contribution of the high-permeability layer was always higher than that of the low-permeability layer. After that, the CBM production contribution of the low-permeability layer surpassed that of the high-permeability layer and became the main production layer in the later stage. The high-permeability layer almost no longer produces CBM at the end of the experiment. The above phenomena indicate that the production contribution deviates obviously from the KH splitting result, which confirms the problem of interlayer interference in multilayer co-production. The reason is that under the same production pressure, the high-permeability layer will inhibit the CBM production of the low-permeability layer. As the CBM production progresses, the pressure of the high-permeability layer decreases, resulting in the recoverable reserve decrease of the high-permeability layer. At this time, the inhibition effect of the high-permeability layer weakens, and massive

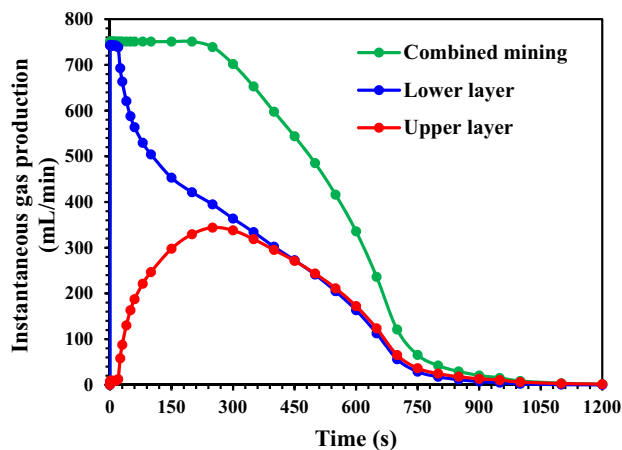


Fig. 5 Change diagram of stratified instantaneous gas production

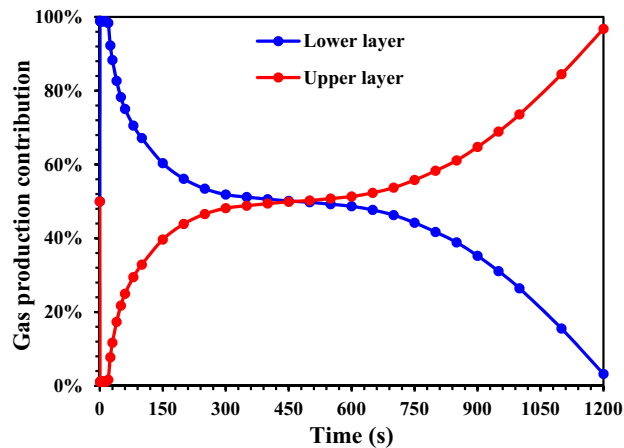


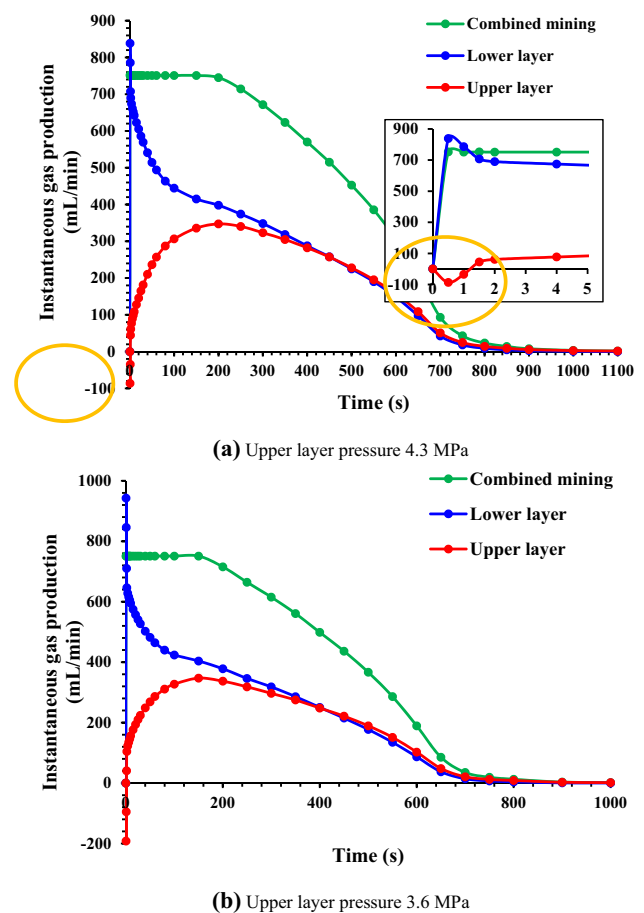
Fig. 6 Variation diagram of stratified gas production contribution

CBM in the low-permeability layer begins desorbing. In the later stage, the recoverable reserve of the high-permeability layer are further reduced and enter the exhaustion period, which cannot restrain the gas production of the low-permeability layer. Finally, the CBM production contribution of the low-permeability layer is greater than that of the high-permeability layer.

### Multilayer-commingled production under different pressure systems

Upper layer permeability 91 mD, lower layer permeability 420 mD

Fix the pressure of the lower layer as 5 MPa, and set that of the upper layer to 4.3, 3.6, and 2.9 MPa in the simulation experiments. At the beginning of the simulation experiment, the CBM production rate of the high-permeability layer was much higher than that of the low-permeability layer. The maximum flow rates of the high-permeability layer are 838, 941, and 1081 mL/min, respectively, and the low-permeability layer has a negative value. The CBM production rate decreases when the high-permeability layer is unable to satisfy the maximum gas supply. In contrast, many adsorbed CBM in the low-permeability layer desorb, and its CBM production rate increases to maintain the stable commingled production rate. When the commingled production system cannot maintain stable production rate, it begins to decline. At this time, the CBM production rate of the low-permeability layer reaches the maximum, and then the CBM production rates of the two layers decrease simultaneously. At 470, 420, and 360 s, respectively, the CBM production rate curves between the high- and low-permeability layers cross. Then, the CBM production of the low-permeability layer exceeds that of the high-permeability layer and becomes the main gas supply layer in the later stage (Fig. 7). Figure 8 shows the production contribution of the two layers in different production stages. At the beginning of the experiment, the produced CBM mainly comes from the high-permeability layer, and its production contribution curve is greater than 1 in a short time, which indicates that the CBM produced from the high-permeability layer flows into the low-permeability layer, increasing the pressure of the low-permeability layer (Fig. 9). At this time, the low-permeability layer has a negative contribution value due to the complete inhibition of gas production. As the experiment progresses, the inhibitory effect of the high-permeability layer decreases gradually, and massive CBM in the low-permeability layer begins to desorb and exert the gas production capacity so that the pressure of the two layers gradually tends to be consistent. The production contribution curves are gradually close, and cross at 470, 420, and 360 s, respectively. Since then, the high-permeability layer cannot inhibit the gas production of the

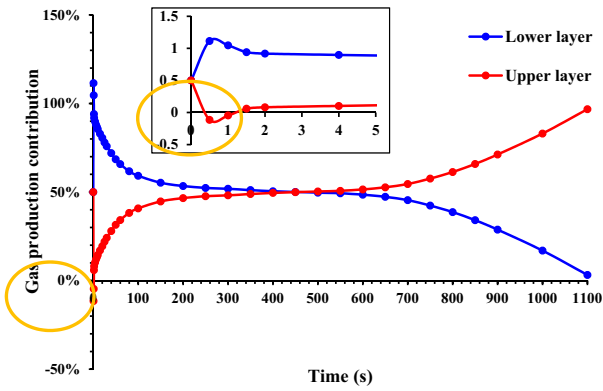


**Fig. 7** Variation diagram of stratified instantaneous gas production under different upper layer pressure. The circle indicates an enlarged display

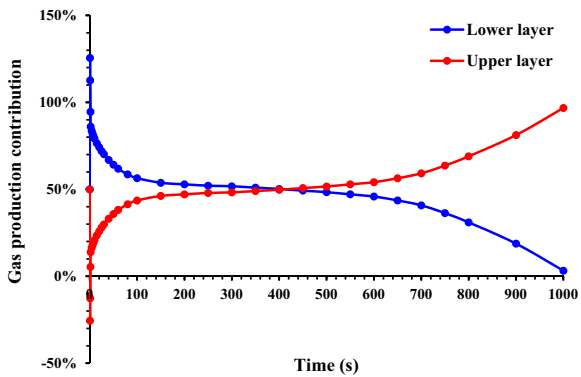
low-permeability layer due to the lack of energy, resulting in the CBM production contribution rate of the low-permeability layer gradually surpassing the high-permeability layer and becoming the main gas supply layer in the later stage of the commingled production system.

### Contribution rate of gas production under different pressure differences

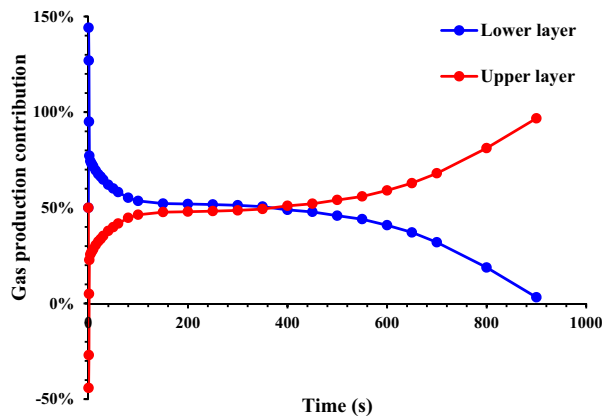
From the above analysis, it can be seen that the coal seam strongly affected by interlayer interference is the low-pressure seam in the CBM co-production system with interlayer pressure difference. When the interlayer pressure difference is 0.7, 1.4, and 2.1 MPa, at the beginning of the experiment, the minimum production contribution of the low-pressure layer is  $-0.11$ ,  $-0.25$ , and  $-0.44\%$ , respectively, and the maximum amount of irrigation calculated is 86, 191, and 331 mL/min. The time for the contribution rate to be zero is gradually extended. This shows that the greater the interlayer pressure difference



(a) Upper layer pressure 4.3MPa



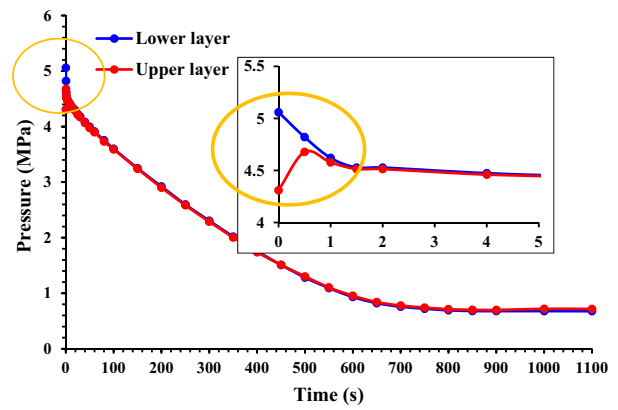
(b) Upper layer pressure 3.6MPa



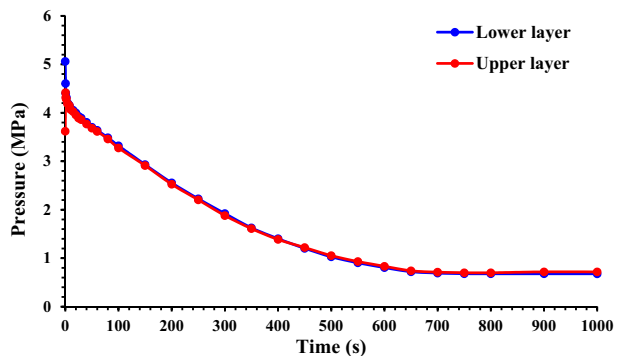
(c) Upper layer pressure 2.9 MPa

**Fig. 8** Variation diagram of layered yield contribution under different upper layer pressure. The circle indicates an enlarged display

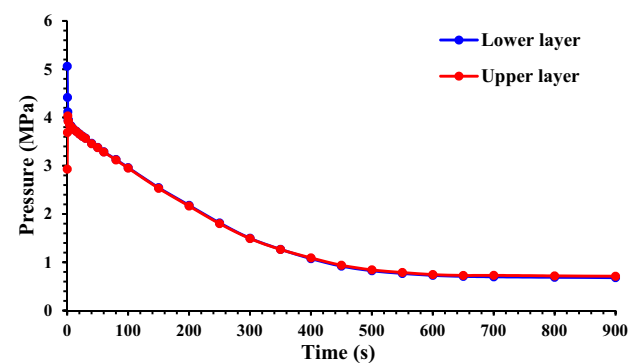
is, the more obvious the backflow phenomenon of the low-pressure layer in the early stage, the more obvious the difference of layered production contribution in the later stage, and the stronger the interlayer interference (Fig. 10).



(a) Upper layer pressure 4.3MPa



(b) Upper layer pressure 3.6 MPa



(c) Upper layer pressure 2.9 MPa

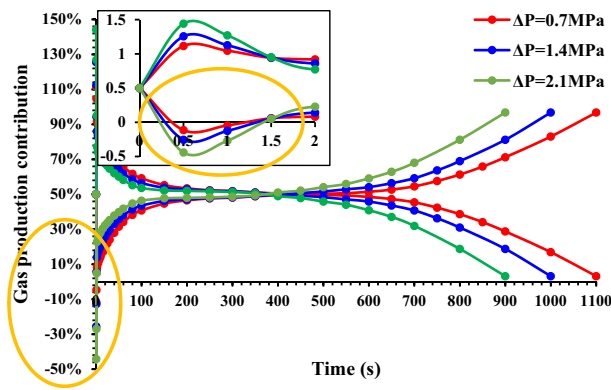
**Fig. 9** Variation diagram of the layered yield contribution under different upper layer pressure. The circle indicates an enlarged display

### Multilayer succession-commingled production under different pressure systems

Upper layer permeability 91 mD, lower layer permeability 420 mD

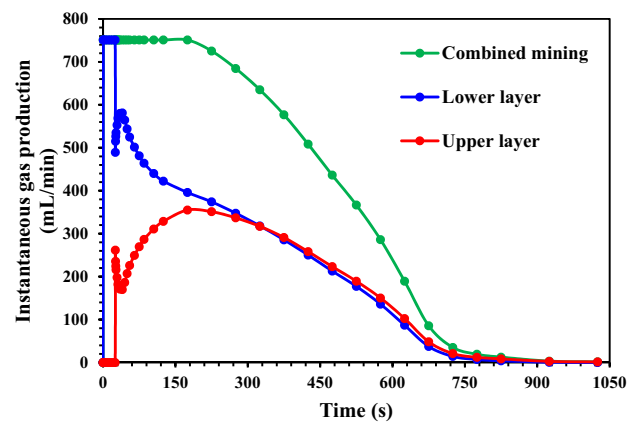
Fix the lower layer pressure at 5 MPa, and set the upper layer pressure to 4.3, 3.6 and 2.9 MPa. In the initial stage of the experiment, the high-permeability layer is produced individually, and the CBM production rate is maintained at 750 mL/



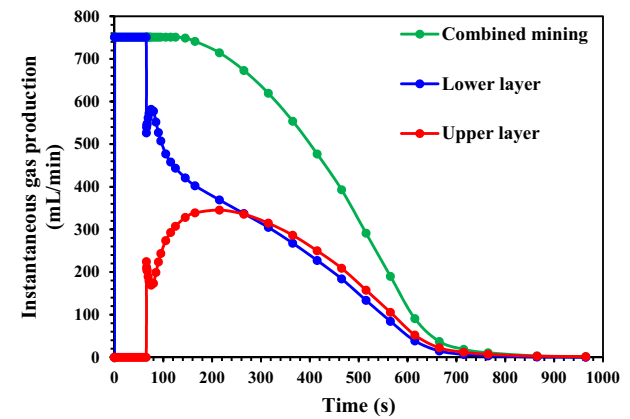


**Fig. 10** Variation diagram of the production contribution of multi-layer co-production under different pressure difference. The circle indicates an enlarged display

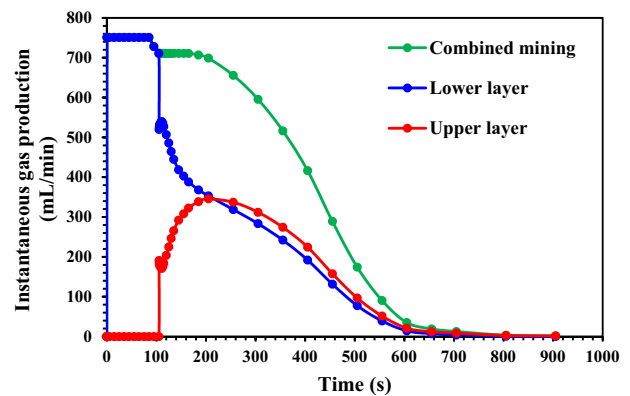
min. The low-permeability layer participates in production when its pressure is consistent with the high-permeability layer's. The early CBM production rate of the high-permeability layer is higher than that of the low-permeability layer, which is the main gas supply layer. The production of the low-permeability layer increases sharply due to the free gas production, resulting in an CBM production interference and the gas production rate of the high-permeability layer drops to 489, 526, and 520 mL/min, accordingly. Then, the gas production in the high-permeability layer rises gradually, while the high-permeability layer still inhibits the low-permeability layer, resulting in a downward trend in the CBM production of the low-permeability layer. Along with the CBM production of the high-permeability layer, the inhibition effect decreases. A large amount of adsorbed CBM in the low-permeability layer desorbes. The CBM production rate increases to maintain commingled production together with the high-permeability layer. When the commingled production system cannot maintain stable CBM production, the commingled production rate begins to decrease, and the CBM production rates of the two layers tend to be the same at 335, 285, and 225 s, respectively. Subsequently, due to the reduction of the remaining recoverable reserve in the high-permeability layer, the CBM produced from the low-permeability layer cannot be inhibited, which is becoming the main production layer, and surpasses that from the high-permeability layer in the later stage (Fig. 11). Figure 12 shows the variation of layered production contribution during the commingled production. It can be seen that when producing the high-permeability layer alone, its production contribution rate is 1. As the low-permeability layer is involved in the production, the initial free gas production leads to a short decline on the production contribution curve of the high-permeability layer, then an increase and a decline along with the production progress. After the low-permeability layer participates in the commingled production, the CBM



**(a)** Upper layer pressure 4.3MPa



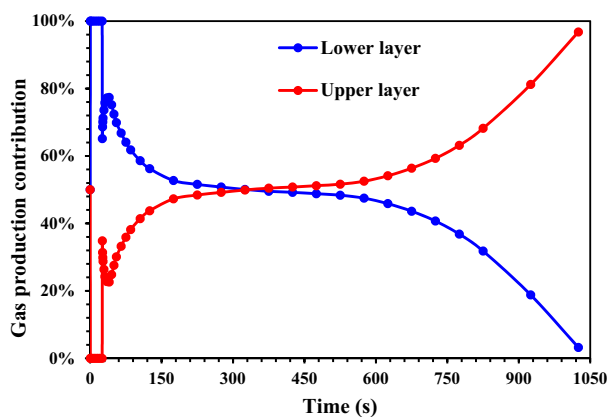
**(b)** Upper layer pressure 3.6MPa



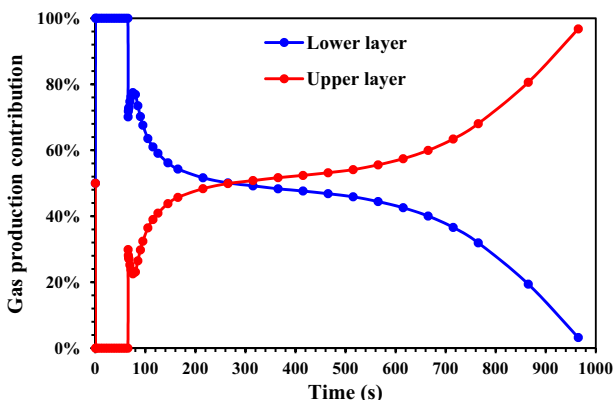
**(c)** Upper layer pressure 2.9MPa

**Fig. 11** Variation diagram of stratified instantaneous gas production under different upper layer pressure

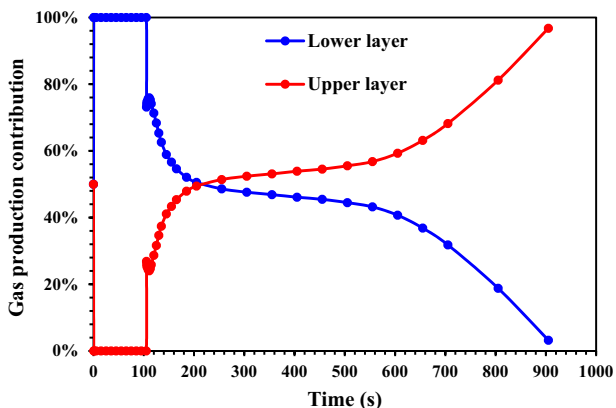
production contribution curve of the low-permeability layer first rises sharply, then decreases and then rises. At 335, 285, and 225 s, respectively, the gas production contribution curve of the low-permeability layer crosses with that of the high-permeability layer, and then it gradually exceeds the high-permeability layer.



(a) Upper layer pressure 4.3MPa



(b) Upper layer pressure 3.6MPa



(c) Upper layer pressure 2.9MPa

Fig. 12 Variation diagram of layered yield contribution under different upper layer pressure

**Contribution rate of gas production under different timing of succession production**

By comparing and analyzing the changes of the layered gas production contribution under different conditions of interlayer pressure differences, the greater the interlayer pressure difference, the greater the sudden drop in the contribution

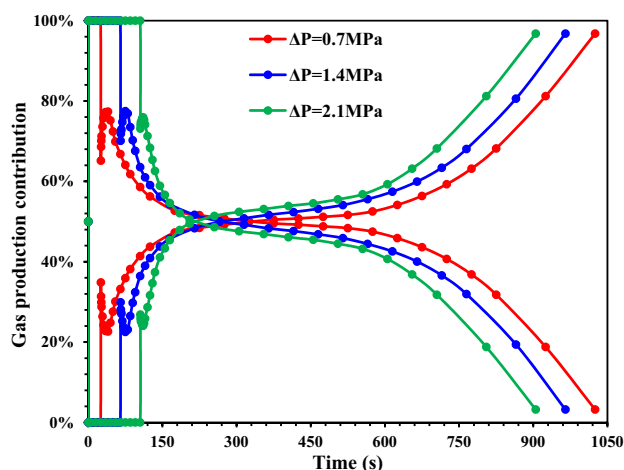
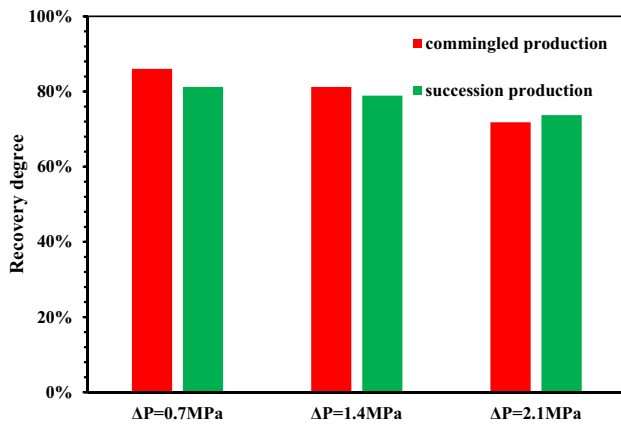


Fig. 13 Variation diagram of gas production contribution of succession co-production under different pressure difference conditions

rate of high-pressure layer. With the progress of the experiment, the faster the gas production contribution curve approaches, the earlier the cross point occurs, and the more obvious the difference in the later stratified production contribution rate is (Fig. 13).

**Evaluation of recovery degree**

Due to the obvious difference of gas contents and reservoir pressures in a multilayer stacked gas-bearing system, the interlayer interference occurs during commingled production, so as to inhibit the gas production of coal seams with low pressure. This phenomenon greatly limits the CBM development of multilayer stacked gas-bearing system. Therefore, in order to reduce interlayer interference, this paper conducted multilayer succession production experiments based on the multilayer-commingled production simulation under different pressure systems, and comprehensively evaluated the recovery efficiency under different interlayer pressure conditions (Fig. 14), so as to provide technical guidance for the CBM high-efficiency development. As the interlayer pressure difference increases, the difference between multilayer commingled production and succession production gradually gets larger. Co-production is better than the succession production when the interlayer pressure difference is less than 2.1 MPa, while the results are quite different when the interlayer pressure difference is greater than 2.1 MPa, that is, the succession production is better than the co-production. The results show that the succession production may reduce the interlayer interference caused by differential pressure. This also reflects that the initial pressure difference must be controlled within a certain range to reduce the interlayer interference in the actual production. However, for the multi-layered CBM reservoirs with large



**Fig. 14** Recovery degree of commingled production and succession production under different interlayer pressure differences

interlayer pressure differences, it is necessary to adopt the succession production policy (Tan et al. 2015).

## Summary and conclusions

- (1) Based on the self-developed multilayer-laminated CBM simulation system, this study performed a multi-layered CBM commingled production simulation experiment. Seven experiments were conducted under different permeability and pressure combinations, and the variation law of multilayer-commingled production capacity and the interlayer interference characteristics are clarified.
- (2) In the multilayer-commingled production, when the different coal seams are blended under the same pressure, the production contribution deviates from the KH splitting method, indicating an interlayer interference during the commingled production. The greater the interlayer pressure difference, the more obvious the backflow phenomenon from the high-pressure layer to the low-pressure layer in the initial stage, and the larger the production contribution of the high-pressure layer (> 1), the stronger the interlayer interference.
- (3) Succession production can significantly reduce the interlayer interference caused by the interlayer pressure difference of coal seams. The larger the interlayer pressure difference, the greater the sudden drop of the production contribution rate of the high-pressure layer when the low-pressure layer participates in commingled production. With the progress of the experiment, the faster the layered gas production contribution curve approaches, the earlier the intersection appears, and the more obvious the difference of the layered production contribution rate in the later stage.

- (4) With the increase of interlayer pressure difference, the recovery degree of multilayer commingled production and succession production gradually decreases. When the interlayer pressure difference is less than 2.1 MPa, the commingled production is better than the succession production. When the interlayer pressure difference is greater than 2.1 MPa, the commingled production is weaker than the succession production.
- (5) The research shows that in the actual CBM production, the multilayer commingled production strategy should be selected for multi-layered CBM reservoirs with small interlayer pressure differences. For these CBM reservoirs with large interlayer pressure differences, the succession production strategy can be selected to reduce the reservoir damage caused by pressure differences. Furthermore, specific technical limits of interlayer differential pressure can be evaluated by the numerical simulation or physical simulation according to the coalbed methane reservoir conditions.

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