Key Technology of Efficient Exploitation of Coalbed Methane in Qinshui Basin of CNOOC

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Abstract

Three key technologies have been developed for the development of coalbed methane in Qinshui Basin. The first technology is the gas content analysis technology coupled with isothermal adsorption theory and production dynamics. By fitting bottom-hole flow pressure and critical desorption pressure of coal reservoir, combined with the isothermal adsorption curve of coal reservoir, the gas content of the reservoir can be accurately predicted. This technique provides important geological parameters for evaluating coal reservoirs. The second technology is production system optimization technology based on reservoir seepage mechanism and numerical simulation analysis. Velocity sensitive response, stress sensitive effect and gas-water two-phase flow are considered in the process of production system optimization. By understanding the main contradictions in different production and discharge stages of coalbed methane wells and taking the final cumulative gas production and peak gas production as optimization objectives, the quantitative optimization method of coalbed methane drainage and production system is formed. One optimization system for each coalbed methane well and one optimization system for each day has been realized. This technology is used throughout the entire production cycle of a coalbed methane well. The third technology is the efficient development technology of horizontal well in coal seam with fractured coal structure.Through numerical simulation study, it is clear that No. 15 coal seam in Panhe Block is suitable for integrated horizontal well development. In the early stage of horizontal well drilling, problems such as wall instability, drilling depth of some wells is not up to the design, and the length of horizontal section of real drilling is not up to the design. Aiming at this problem, the stability model of borehole wall of Panhe River is established by using the four-dimensional geostress modeling technique. The model reveals that the collapse pressure of horizontal wells is higher than that of vertical wells, and complex accidents such as collapse block are more likely to occur. In view of this feature, suspension agent, drainage aid and inhibitor are selected to improve the return of pulverized coal pressure, promote the fracturing fluid backflow, reduce the viscosity of mineral collision, and select a new type of active water fracturing fluid system. The successful application of the three key technologies provides a strong support for the efficient development of coalbed methane in Qinshui Basin, and also provides a technical reference for the efficient development of other coalbed methane basins.

Introduction

Coalbed methane refers to the methane that exists in coal seams. Coalbed methane mainly exists in two ways: free and adsorption. The methane in coal seam is mainly adsorbed, and the free gas is little. The adsorbed gas is adsorbed in the coal matrix in a dynamic equilibrium manner. In the process of exploitation, with the decrease

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of formation pressure, the adsorbed gas gradually resolves from the adsorbed state to free gas. The free gas enters the natural fracture system and participates in the flow through diffusion. Eventually methane flows through natural fractures into hydraulic fractures and eventually into the wellbore.

After nearly 10 years of development, Qinshui Basin has become the largest investment area of offshore unconventional oil and gas exploration and development. From 2013 to 2020, CNOOC's onshore unconventional natural gas development has entered a stage of rapid development, with its output rising from 435 million cubic meters to 2.18 billion cubic meters. Starting from 2021, CNOOC's onshore unconventional development has accelerated and entered a leapfrog development stage. With the cumulative output reaching 3.59 billion cubic meters in 2021 and the maximum daily gas production reaching 14.07 million cubic meters. CNOOC has made remarkable achievements in the development of coalbed methane in Qinshui Basin. Panhe Block has become the first national demonstration project for coalbed methane development. Shizhuang block has begun to take shape in scale and efficient development. Shouyang block has implemented an integrated exploration and development plan and has begun to achieve results. At present, CNOOC has 8 blocks in Qinshui Basin, with a total area of 7309 square kilometers, and proved geological reserves of coalbed methane of 1198.25 hundred million square meters, which is the main battlefield for the development of coalbed methane of CNOOC. At present, Panhe gas field is in the stable production stage of the old gas field, and the effect of increasing and stabilizing production is obvious, and the development technology is constantly innovative. The Panhe block mainly develops No. 3 coal and No.15 coal. No. 3 coal was developed earlier, and the development mode was vertical well development. No.3 coal is currently in the decline stage, the main task is to reduce its decline rate. The technologies used mainly include negative pressure extraction and optimize production system (Li et al. 2019; Wang et al. 2011). No.15 coal will be officially put into production in 2019. The method used for No.15 coal is large-scale horizontal well development (Liu et al. 2020), assisted by optimize production system and increase the number of horizontal wells per unit area (Xu et al. 2019; Qin and Wang 2019). In the drilling process of No.15 coal, embedding temporary plugging drilling fluid technology is adopted, which effectively avoids the collapse of the wall of a well and has a good reservoir protection effect in the drilling process (Wang et al. 2018). Although No. 15 coal has been put into operation for less than three years, its output has surpassed the vertical well and become the main force contributing to the output of Panhe Block. The main coal seam developed in Shizhuang South block is No. 3 and No. 15 coal. In recent years, the main workload of Shizhuang South block is the treatment of low production and low efficiency wells and the optimization of well pattern. By studying the fracture distribution characteristics of Shizhuang South block, the calculation model between stress, strain and fracture parameters is established. At present, the geological characteristics and natural fracture distribution characteristics of Shizhuang South block have been basically clarified (Zhang et al. 2022; Liu 2017; Guo 2018). The evaluation model of key characteristic parameters of Shizhuang South block is established. Based on logging data, the evaluation model can explain the industrial composition of coal reservoir, coal structure, gas content, critical desorption pressure, Langmuir parameter, permeability, etc. The model realizes the transformation of productivity discrimination from relying on experience to data-driven, and realizes the application of big data in coalbed methane development (Yang 2021; Li and Ling 2019; Miao et al. 2016; Wu et al. 2014; Huang et al. 2013; Meng et al. 2008).

Calculation of Gas Content of Coalbed Methane

Coalbed Methane Isothermal Adsorption Equation. It is very important to evaluate the gas content of coalbed methane in exploration stage and development stage. The coal reservoirs are organic reservoirs, and the coalbed methane reserves are calculated using gas content rather than free gas saturation in the pores. Currently, the gas content comes from laboratory isothermal adsorption tests of coal core. Coalbed methane is a kind of gas with relatively poor economic benefit, and the development mode is mainly low-cost development. In the process of development, there are few gas content tests. It is necessary to find an effective method to evaluate the distribution of gas content in the reservoir.

In the original state of coalbed methane, for unsaturated coalbed methane reservoir, the initial formation pressure is greater than the critical desorption pressure. In the process of production, the pressure in the formation is gradually reduced through the early drainage process. When the reservoir pressure drops to the critical desorption pressure, coalbed methane begins to desorption, and enters the natural fracture system to participate in the flow, and is finally extracted. Therefore, the production system of drainage and depressurization gas recovery is the characteristic of coalbed methane development (**Figures 1** and **2**).

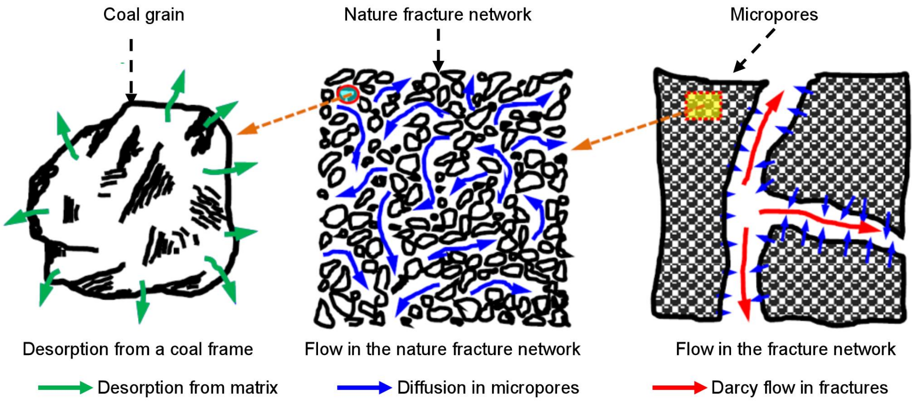

Figure 1—Adsorption, diffusion and Darcy flow in coalbed methane.

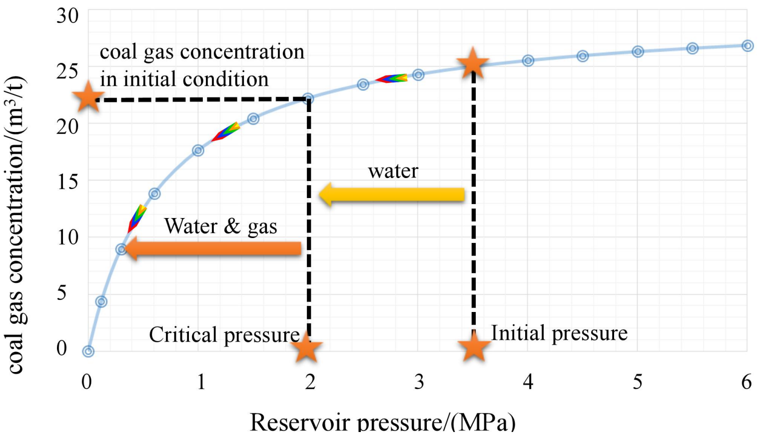

Figure 2—Change of gas content in coalbed methane development.

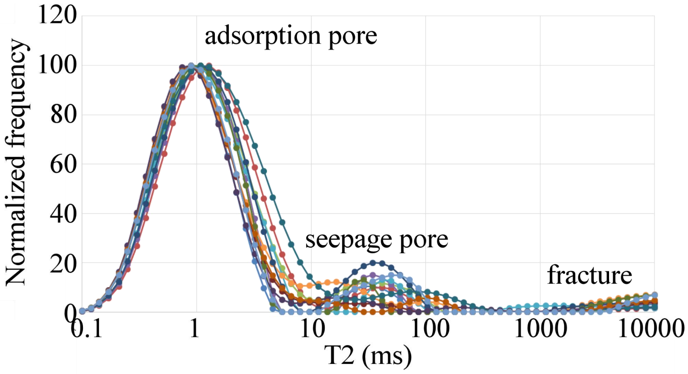

Figure 3—T2 spectrum characteristics of No. 3 coal in SZN block.

The adsorption curve of high rank coal in southern Qinshui Basin belongs to type I, and the adsorption and desorption process of coalbed methane can be described by Langmuir isothermal adsorption equation. According to the T2 spectrum characteristics of coal samples, the pores in the coal seam are mainly adsorption pores, followed by seepage pores, and few fracture holes (**Figure 3**). According to the isothermal adsorption test data, the fitting relationship between the isothermal adsorption test data of coalbed methane in Qinshui Basin and the Langmuir isothermal adsorption curve is very good (**Figure 4** and **Table 1**).

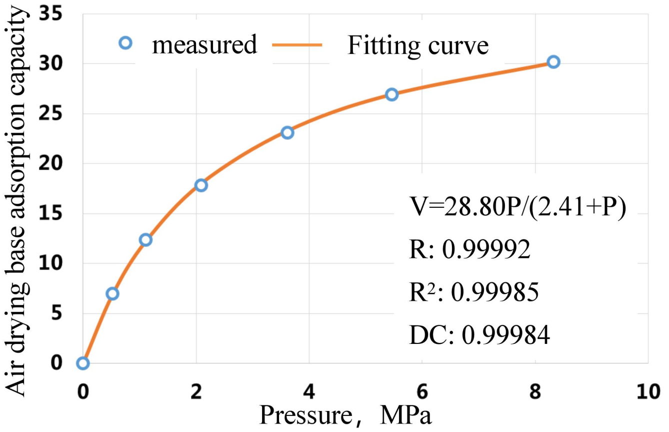

Figure 4—Gas content fitting map of SZN block.

Table 1—Data from seven samples from two wells.

The samples	The correlation coefficient	Correlation coefficient squared	Decision coefficient
Sample 1	0.9999	0.9999	0.9998
Sample 2	0.9999	0.9999	0.9998
Sample 3	0.9999	0.9997	0.9997
Sample 4	0.9995	0.9991	0.9991
Sample 5	0.9997	0.9995	0.9995
Sample 6	0.9947	0.9894	0.9889
Sample 7	0.9996	0.9992	0.9992

Based on the isothermal adsorption theory, the Langmuir equation is used to establish the calculation method of air content. Langmuir equation can be expressed as:

$$V = \frac{PV_L}{P+P_L} \quad (1)$$

In the formula, V is the gas content of coalbed methane, m^3/t, P is the reservoir pressure, MPa, V_L is Langmuir volume, m^3/t; P_L is Langmuir pressure, MPa.

The gas content of coal seam corresponding to the original reservoir pressure P_i is the maximum adsorption amount of coal seam, that is, the saturated gas content V_i. For unsaturated coalbed methane reservoir, the measured gas content V_c is less than the saturated gas content. When the coal reservoir pressure is reduced to the pressure P_c corresponding to the measured gas content, coalbed methane begins to desorption from coal to free state, so the measured gas content of coal seam corresponds to the critical desorption pressure. The gas content calculation formula 1 shows that when p is the critical desorption pressure, the corresponding gas content is the original gas content of the coal seam. Therefore, the initial gas content of coal seam can be calculated according to the critical desorption pressure.

$$V_i = \frac{P_c V_L}{P_c+P_L}, \quad (2)$$

Where P_c is the critical desorption pressure, MPa; V_i is saturated gas content, m^3/t.

Calculation of Gas Content in Coal Reservoir. According to **Eq. 2**, the key to calculating the gas content is to calculate the formation pressure when gas desorbed, that is, the critical desorption pressure of coalbed methane reservoir. According to the principle of seepage in the formation, the pressure reduction in the formation will be "funnel-shaped" distribution along the wellbore. Before the pressure wave reaches the boundary, one end of the funnel is the bottom-hole pressure and the other end is the original formation pressure. The lowest pressure in the formation is at the bottom of the well. According to Langmuir isothermal equation, the first desorption place is the bottom of the well. Therefore, the bottom-hole pressure when gas desorbed is the critical analytical pressure of coal reservoir. As long as the bottom-hole pressure is measured, the critical desorption pressure can be obtained, and then the gas content value of the well can be obtained according to the Langmuir isothermal equation.

At present, there are two main errors in measuring bottom-hole pressure when gas desorbed. First, due to the effect of well storage, when the coal reservoir begins to desorption, coalbed methane gradually flows into the wellbore and rises to the oil jacket ring control, which is detected by the pressure gauge, so there is a lag phenomenon in time. The second is the accuracy of the pressure gauge. When the pressure change range in the wellbore is small, the pressure gauge cannot detect, and when the pressure gauge begins to have degrees, the bottom hole flow pressure is already below the critical desorption pressure. Therefore, it is necessary to correct the data when calculating the critical desorption pressure.

Through the analysis of the causes of error, it can be found that the main factors affecting the test error include: gauge specifications, well structure and coal seam depth. Under the same conditions, the correction can be made using linear regression (**Figure 5**).

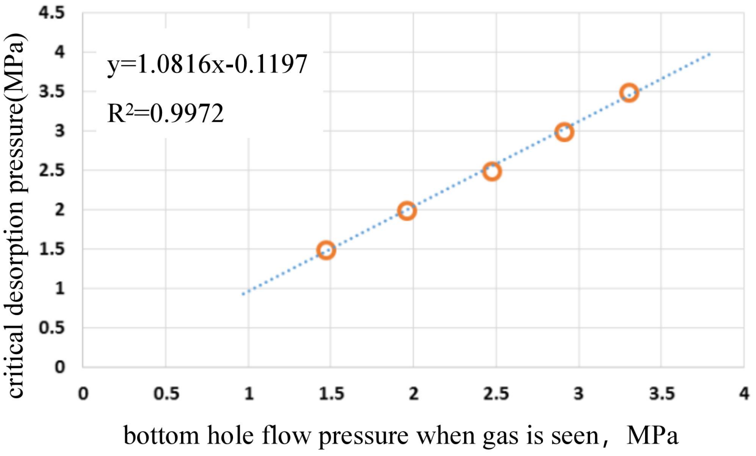

Figure 5—Linear regression corrects for critical desorption pressure

According to Langmuir isothermal and linear regression equation, the gas content can be expressed as,

$$V_c = \frac{aP_gV_L + bV_L}{aP_g + P_L + b}, \qquad (3)$$

where *a* and *b* is the linear regression coefficient.

Field Application. ***Block Profile.*** PH block is located in the southeastern slope zone of Qinshui Basin, and the main coal seam is No.3 coal of Shanxi Formation. PH block is located in the delta front, the coal forming environment is favorable, and it is in the development area of thick coal belt. The block area is 17 square kilometers.The structure of the demonstration area is simple, with north-south folds and PH syncline in the middle. The top surface of the area is low in the middle, and the two wings are high.

Calculation of Block Critical Desorption Pressure. Based on the test data of the parameter well, the correlation between the critical desorption pressure of coal in block No. 3 and the bottom pressure of the gas well is analyzed, and the linear regression diagram of the two is established (**Figure 6**). Through correlation analysis, the relationship between the critical desorption pressure of No. 3 coal in PH block and the bottomhole pressure of the gas desorbed can be obtained as follows,

$$P_c = 1.3263P_g + 0.7131 \qquad (4)$$

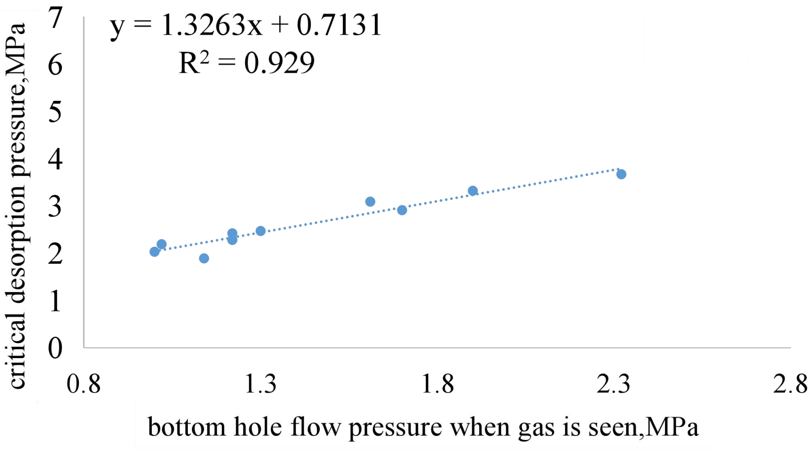

Figure 6—Relationship between critical desorption pressure and bottomhole pressure in PH block.

Gas Content Calculation of Block Single Well. There are relatively many gas content test data in PH block. Based on the laboratory gas content test data, isothermal adsorption curves of different regions can be obtained. Combining the isothermal adsorption curves of each block and formula 4, the gas content of the current production wells in PH block can be calculated, and then the gas content of the whole region can be evaluated (**Figure 7**).

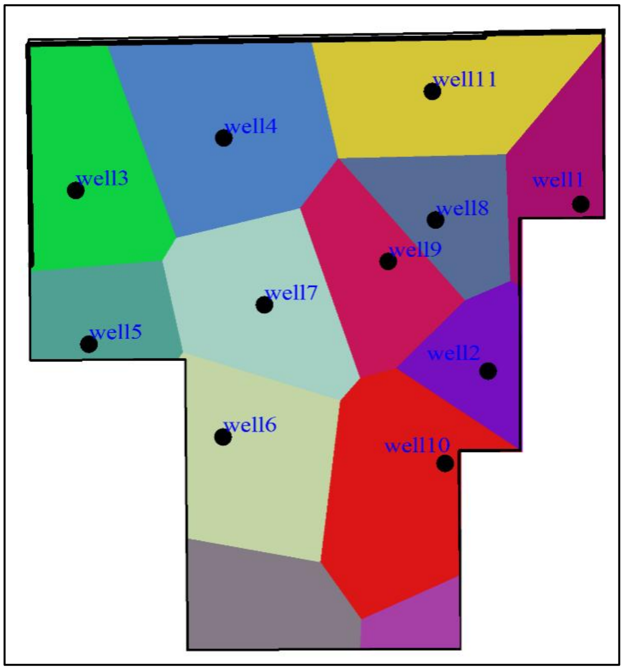

Figure 7—Isothermal adsorption curve turtle diagram.

Block Plane Gas Content Calculation. Combined with the isothermal adsorption curve of each block and formula 4, the gas content of each production well in the PH block can be calculated, and then the gas content of the whole PH block can be obtained (**Figure 8**).

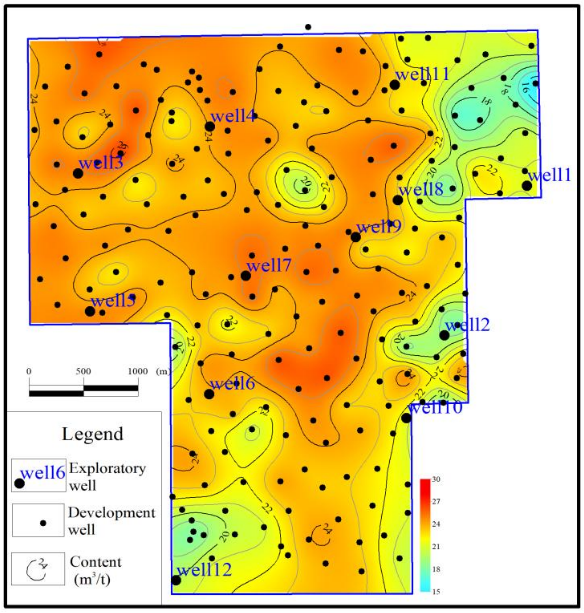

Figure 8—Calculation results of gas content in PH block.

By comparing the calculated results with the measured results, the error of the calculated results by this method can be controlled within 8%. Through the comparison of 6 wells, the average error of gas content calculation of this method is 2.63%, and the calculation accuracy is high. The method provided in this paper has high accuracy in calculation (**Table 2**). The error in Table 2 are defined as,

$$\text{Error} = \frac{|Measured\ gas\ content - Calculated\ gas\ content|}{Measured\ gas\ content} \times 100\% \tag{5}$$

Table 2—Comparison of measured gas content with calculated gas content.

Well name	Measured gas content (m^3/t)	Calculated gas content (m^3/t)	Error
Well 1	30.9	29.6	4.2%
Well 2	27.6	28.1	1.8%
Well 3	27.8	27.6	0.7%
Well 4	15.91	15.75	1.0%
Well 5	10.73	10.63	0.9%
Well 6	9.45	10.13	7.2%

Optimization of Coalbed Methane Production System

The Effective Permeability of Reservoir Decreases due to Gas-water Two-phase Flow. In the production process of coalbed methane, the phase of single-phase water flow in the early stage is transformed into the phase of gas-water two-phase flow. In addition to the change of flow pattern, the effective permeability of the reservoir will be reduced. A large number of studies have shown that the permeability at the isotonic point in coal reservoir is 0.2 times of the absolute permeability. Reasonable control of the arrival time of the two-phase flow can not only reduce the reservoir pressure to the maximum extent and promote the desorption of adsorbed gas, but also increase the drainage and production efficiency and increase the economic benefit of the development of coalbed methane wells.

When the reservoir pressure is lower than the critical desorption pressure, the reservoir begins to produce gas and the coal seam enters the phase of gas-water two-phase flow. According to the phase permeability curve of the reservoir, when the two-phase flow stage enters, the sum of the two-phase permeability is less than the single-phase flow permeability, and the permeability of the reservoir is actually reduced. Therefore, extending the single-phase flow of the reservoir as far as possible is conducive to the production of reservoir fluids, but when the single-phase flow stage is too long, most of the energy in the formation is used to produce water, which is not conducive to the production of gas in the reservoir. Therefore, there is an optimal pressure control time, which can not only satisfy the production of water in the reservoir, but also facilitate the production of gas in the reservoir.

On the basis of the same geological model, different pressure control times are set to simulate the reservoir pressure drop during production. The final pressure drop funnel shows that when the pressure control time of well A is 4 months, the final pressure drop funnel is the lowest, and the reservoir desorption effect is the best (**Figure 9**).

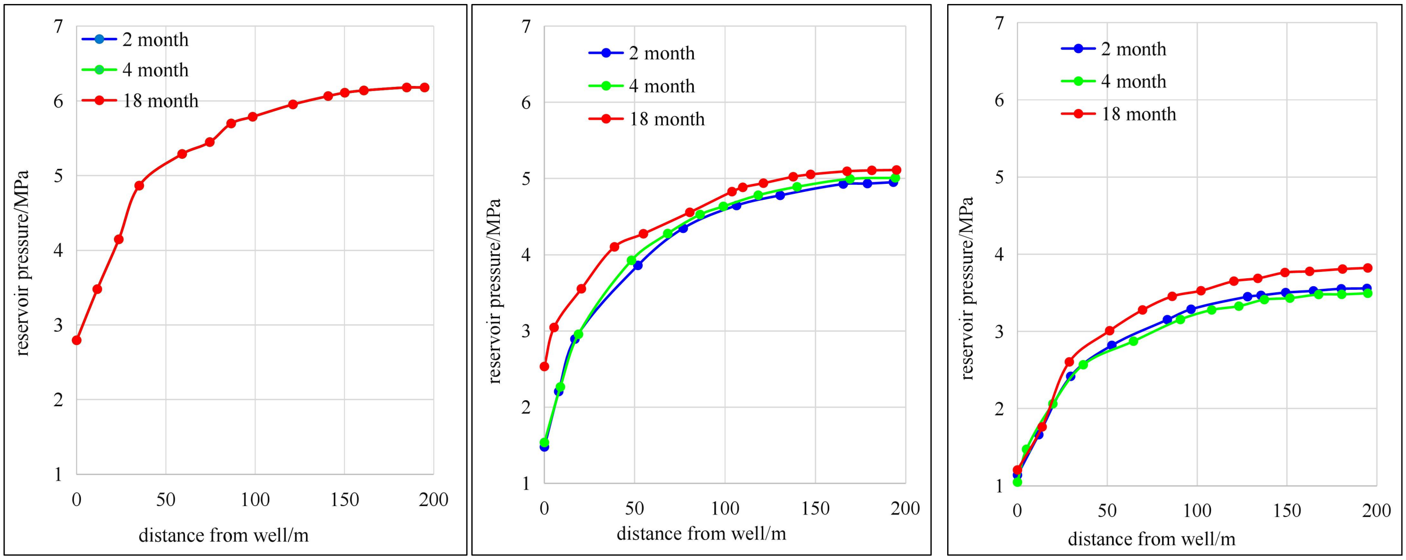

Figure 9—Production of 10/20/38 months pressure drop funnel.

The optimal pressure control time is inversely proportional to reservoir permeability and gas content, and positively proportional to reservoir porosity. The optimal pressure control time can be determined by drawing method and numerical simulation method. With the decrease of reservoir permeability, the optimal pressure control time increases (**Figure 10**). This is mainly due to the decrease of permeability, the deterioration of reservoir flow capacity, the decrease of pressure drop rate, and the increase of the time to reach the optimal pressure control state. With the decrease of coal gas concentration, the optimal pressure control time increases (**Figure 11**). With the increase of reservoir porosity, the optimal pressure control time increases (**Figure 12**), mainly because the porosity increases, the water in the reservoir increases, and the time required for drainage to the optimal pressure control state increases. The relationship diagram of pressure control time under different reservoir conditions is established, which is convenient to directly find the optimal pressure control time according to different reservoir conditions in the application process. In the actual application process, the method of combining numerical simulation and chart is mainly used to predict the optimal pressure control time.

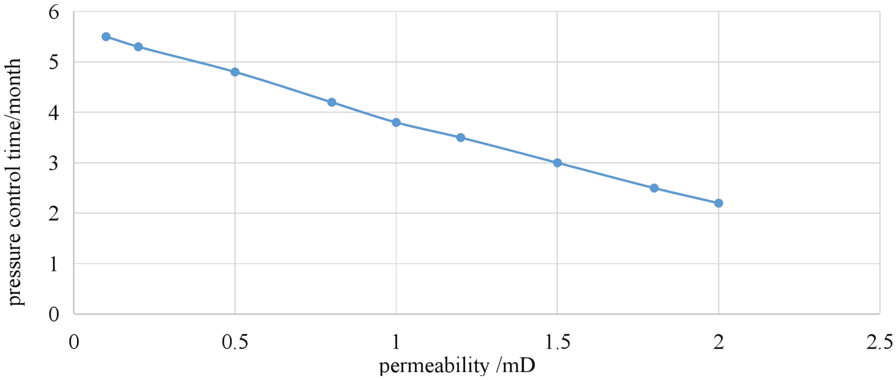

Figure 10—Optimal pressure control time under different permeability.

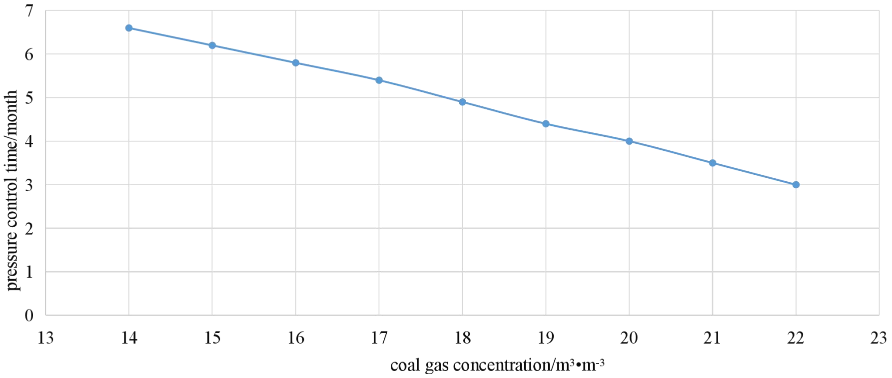

Figure 11—Optimal pressure control time under different coal gas concentration.

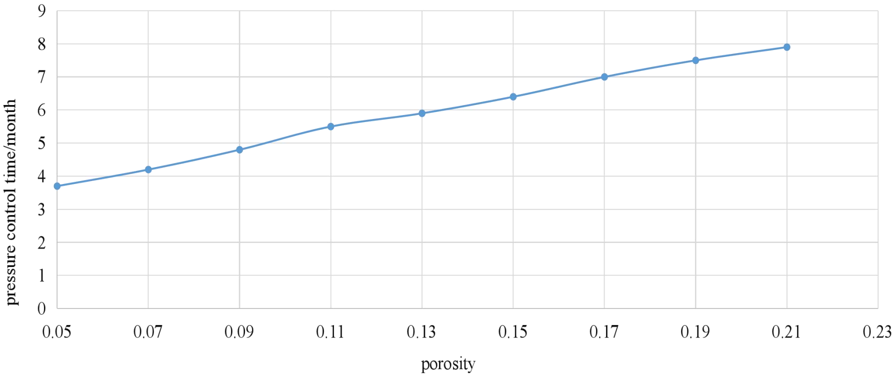

Figure 12—Optimal pressure control time under different porosity.

Effect of Pulverized Coal Migration on Seepage Capacity of Reservoir. In the process of coalbed methane development, the fluid velocity in the reservoir is too high to cause the coal powder to migrate. When the fluid velocity in the reservoir exceeds the velocity that can carry the pulverized coal, the pulverized coal that has been deposited in the reservoir will re-participate in the flow. When the fluid velocity in the reservoir exceeds the velocity that can denude the reservoir, the coal powder attached to the coal seam will fall off and participate in the flow. More pulverized coal enters the fracture system, blocking the flow channel and causing permeability damage. At the same time, if the flow velocity is too high, the fluid will carry the coal powder out of the reservoir and increase the permeability of the reservoir. Therefore, in the process of drainage, there is an optimal flow rate, which can bring out part of the coal powder without stripping the coal powder in the reservoir.

The current numerical simulation software for oil and gas development cannot simulate pulverized coal migration in coal seams. The main research method is core displacement test, in which the permeability changes of the core are measured by different flow rates, so as to obtain the best flow rate of the core. The core is usually used to represent the pulverized coal migration of the whole block. After obtaining the permeability of coal seam under different seepage velocities, combined with numerical simulation, the gas production curves under different drainage velocities can be obtained. By targeting peak gas production or cumulative gas production during the production cycle, the extraction rate can be optimized.

Effect of Matrix Shrinkage on Optimization of Drainage and Production System. The coalbed methane reservoir itself has the characteristics of brittleness and adsorbed gas. Compared with other gas reservoirs, the permeability in coal seam is more sensitive to pressure changes during development. On the one hand, due to the greater brittleness of the coal seam matrix and the existence of cracks, in the production process, due to the reduction of reservoir pressure, the overlying strata will compress the coal seam and reduce the permeability

(**Figure 13**). On the other hand, as production proceeds, the adsorbed gas is desorbed from the substrate. This phenomenon will cause the pressure balance around the matrix to be broken, the pressure on the matrix will increase, the matrix will be compressed, the cracks between the matrices will increase, and the permeability of the entire matrix system will increase (**Figure 14**).

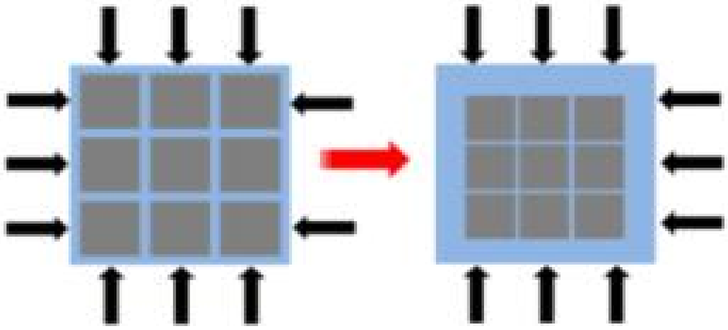

Figure 13—The compression of overburden causes the matrix permeability to decrease.

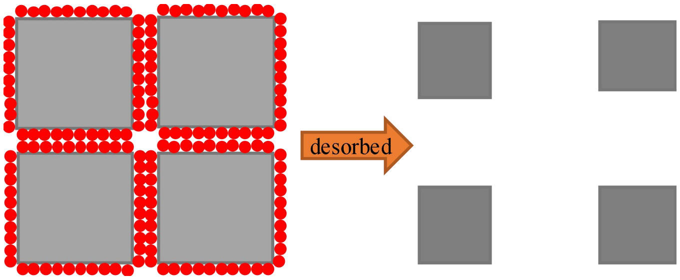

Figure 14—Adsorption gas desorption results in increased matrix permeability.

At present, there are many models describing the contraction and expansion of coalbed methane reservoirs, but there are four mainstream models, all of which describe the relationship between pressure and porosity permeability in coalbed methane reservoirs. Through this model, an analytical solution model of coalbed methane reservoirs can be established considering the contraction/expansion of coalbed methane reservoirs.

At present, there are many equations describing stress sensitivity and matrix shrinkage, but the four mentioned in the introduction are more widely used.

Seidle and Huitt models:

$$\frac{\phi}{\phi_i} = 1 + \left(1 + \frac{2}{\phi_i}\right) C_m (10^{-6}) V_L \left(\frac{p_i}{p_L + p_i} + \frac{p}{p_L + p}\right), \tag{6}$$

Palmer and Mansoori models:

$$\frac{\phi}{\phi_i} = 1 + \frac{C_{ma}}{\phi_i}(p - p_i) + \frac{\varepsilon_l}{\phi_i}\left(\frac{K}{M}\right) V_L \left(\frac{p_i}{p_L + p} - \frac{p_i}{p_L + p_i}\right), \tag{7}$$

Shi and Durucan models:

$$k = k_i e^{-3c_f(\sigma - \sigma_i)} \tag{8}$$

When the local layer pressure is higher than the desorption pressure pd (pi > p > pd):

$$\sigma - \sigma_i = -\frac{\nu}{1-\nu}(p - p_i), \tag{9}$$

When the layer pressure is lower than or equal to the desorption pressure(pd ≥ p > 0):

$$\sigma - \sigma_i = -\frac{\nu}{1-\nu}(p - p_i) + \frac{E}{3(1-\nu)} \varepsilon_l \left(\frac{p}{p + p_\varepsilon} - \frac{p_i}{p_\varepsilon + p_i}\right), \tag{10}$$

Constant exponential permeability model:

$$I = -\frac{1}{k}\frac{\partial k}{\partial p} , \qquad (11)$$

The symbol in this formula indicates that the change of permeability is inversely proportional to the change of pressure. The equation 6 is integrated and the initial conditions are taken into account.When permeability is the original permeability of the reservoir and pressure is the original pressure of the reservoir, we get:

$$\frac{k}{k_i} = e^{-I(p_i - p)} \qquad (12)$$

High Efficient Development Technology of Horizontal Well in Coal Seam with Fractured Coal Structure

Development Status of Horizontal Wells in Major Coalbed Methane Blocks. At present, CNOOC has deployed a certain number of horizontal wells in the four main blocks of Panhe, Shizhuang South, Shizhuang North and Shouyang in Qinshui Basin. Among them, 22 horizontal wells will be implemented in Panhe Block in 2019 and 60 horizontal wells in 2020. No. 3 coal is developed by vertical well, and No. 15 coal is developed by horizontal well. From the current gas production effect, the average daily gas output per well of horizontal wells is 8818 cubic meter , and the cumulative production will be 200 million square meters in 2021. Although horizontal wells began to be used on a large scale in 2019, their output has surpassed vertical wells and become the main contributor to the output of Panhe Block (**Figure 15**). Horizontal wells are characterized by fast production speed, high output per well and high cumulative production.

From the current gas production effect, the gentle and updip development effect is the best, and the convex, concave, fluctuating and downdip development effect is poor. Downdip horizontal wells are prone to accumulation of formation water at the toe end, resulting in pressure plugging, and the effective length of horizontal wells is reduced. There is a negative correlation between the number of sidetracking and the output of horizontal wells: the sidetracking of horizontal wells in Panhe block is often caused by drilling through the roof, resulting in communication between the roof limestone and the coal seam, and external water entering the coal seam, affecting the drainage and pressure reduction of the coal seam, and reducing the output of horizontal wells (**Table 3**).

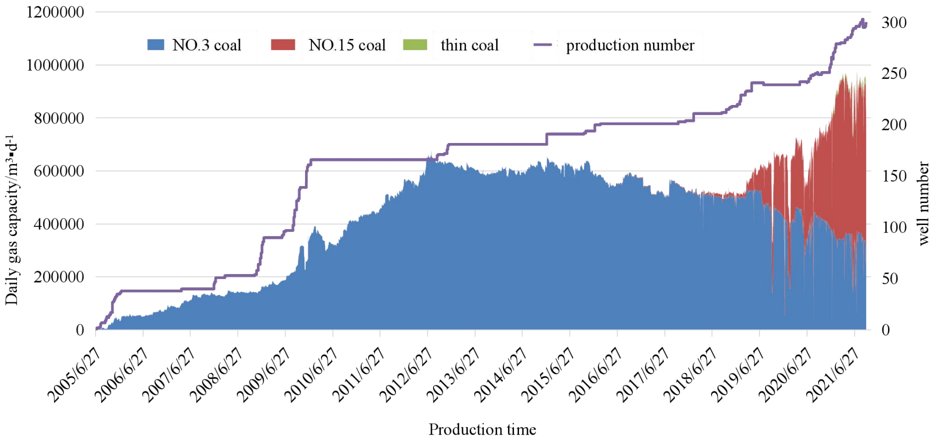

Figure 15—Superimposed map of daily gas production in Panhe block.

Table 3—Horizontal well trajectory and gas production in Panhe block.

Panhe block	Well number	Average gas production/$m^3 \cdot d^{-1}$
Updip	33	8684
Downdip	1	4929
Gently	6	9234
Convex type	5	7325
Concave type	1	5443
Wave pattern	14	4572

At present, there are 15 horizontal wells in No.3 coal in Shizhuang South block, including 6 staged fracturing wells and 9 screen completion wells. The average gas production of staged fractured horizontal wells is 3392 cubic meter per day, and the average gas production of screen completion wells is 1988 cubic meter per day.

There are 9 newly put into operation horizontal wells in Shizhuang North block, some of which have high bottom-hole flow pressure, high output and high production potential. However, production results were uneven, with high production rates reaching 4416 cubic meter per day. The development effect of horizontal wells in Shouyang block is very different, and the production difference between wells is mainly affected by geological and engineering factors.

Efficient Development of Horizontal Wells in Panhe Block. According to the geological parameters of No.15 coal seam in Panhe Block, the numerical simulation of different well types is carried out. The research shows that the horizontal well development in Panhe block has a good effect. The numerical simulation results show that under the current geological conditions of Panhe block, the peak gas production of horizontal wells will be 5.6 times that of vertical wells, the average gas production will be 3.8 times that of vertical wells, and the 20-year production degree will be 1.3 times that of vertical wells. Horizontal wells are suitable for development in Panhe block (**Table 4**).

The numerical simulation shows that when the length of horizontal section is more than 1000 meters, the recovery degree and cumulative gas production do not increase significantly (**Figure 16**). When the well spacing exceeds 300 meters, the increase of peak gas production of a single well slows down (**Figure 17**). When the well spacing is small, the controlled reserves are small, resulting in the reduction of cumulative gas production per well. The comprehensive comparison shows that the recommended reasonable well spacing between 250 meters and 300 meters.

Table 4—Comparison of development indicators of horizontal straight wells.

Development index	Vertical wells	Horizontal wells	Ratio
Peak gas production (m^3/d)	1854	10384	5.6
Average gas production (m^3/d)	865	3253	3.8
20 years of cumulative gas production (10^{4}m^4)	632	2374	3.8
20 years of recovery (%)	57.8	72.4	1.3

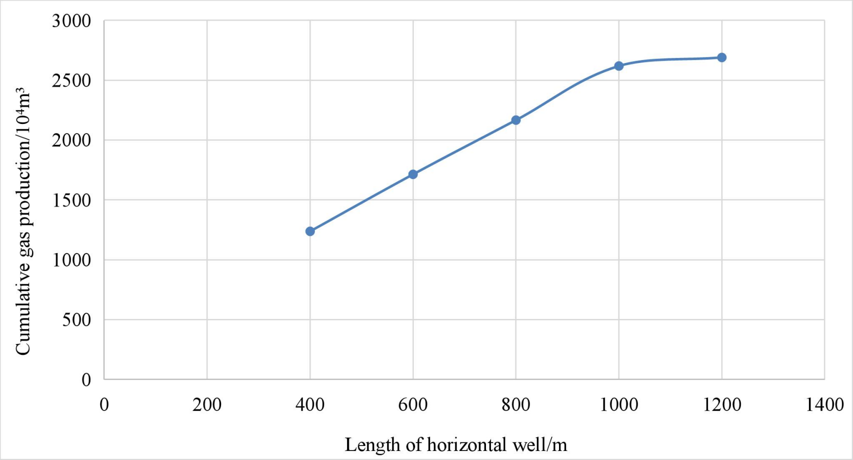

Figure 16—Horizontal wells of different lengths produce gas repeatedly in Panhe block.

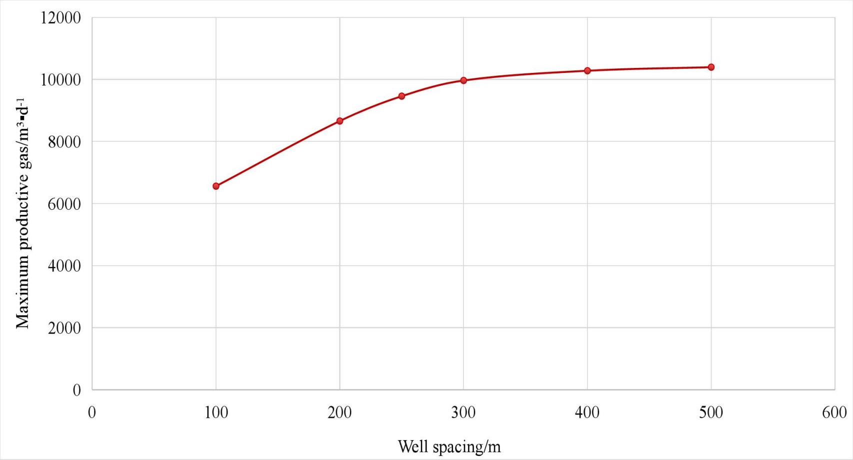

Figure 17—Horizontal wells with different well spacing produce gas repeatedly in Panhe block.

In the early process of horizontal well drilling in Panhe block, wellbore instability often occurred in horizontal well drilling, and the drilling depth of some wells did not meet the requirements of the design depth, and the length of the horizontal section in real drilling did not meet the requirements of the design horizontal section length. Wall instability accidents lead to problems such as drilling pipe sticking, drilling leakage, feed abandonment, coal seam sidetracking, advance drilling and completion difficulties, etc., thus losing a lot of construction time and increasing the comprehensive cost of drilling and completion. The four-dimensional geomechanical model of shaft wall stability in Panhe shows that the collapse pressure of coal seam in Panhe is high and it is easy to collapse. The collapse pressure of horizontal wells is higher than that of vertical wells, and complex accidents such as collapse are more likely. Wellbore instability and collapse are the main factors that lead to complex drilling and completion conditions. The average formation pressure of Panhe block is 0.8 g/cc, which is slightly lower than the normal formation pressure. Except that the collapse pressure of coal seam exceeds the formation pressure, the collapse pressure of other sand and mudstone intervals is less than 0.5 g/cc. The fracture pressure of coal seam is slightly higher, the fracture pressure of No. 3 coal seam is 2.1 g/cc, and the fracture pressure of No.15 coal seam is above 2.15 g/cc. The average fracture pressure of other sand-mudstone intervals is 2.04 g/cc. The three-pressure profile of the horizontal section of the coal seam is calculated. The average collapse pressure of the horizontal section of the coal seam is about 1.14 g/cc, and the average rupture pressure is between 2.1-2.4 g/cc.

Based on 3D geomechanical model and 3D numerical model of oil and gas reservoir, a four-dimensional dynamic geostress analysis method was established with dynamic pore pressure field as the boundary condition (Zhu et al. 2018). In the later production process of the block, with the production of each well in the block, the direction of the ground stress will be deflected to a certain extent.

By improving the plugging performance of drilling fluid system and adjusting drilling fluid density, the complexity of horizontal wells was reduced by 65% and the sidetracking frequency by 53%. In the process of fracturing with ordinary active water and 2% KCl fracturing liquid system, due to the “loose, brittle and soft” coal seam, a large amount of pulverized coal and coal cuttings are formed under the erosion of high-speed fluid, resulting in fracture damage. A new type of active water fracturing fluid system was optimized by optimizing suspension agent, drainage aid and inhibitor to promote the return of pulverized coal after pressure and fracturing fluid, and reduce the collision of viscous minerals. The system has good compatibility, little damage to the permeability of coal and rock, and good reservoir protection effect, which can meet the field demand (**Figure 18**). The field fracturing test of the new fracturing fluid system has been applied to five wells, and the effectiveness of the new fracturing fluid system has been verified.

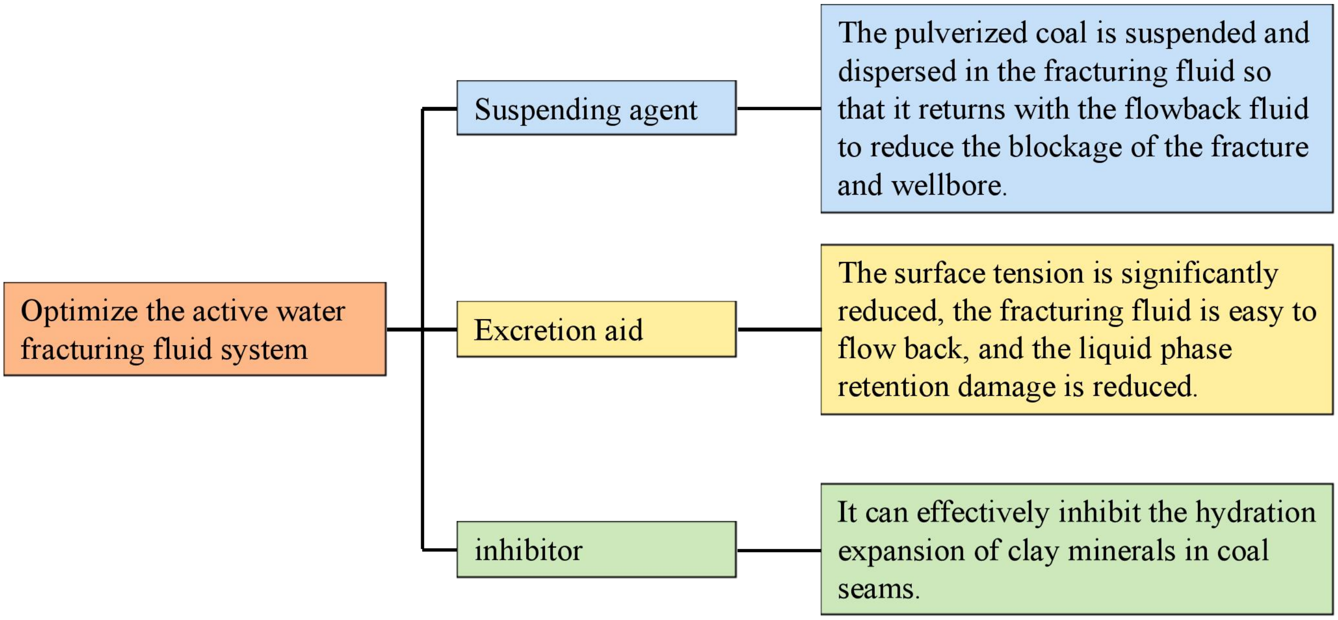

Figure 18—Active water fracturing fluid optimization system.

Conclusions

In this study, we conducted geological research, production analysis, numerical simulation, and summarize the conclusions as follows.

1. Through the fitting of bottom-hole flow pressure and critical desorption pressure, combined with the production dynamic parameters of coalbed methane wells, the gas content of a single well can be accurately calculated. This method can provide accurate and valuable geological parameters for the evaluation of coalbed methane reserves and the optimization of the development of sweet spots.
2. The drainage and production system affects the production of coalbed methane wells, and a suitable drainage and production system can improve the flow environment of the reservoir. The main factors affecting the drainage and production system include the transformation of unidirectional two-phase flow affecting the absolute permeability, the precipitation and denudation of coal powder, and the matrix shrinkage effect of coal reservoir.
3. The collapse pressure of Panhe coal seam is high, and the collapse block is easy to happen. The collapse pressure of horizontal wells is higher than that of vertical wells, and complex accidents such as block collapse are more likely to occur. At present, the fracturing fluid system forms a large amount of pulverized coal and coal dust under the erosion of high-speed fluid, which causes fracture damage. The optimized fracturing fluid system can promote the fracturing fluid flowback and reduce the viscosity collision.

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Conflicting Interests

The author(s) declare that they have no conflicting interests.

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