CBM Desorption Model and Stages Based on a Natural Desorption Experiment

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Abstract: Coalbed methane (CBM) desorption modeling is critical for understanding CBM desorption mechanisms and objectively analyzing the production characteristics of CBM wells. According to the CBM natural desorption experimental data of 64 coal samples taken from the Qinshui Basin, we established a CBM desorption model, quantitatively identified the CBM desorption stages, and discussed the relationship between CBM desorption characteristics and well productivity. The results indicated a very significant functional relationship between the CBM natural desorption time and cumulative desorption quantity, which could be accurately described by the model \( V = a L_t / (t + b) \). On the basis of this model and the numerical description of the desorption data, the CBM natural desorption process was divided into four stages: the desorption startup stage, desorption sensitive stage, desorption steady stage, and desorption decay stage. As indicated by analogical reasoning of the CBM well production process, the desorption startup stage corresponded to the drainage-based pressure drop stage, the desorption sensitive and steady stages corresponded to the steady production stage, and the desorption decay stage corresponded to the production declining stage. The CBM adsorption time exponentially decreased with the increase in the average CBM desorption rate and with the increase in the CBM gas content and vitrinite/inertinite ratio. Furthermore, within a certain range of desorption pressure, a high ratio between the adsorption time and gas content corresponded to the extension of the steady production stage of CBM wells, whereas higher or lower ratios were adverse to steady production.

1. INTRODUCTION

Coalbed methane (CBM), an important, nontraditional, clean energy resource, exists in coal seams in a free, adsorbed, solid-solution and dissolved state and mainly exists in an adsorbed state in coal matrices.\(^1\)\(^-\)\(^3\) In CBM recovery or gas drainage prior to coal mining, gas desorbs from the wall of the pores in the coal matrix and diffuses through the pore system to the cleat due to the difference of gas concentration, then flows to the production well or drainage borehole through the cleat system due to a pressure difference.\(^4\)\(^-\)\(^8\) Hence, the desorption characteristics of coal are key factors to CBM extraction.\(^9\)\(^-\)\(^10\)

Desorption refers to the process by which movable gas molecules in organic matter (OM) are removed from the OM’s inner surface and transformed into the free phase as a result of changes in the temperature, pressure, and other physical conditions of the molecules, which increase the energy of thermal motion and overcome the gravitational field.\(^10\)\(^-\)\(^11\) This process can be quantitatively characterized by physical experiments and molecular simulation.\(^11\) The 3-fold fracture and pore construction of coal seams determines the characteristics of the CBM desorption stages. Since the characteristics of coalbed methane desorption have direct effect on the production per well, and thus the industrialization of coalbed methane, its research has always been a hot spot.\(^12\)\(^-\)\(^13\) Many scholars have put forward many formulas to describe the law of coalbed methane desorption, but they are empirical or semi-empirical formulas based on different assumptions, which have certain limitations in revealing the characteristics of coalbed methane desorption.\(^14\)\(^-\)\(^18\) For specific coal mines, even for different coal seams of a single coal mine, the CBM desorption laws of coal seams are different, so a large number of simulation experiments need to be carried out in the laboratory to find the CBM desorption laws suitable for specific coal seams, especially since no reports describing CBM desorption models or stages based on desorption experiments exist. In order to better predict the productivity characteristics of coalbed methane wells, many scholars have divided the desorption stage based on the isothermal adsorption curve. For example, some scholars have

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divided the desorption stage into four stages by using three key pressure points, including start-up pressure, transition pressure, and sensitive pressure. Based on the isothermal adsorption curve and the actual gas production, the desorption stage and the drainage and production stage were divided, but few scholars divide the natural desorption stages of coalbed methane, and have not clarified the relationship between the desorption stage of coalbed methane and production capacity. Based on this, the purpose of the present work was to study the characteristics of CBM natural desorption through experimental and numerical investigations in order to forecast phases of drainage and extraction of CBM and hence provide a basis for diagnosing production states of CBM wells. The study was conducted using 64 anthracite coal samples from six CBM wells in the south of the Qinshui Basin, China. A mathematical model of CBM natural desorption was established, and with the mathematical manipulation of the desorption data, the natural desorption stages of CBM were quantitatively identified. Furthermore, the research investigated the relationship between the CBM desorption stages and CBM well productivity, as well as the characteristics and geological controls of CBM desorption.

Table 1. Data from Basic Analyses of Representative Coal Samples

| Sample no. | Coal seam no. | \( R_{o,max} \) (%) | Gas content | Lost gas | Natural desorbed gas | Residual gas | Adsorption time (d) | Coal macerals (mmf, %) | Proximate analysis (%) |
|------------|---------------|----------------------|-------------|----------|----------------------|--------------|---------------------|------------------------|------------------------|
|            |               |                      |             |          |                      |              |                     | Vitrinite               | Inertinite             |
|            |               |                      |             |          |                      |              |                     | \( M_{ad} \)             | \( A_d \)              | \( V_{daf} \)          |
| Pan-1-RS01 | 3             | 3.67                 | 17.72       | 0.29     | 17.22                | 0.14         | 19.70               | 45.9                   | 54.1                   | 6.19                  |
|            | 15            | 3.97                 | 22.66       | 0.46     | 22.17                | 0.03         | 4.30                | 66.9                   | 33.1                   | 0.85                  | 13.11                 | 6.58                  |
| Pan-2-RS02 | 3             | 4.00                 | 16.79       | 0.19     | 16.43                | 0.16         | 20.31               | 77.1                   | 22.9                   | 2.70                  | 8.55                  | 5.63                  |
|            | 15            | 4.02                 | 20.75       | 0.97     | 19.78                | 0.00         | 2.36                | 90.2                   | 9.8                    | 2.84                  | 22.10                 | 6.72                  |
| Pan-3-RS03 | 3             | 4.30                 | 18.50       | 0.66     | 17.82                | 0.01         | 10.03               | 84.5                   | 15.5                   | 2.55                  | 9.69                  | 6.77                  |
|            | 15            | 4.25                 | 30.44       | 1.49     | 28.92                | 0.03         | 3.79                | 91.4                   | 8.6                    | 2.26                  | 8.04                  | 5.97                  |
| Pan-4-RS04 | 3             | 4.36                 | 20.04       | 0.43     | 19.60                | 0.01         | 8.50                | 86.9                   | 13.1                   | 3.06                  | 4.18                  | 4.67                  |
|            | 15            | 4.21                 | 17.79       | 0.65     | 17.32                | 0.01         | 2.71                | 82.6                   | 17.4                   | 1.76                  | 24.58                 | 8.84                  |
| Pan-5-RS05 | 3             | 4.23                 | 20.30       | 0.50     | 19.78                | 0.01         | 9.79                | 80.2                   | 19.8                   | 2.16                  | 10.45                 | 6.38                  |
|            | 15            | 4.17                 | 20.67       | 1.19     | 19.46                | 0.02         | 2.16                | 86.3                   | 13.7                   | 1.59                  | 26.24                 | 9.08                  |
| Pan-6-RS06 | 3             | 4.10                 | 24.30       | 0.37     | 23.90                | 0.03         | 8.50                | 77.6                   | 22.4                   | 1.48                  | 7.96                  | 5.73                  |
|            | 15            | 4.09                 | 31.23       | 1.75     | 29.47                | 0.01         | 2.17                | 87.2                   | 12.8                   | 1.63                  | 5.25                  | 4.98                  |

Note: \( R_{o,max} \) = immersed maximum reflectance of vitrinite; \( M_{ad} \) = moisture content (air-dried basis); \( A_d \) = ash yield (dry basis); \( V_{daf} \) = volatile yield (dry ash-free basis); \( ad \) = air-dried basis; mmf = mineral-matter-free basis. RS = randomly selected: samples used here were randomly selected from each of the six CBM wells in the study area.
2. SAMPLES AND EXPERIMENTS

The study area, the Panzhuang Block, located in the south of the Qinshui Basin, China (Figure 1), is the first large-scale commercial block of surface CBM development; it has a relatively long developmental history and rich exploration and developmental data. As a result, many desorption tests and associated well production histories can be assembled to evaluate the usefulness of such data to investigate the relationship between CBM desorption characteristics and well productivity. Sixty-four samples from six different CBM wells were selected from a larger database for desorption tests from the depth of 244.68 to 775.15 m in Permian in coal seam No. 3 of the Shanxi Formation and coal seam No. 15 of the Taiyuan Formation in the Panzhuang Block.

Desorption testing procedures used in this study were set forth by Diamond and Levine following the work by Kissell et al. and others at the U.S. Bureau of Mines. The natural desorption experiment (excluding thermal desorption and crushed desorption), for the purposes of this paper, was conducted by the China Coal Technology & Engineering Group Corp Xi’an Research Institute (CCTEG) following the procedure in accordance with ASTM standard.

Table 2. Parametric Statistics of CBM Desorption Characteristics

| Bore no. | Coal seam no. | Gas content (cm$^3$/g) | Average desorption rate (cm$^3$/g·d) | Adsorption time (d) | Bore no. | Coal seam no. | Gas content (cm$^3$/g) | Average desorption rate (cm$^3$/g·d) | Adsorption time (d) |
|----------|---------------|-------------------------|--------------------------------------|---------------------|----------|---------------|-------------------------|--------------------------------------|---------------------|
| Pan1     | 3             | 16.98(6)                | 0.169(7)                             | 12.96(7)            | Pan4     | 3             | 17.58(6)                | 0.180(5)                             | 9.24(5)              |
|          | 15            | 22.18(5)                | 0.236(4)                             | 5.81(4)             |          | 15            | 17.59(2)                | 0.249(1)                             | 2.71(1)              |
| Pan2     | 3             | 18.83(7)                | 0.212(6)                             | 10.46(6)            | Pan5     | 3             | 19.62(7)                | 0.147(7)                             | 10.15(7)             |
|          | 15            | 21.15(3)                | 0.302(2)                             | 1.92(2)             |          | 15            | 24.17(4)                | 0.375(3)                             | 2.76(3)              |
| Pan3     | 3             | 18.87(7)                | 0.180(6)                             | 7.32(6)             | Pan6     | 3             | 23.92(7)                | 0.268(6)                             | 5.45(6)              |
|          | 15            | 28.27(4)                | 0.389(3)                             | 3.24(3)             |          | 15            | 28.45(4)                | 0.454(3)                             | 2.08(3)              |
| Sum      | 3             | 19.30(43)               | 0.187(36)                            | 9.37(36)            | Sum      | 3, 5         | 21.46(64)               | 0.240(52)                            | 7.52(52)             |
|          | 15            | 23.62(21)               | 0.359(16)                            | 3.38(16)            |          |               |                         |                         |                     |

Figure 2. Different examples of the canister desorption tests curves: (a) Pan-1-RS01, (b) Pan-2-RS02, (c) Pan-3-RS03, (d) Pan-4-RS04, (e) Pan-5-RS05, (f) Pan-6-RS06.
of readings over a period of weeks or months, until little or no more gas was produced. Because the measurement needed to be corrected to standard temperature and pressure conditions (STP), the ambient barometric pressure and temperature were recorded at the time of each reading. There were several significant variables that are not commonly controllable, such as the heterogeneous nature of coal, sample particle size, and temperature, which may have affected the desorption rate or even the final test results during the desorption testing procedure. Despite the aforementioned problems, the desorption trend and its relationship with early gas production was preserved. The coal samples were also subject to isothermal adsorption, proximate analysis, maceral quantification, and other analyses; Table 1 shows the results for several representative samples.

The coal samples mainly consisted of semibright coal and semidull coal, followed by bright coal and dull coal. The maximum reflectivity of vitrinite, \( R_{o,max} \), was 3.67% ∼ 4.36%, which is typical of anthracite coal. The maceral composition was mainly composed of vitrinite with a concentration between 45.9% and 93.8% (80.13 ± 5.27% on average), followed by inertinite; no exinite was found. Coal seam No. 3, rated as low ash-medium ash and low sulfur coal, had a relatively low ash yield and total sulfur content; coal seam No. 15, rated as medium-high sulfur coal, had a relatively high ash yield and total sulfur content.

The desorption results show (Table 2) that the coal seam in the Panzhuang Block was characterized by a high gas content (air-dried basis) and a greatly varied adsorption time (herein defined as the time required for desorbing 63.2% of the total volume of the natural desorbed gas). The average gas content of the 64 coal samples was 21.46 cm\(^3\)/g, and the average adsorption time was 7.52 d. The gas content of coal seam No. 3 ranged from 16.98 to 23.92 cm\(^3\)/g (19.30 cm\(^3\)/g on average), and the gas content of coal seam No. 15 ranged from 17.59 to 28.45 cm\(^3\)/g (21.45 cm\(^3\)/g on average). In general, the gas-bearing property of coal seam No. 15 was stronger than that of coal seam No. 3, and the average desorption rate (the ratio between the cumulative desorption quantity and the product of the coal sample mass and the cumulative natural desorption time) of coal seam No. 15 was also higher than that of coal seam No. 3. The adsorption time of coal seam No. 3 ranged from 5.45 to 12.96d (9.26d on average) and that of coal seam No. 15 ranged from 1.92 to 5.18d (2.98 d on average); the latter was significantly shorter than the former.

### 3. CBM Desorption Modeling

#### 3.1. CBM Desorption Model

In general, coal samples can be fully desorbed in a desorption canister, and the desorption...
can generally last for dozens of days to several months.\textsuperscript{28} In the present analysis, the characteristics of the natural desorption curves of the coal samples were generally similar (Figure 2) and showed a significant functional relationship. The natural desorption curves of the coal samples were fitted, and the desorption law curve could be precisely described by \textbf{Equation 1} (Table 3).

\[ V = \frac{a_t^t}{t + b_t} \]  
(1)

The parameter \( V \) (\( \text{cm}^3/\text{g} \)) is the desorption quantity at \( t \), \( t \) (d) is the natural desorption time, \( a_t \) (\( \text{cm}^3/\text{g} \)) is defined as the natural desorption quantity constant (NDQC), and \( b_t \) (d) is defined as the natural adsorption time constant (NDQT). The physical significance of \( a_t \) and \( b_t \) are discussed below.

\textbf{3.2. CBM Desorption Stages and Desorption Time.} The CBM desorption stages were quantitatively divided on the basis of the curvature of the CBM desorption curves. The curvature quantitatively represents the bending of the curves (e.g., when the curvature is greater, the curve bending is higher). With the differential desorption model (eq 1), we developed an equation to describe the curvature \( K_V \).

\[ K_V = \frac{b_t}{(1 + y^2)^{3/2}} = \frac{|\eta|}{(1 + y^2)^{3/2}} \]  
(2)

The parameter \( \eta \) is the desorption rate, which is an important parameter for describing the CBM desorption characteristics and is defined as the desorption quantity per unit time. It can be expressed as the first derivative of the desorption curve.

\[ \eta = \frac{\Delta V}{\Delta t} = \frac{dV}{dt} = \frac{a_t b_t}{(t + b_t)^2} \]  
(3)

Thus, (Figure 3a):

\[ K_V = \frac{2a_t b_t}{(t + b_t)^2} \left\{ 1 + \left[ \frac{a_t b_t}{(t + b_t)^2} \right]^2 \right\}^{3/2} \]  
(4)

The natural desorption curvature curve has two inflection points (Points B and C in Figure 3b). If the second derivative of the natural desorption curvature is 0, then

\[
K_V' = 12a_t b_t (t + b_t)^{-13} \times \left[ 1 + \left( \frac{a_t b_t}{(t + b_t)^2} \right)^2 \right]^{3/2} \times [(a_t b_t)^3 - 7(a_t b_t)^2 (t + b_t)^4 + 2(t + b_t)^8] = 0
\]

(5)

In this case, the corresponding desorption time is shown as follows (Figure 3c):

\[ t_{de} = \frac{7 - \sqrt{41}}{4} \times (a_t b_t)^{1/2} - b_t, \quad t_{de} = \frac{7 + \sqrt{41}}{4} \times (a_t b_t)^{1/2} - b_t \]

(6)

where

\[
K_V' = 6a_t b_t (t + b_t)^{-8} \times \left[ 1 + \left( \frac{a_t b_t}{(t + b_t)^2} \right)^2 \right]^{3/2} \times [(a_t b_t)^3 - (t + b_t)^4] \]

(7)

\textbf{4. RESULTS AND DISCUSSION}

\textbf{4.1. CBM Desorption Constant.} Previous studies on coalbed methane adsorption have dominantly adopted the Langmuir isothermal adsorption theory (i.e., the present monolayer dynamic adsorption theory),\textsuperscript{30} whereas only a few theories on CBM desorption processes have been analyzed. It has generally been acknowledged that these processes are theoretically reversible.\textsuperscript{31,32} The present study is the first to establish a CBM desorption model based on coal samples from a natural desorption experiment (eq 1).\textsuperscript{33,34} Further research will be conducted to investigate the relationships of NDQC \( a_t \) and NDQT \( b_t \) with the natural desorption quantity and adsorption time to better illustrate the physical significance of these constants. The results (Figure 4) show that \( a_t \) and \( b_t \) are positively correlated with the natural desorption quantity and adsorption time (i.e., the longer is the adsorption time of a sample, the greater is the value of \( b_t \)), indicating that \( b_t \) can precisely represent the difficulty level of CBM desorption. The constant \( b_t \) represents the time when the actual desorption quantity reaches up to 50% of the limit desorption quantity. When the desorption quantity is higher, the value of \( a_t \) is greater,
and the fitted slope between them is close to 1 (i.e., the natural desorption quantity is approximately equal to \( a_L \)). Namely, when a coal sample is totally desorbed, the value of \( a_L \) is equal to the natural desorption quantity, indicating that \( a_L \) can reflect the maximum desorption capacity of a coal seam. The constant \( a_L \) represents the limit of the desorption quantity of the coal seam (\( t \to \infty \)), and it is determined by the properties of the coal-rock mass but is independent of temperature and pressure.

4.2. Division of CBM Desorption Stages. The CBM natural desorption curve has three crucial turning points (Points A, B, and C in Figure 3). These points are respectively defined as the sensitive desorption time \( (t_s) \), the steady desorption time \( (t_d) \), and the desorption decay time \( (t_a) \). The CBM natural desorption process is divided by these three time points into the desorption startup stage, desorption sensitive stage, desorption steady stage, and desorption decay stage (Figure 3a and Figure 5). The characteristics of each stage are described as follows.

(I) Desorption startup stage. At the start of the desorption process, the curvature of the desorption curve and its value slightly increase. However, the incremental desorption quantity gradually increases with the emergence of the first peak. A great quantity of gas in large and medium pores is believed to be desorbed, causing a great increase in the amount of gas. The CBM cumulative desorption rate is small, generally less than 10%.

(II) Desorption sensitive stage. The desorption curve begins to slowly increase, causing the slope of the curve to continually increase until it finally reaches the extreme positive point of the curve. A great amount of gas in micropores begins to be desorbed, and the CBM cumulative desorption rate and the periodic CBM production rapidly increase.

(III) Desorption steady stage. The desorption curve changes from rapidly increasing to rapidly decreasing, and the slope of the curve changes from positive to negative accordingly until it finally reaches the extreme negative point. The gas in the micropores is continually desorbed, the CBM cumulative desorption rate steadily increases, and the desorption quantity gradually stabilizes.

(IV) Desorption decay stage. The desorption curve slowly decreases, and the slope gradually approaches zero from the negative extreme point accordingly. The CBM cumulative desorption rate slowly increases, and the desorption quantity gradually declines.

Theoretically, the natural desorption process of any coal sample should undergo the above four stages. However, due to the differences in the adsorption capacity, coal reservoir pressure, gas saturation, coring time, etc. of a coal sample, the natural desorption process of some samples may fail to completely experience all four stages in the actual desorption process. Moreover, some samples may directly enter the desorption sensitive or steady stages, resulting in a great deviation of the calculated gas content from the actual gas content of the coal sample. This is because some CBM reserves may have undergone several desorption stages over the course of geological history, which is one reason for the larger differences between the measured gas content of low-rank coal and the actual gas content.

4.3. Analogy Analysis of CBM Desorption Stages and Production Process. The coal desorption experiment was conducted under atmospheric pressure without an environmental pressure drop, which is in contrast to the drainage-based pressure drop in CBM production wells. Nevertheless, the CBM desorption characteristics are still significant for identifying the CBM production process. The natural desorption of CBM is a phased process, which is a temporal reflection of the distribution and connectivity of the rock pores, fractures, and other features of coal. The analysis of the periodic desorption curve (Figure 5) of the coal samples showed that the curve has two "peaks". The analysis of the vertical well production trend and fracturing effects revealed that the CBM well production curve also has two "humps", and we believe that the CBM well drainage-based production process can be divided into three stages: the drainage-based pressure drop, steady production, and production decline.

The similarity between the natural CBM desorption and CBM drainage-based production indicates that they have a strong relationship. We reason that (1) the desorption startup stage corresponds to the drainage-based pressure drop: only a small amount of gas is desorbed in the beginning, the ratio of the desorption quantity to the gas content is very low (generally less than 10%), and the contribution to the CBM well productivity is slight; (2) the desorption sensitive and steady stages correspond to steady production: the gas is rapidly desorbed, the desorption quantity gradually stabilizes along with the desorption progress, the production reaches a peak, the ratio of the desorption quantity to the gas content is very high (generally between 60% and 70%), and the contribution to the CBM well productivity is the highest; (3) the desorption decay stage corresponds to a
Decline in production: most of the gas has already been produced along with the desorption progress, the desorption quantity decreases, and the production of the CBM gas also gradually decreases.

The duration of each stage varies depending on the geological conditions, physical properties, abundance, and drainage-based production system of the coal seam.

4.4. Possible Impact of CBM Gas Content and Adsorption Time on CBM Production. The gas content and absorption time are key factors impacting the CBM recovery efficiency and drainage effect. The gas content is an important parameter for characterizing the CBM development potential. A high gas content corresponds to a high CBM yield, whereas a lower gas content cannot reach the industrial production capacity. The adsorption time is a quantitative indicator of the estimated gas diffusion rate, as well as an important parameter for measuring the CBM desorption speed and predicting the initial CBM production. According to a study on the desorption characteristics of the Black Warrior Basin in the United States, the desorption quantity of coal rock was linearly correlated with the cumulative gas production of a single well, with a correlation coefficient of greater than 80%. Moreover, the sensitivity simulation of the CBM wells in the Black Water Basin indicated that the gas production curves corresponding to three simulated desorption times were significantly different. Specifically, the times at which the gas production peaks occurred were different, as was the gas production corresponding to the peaks.

In this study, we found that adsorption time is well correlated with gas content and coal rock maceral (Figure 6c,d). When the gas content of a coal sample is higher, the vitrinite/inertinite ratio is higher and the adsorption time is shorter. A higher gas content can cause the coal matrix block to maintain a high concentration gradient, whereas the concentration gradient is the driving force of the CBM diffusion in the coal matrix block, and thus a higher gas content can improve the average CBM desorption rate (Figure 6b). The adsorption time has an exponential relationship (Figure 6a) with the average desorption rate. The adsorption time exponentially decreases when the average desorption rate increases, indicating that a high desorption rate can shorten the adsorption time. Coal rock maceral can affect the CBM gas content through its porosity and adsorption capacity difference. The adsorption capacity of vitrinite-rich coal of the same rank is much higher than that of inertinite-rich coal. Previous studies have shown that vitrinite treated by humic gel dehydration and asphaltization developed with metamorphic pores, making the development of micro-pores and specific surface areas higher than and the adsorption capacity stronger than that in inertinite. The improvement of the adsorption capacity could lead to an increase in the gas content of coal seams (Figure 6d) and thereby affect the adsorption time.

On the basis of the above analysis, the desorption sensitive and steady stages have significant impacts on CBM well productivity; a steady desorption time and desorption decay time are the key parameters controlling these two stages. The
results show that steady desorption and desorption decay times do not exhibit simple linear relationships with the adsorption time/gas content ratio (Figure 7). Within a certain range, the steady desorption and desorption decay times will increase with the increase in the adsorption time/gas content ratio, but this trend reverses after reaching a peak. Moreover, the changes in the steady desorption and desorption decay times are not synchronized, indicating that a too high or low adsorption time/gas content ratio is adverse to the steady production of CBM wells.

5. CONCLUSIONS

(1) We established a CBM desorption model, \( V = a_L t / (t + b_L) \), and discussed the physical significance of the relevant parameters.

(2) We established a model and method based on CBM natural desorption curves to identify the division parameters \( t_{st}, t_{de} \) of the CBM desorption stages and divide the desorption process into the desorption startup stage, desorption sensitive stage, desorption steady stage, and desorption decay stage.

(3) The CBM natural desorption stage corresponded to the CBM drainage-based production stage. We hypothesized that the desorption startup stage corresponds to the drainage-based pressure drop stage, the desorption sensitive and steady stages correspond to the steady production stage, and the desorption decay stage corresponds to the production decline stage.

(4) The CBM adsorption time decreased with the increase in the average CBM desorption rate; the gas content and coal rock maceral could affect the adsorption time by impacting the average desorption rate, and the adsorption time decreased with the increase in the gas content and vitrinite/inertinite ratio.

(5) The CBM desorption quantity and adsorption time influenced the CBM well production. Within a certain range, the duration of the steady production stage increased with the increase in the adsorption time/gas content ratio, but a higher or lower value of the ratio was adverse to steady production.

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