Analysis of the Main Controlling Factors of the Development Effect of a Single Well for Coalbed Methane

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Abstract. To determine the main controlling factors of the coalbed methane (CBM) development effect, 64 production wells were selected from the Mabidong Block as the study objective. Three aspects of the main controlling factors that affect production were analyzed: the reservoir geological conditions, the engineering construction quality and the drainage and production system. In addition, two new parameters, i.e., the resource index and the desorption index, were defined to better evaluate the influence laws of geological conditions on production. This study indicates that the resource index, the desorption index and the master fracture density are well correlated to stable gas production. Furthermore, fracturing is an effective way to improve the CBM development effect, but it must be based on the presence of adequate resources. Finally, the drainage and production intensity is strongly correlated with production, and the optimum value of drainage and production intensity for the Mabidong Block is 6~7 m/d.

1. Introduction

The evaluation of the coalbed methane (CBM) development effect has always been a key difficulty [1,2], and determining the main controlling factors of the development effect is the basis for improving it.

Scholars in China and abroad have conducted fruitful research on the influence factor analysis of CBM well production, mainly from four aspects including the geological conditions, the well network deployment, the engineering technique, and the drainage and production system. Wan et al. (2005) [3] analyzed the main factors that influence the CBM production of a single well from the perspective of the CBM occurrence mode and production mechanism. Chen et al. (2009) [4] studied the geological characteristics, fracturing stimulation process, production status and drainage and production technique of CBM in the Fanzhuang Block in the southern Qinshui Basin. By analyzing the production performance data of CBM wells of the Jincheng and Hancheng Mines, Wang et al. (2013) [5] studied the main factors that affect the development effect. Zhang et al. (2015) [6] analyzed the well types, coalbed thickness, hydrogeological conditions and engineering factors of the Liulin Block. Jiang et al.
(2016) [7] proposed that the excessive water production of some CBM wells in the Shizhuang Block constrains the gas production effect and is mainly caused by an allogetic water supply. Fault structures easily connect the aquifers of the hanging walls and footwalls of coalbeds, leading to high water production and low gas production or no gas in CBM wells. By considering that the qualitative analysis of geological factors is mainly used to determine the influence factors of CBM production, Ren et al. (2016) [8] proposed the idea of studying the influence of engineering parameters on production from an engineering perspective. Tang et al. (2017) [9] analyzed the main factors controlling production based on the geological, drainage and production data of 26 CBM gas wells of the Zhengcun Well Block over a period of five years. According to the data of 83 drainage and production wells of three CBM blocks along the eastern edge of the Ordos Basin, Zhao et al. (2007) [10] systematically analyzed the influences of the geological conditions, the engineering technique and the drainage and production system on CBM well production. Based on the actual drainage and production laws of existing vertical wells in a CBM surface development of the Fanzhuang Block in the southern Qinshui Basin, Lu et al. (2017) [11] analyzed the factors that control the low production and high production of CBM single wells from the perspectives of the geology, reservoir characteristics and engineering factors of the No. 3 Coal Bed. Taking the North Shizhuang Block as the target, Lu et al. (2018) [12] studied the deep CBM characteristics, drainage and production variation laws, and production dynamics of typical wells at variable production rates by comprehensively analyzing production data and proposed key factors that affect deep CBM production.

Based on these previous studies, the main controlling factors of the CBM development effect in 64 gas wells in the Mabidong Block were analyzed from the perspectives of the reservoir geological conditions, the engineering construction quality and the drainage and production system. This analysis lays a foundation for evaluating the CBM development effect and formulating production improvement measures.

2. Main controlling factors of the single-well development effect
The CBM single-well development effect is affected by many factors, which are generally classified into three aspects: the reservoir geological conditions, the engineering construction quality and the drainage and production system. Among these factors, the reservoir geological conditions are fundamental and determine the material basis and development difficulty of gas wells. Fracturing construction is a significant measure for improving the reservoir flowing space and is a key step for production and efficiency improvement. The selection of a reasonable drainage and production strategy and a production system after operation is a significant guarantee for improving the CBM single-well development effect.

The geological factors of a reservoir can be grouped into four categories: the resource basis, the desorption capacity, the flow capacity and the fracturing basis. According to previous research, the resource basis is characterized by the resource index, and the desorption capacity is characterized by the desorption index. Flow capacity factors mainly include the master fracture density, the average pore throat diameter, the movable water saturation and the coal body structure. The influence of natural fractures is the most important, and thus, the master fracture density was selected to characterize the flow capacity. The fracturing basis (i.e., the bursting pressure and the brittleness index) has been reflected in engineering construction parameters for developed blocks, and thus, the fracturing basis is not listed separately.

In terms of the engineering construction quality, the perforation thickness, sand fracturing and the fracturing fluid, factors which are widely collected and easily obtained during fracturing operation, are selected to characterize the engineering factors that impact the well development effect.

In terms of the drainage and production system, the drainage intensity (the working liquid level drawdown) is selected to characterize the drainage and production factors that influence the gas well development effect.
2.1. Influence of the geological factors of a reservoir on the single-well development effect

The CBM content is the basis of development. The coalbed thickness multiplied by the gas content is determined as a resource index to reflect the resource basis of CBM development. In addition, the desorption effect is a key factor that affects the CBM development effect. Gas saturation or the critical desorption pressure/reservoir pressure is usually employed to reflect the desorption characteristics of CBM; these parameters can only reflect the time during which CBM is encountered and cannot reflect the amount of CBM that is desorbed. The critical desorption pressure/reservoir pressure multiplied by the desorption ratio is defined as a desorption index to comprehensively reflect the time during which CBM is encountered and the amount of CBM desorption when CBM is encountered.

For the 64 production wells in the Mabidong Block, the influence of three parameters on gas production was analyzed: the resource index, which characterizes the material basis, the desorption index, which characterizes the desorption capacity, and the master fracture density, which characterizes the flow capacity. The statistical analysis indicates that stable gas production has a positive linear correlation with the resource index (figure 1), the desorption index D (figure 2) and the master fracture density (figure 3). Therefore, from a geological perspective, the resource index, desorption index and master fracture density are main controlling factors of the development effect, and they are well correlated to stable production.

![Figure 1](image1.png)  ![Figure 2](image2.png)  ![Figure 3](image3.png)

**Figure 1.** Correlation between the resource index and stable production. **Figure 2.** Correlation between the desorption index and stable production. **Figure 3.** Correlation between the master fracture density and stable production.

2.2. Influence of fracturing operation on the single-well development effect

The statistical results of the fracturing liquid, fracturing sand and perforation thickness of the 64 wells in Mabidong are listed in figures 4, 5 and 6.
The statistical results show that stable production has a positive linear correlation with fracturing liquid, fracturing sand and perforation thickness, but at a low degree. To identify the influence factors, the fracturing construction parameters and geological parameters of the gas wells were compared and analyzed, and the comparison results are shown in figures 7, 8 and 9. For the Mabidong Block, the resource index, desorption index and master fracture density of gas wells have a highly negative linear correlation with fracturing sand; in other words, for gas wells with high fracturing sand, although the degree of fracturing operation is enhanced, the geological conditions of the gas wells and the resource basis are poor, and the coalbed desorption capacity and the development of master fractures are low, resulting in an offset of the effect of improving the fracturing operation intensity to improve gas production.
Thus, the geological conditions are fundamental factors that influence the gas well development effect. Optimizing the well layout in high-quality resource areas is essential for improving the CBM well development effect through the enhancement of fracturing operations.

2.3. Influence of the drainage and production system on the single-well development effect

To study the influence of the drainage and production system on the gas well development effect, the drainage intensity (the working liquid level drawdown) of 64 gas wells at different stages was analyzed, and the results are shown in figures 10 and 11. The gas encountering time and the drainage and production intensity before gas was encountered in the CBM wells are negatively correlated in the form of a power function. The total time between the time at which the CBM well was put into production and the time of peak production and the drainage and production intensity before peak production are negatively correlated in the form of a power function.

Accordingly, improving the CBM well drainage intensity can greatly shorten the time during which gas is encountered in gas wells and the duration to peak production.

To study the influence of the drainage intensity on gas production, 64 wells were selected for regression analysis of the average drainage intensity before peak production and stable daily gas production. The results are shown in figure 12. The two parameters are not monotonically correlated. When the drainage intensity was low, the drainage intensity was high, and the stable production of the gas well was high; however, when the drainage intensity exceeded a certain value, stable production decreased, and the drainage intensity increased.
Figure 12. Correlation between the average drainage intensity before peak production and stable production.

Furthermore, stable gas production was offset using the resource index to eliminate the disturbance of different geological conditions of different gas wells in the analysis. The statistical results are listed in figure 13. The aforementioned laws are still valid.

Figure 13. Correlation between the average drainage intensity before peak production and stable production under the resource index per unit.

Thus, drainage intensity of the Mabidong Block has an optimum value: when the drainage and production intensity varied from 6 m/d to 7 m/d, the stable daily production reached the maximum, the gas encountering time was ~120 d and the total time to peak production was ~150 d.

3. Conclusions
Two new parameters, i.e., the resource index and the desorption index, are identified. The resource index, desorption index and master fracture density are well correlated to stable production, which is a main factor impacting production in terms of geology.

Fracturing operation is an effective measure for production improvement, but favorable areas for resources must be optimized, i.e., the resources are the basis.

The drainage intensity great influences production and is correlated with production in a power function. In addition, the drainage intensity of the Mabidong Block has an optimum value of 6~7 m/d.

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