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Numerical Simulation of Gas Extraction in Coal Seam Strengthened by Static Blasting

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Abstract: For mines with low permeability and high gas emissions, static blasting technology is used to pre-split the coal seam to increase the permeability and strengthen the gas extraction, which will significantly reduce the occurrence of gas accidents in mines. Taking Wangjialing Coal Mine as the research object, the mathematical model of fluid-solid is established. The numerical simulation software COMSOL is used to simulate the established mathematical model. Simultaneously, the factors affecting the efficiency of static blasting gas extraction are analyzed by adjusting the parameters. The results reveal a more significant drop in gas pressure with increasing time. At 10 d, 30 d, 90 d and 180 d, the extraction efficiency increases by 11.80%, 18.67%, 22.22% and 24.13% in comparison to conventional extraction. In studying the influence of expansion pressure and other factors on gas extraction during static blasting, it is found that the change of negative pressure has little effect on gas extraction. Static blasting can significantly reduce gas pressure and achieve safe coal mining, providing a basis of field application of efficient gas extraction in low gas mines.

Keywords: static blasting; conventional extraction; numerical simulation; permeability

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1. Introduction

The coal industry has grown rapidly over the years, and the number of mines and coal production have increased dramatically. In the process of mining, a large amount of gas will be produced. If these gases are discharged into the atmosphere, it will aggravate the 'greenhouse effect' of the earth and cause serious harm to the ecological environment [1,2]. The basic factor that determines the effect of gas extraction in mines is the permeability of mines. At present, gas pretreatment is a direct and effective method to control gas disaster in mines [3–7]. Improving mine permeability and improving the effect of gas pre-extraction are the research hotspots and difficulties in the prevention and control of gas disasters worldwide. The mine permeability directly affects the effect of gas extraction by drilling [8–11]. Most mines in China have permeability in the range 10^{-4}~10^{-3} μm^2, low mine permeability and low gas extraction productivity. Therefore, effective measures of coal seam pressure relief and permeability enhancement are necessary to achieve efficient gas extraction [12–15]. Based on the theory of static blasting technology—that a static expansion agent is added to the borehole to crack coal and rock mass through expansion pressure—we propose using a static expansion agent to expand and crack mines to increase permeability, to expand effective influence range of gas in a single borehole. Improving the gas extraction effect of mines is an important direction of increasing permeability and promoting gas extraction in mines. In the 1980s, China first developed static expansion agent, because it has the advantages of no explosion sound, no flying stone, no shock wave and blasting vibration, etc., and it has been widely used in the field of coal engineering, providing new methods and technologies for coal seam gas extraction and coalbed methane utilization in China's mines, effectively reducing coal seam gas pressure and reducing the occurrence of gas accidents that may be faced in the coal mining process. [16–20]. At the same time, the coalbed methane extracted during the mining process can be used as a clean energy alternative to natural gas, reducing the "greenhouse effect", which has a broad application prospect.

Based on the static blasting technology, many scholars are committed to studying its application in coal engineering. Li et al. [21] introduced the static blasting technology into the treatment of hard floor heave of dynamic pressure roadway to achieve safe and efficient surrounding rock treatment. Hao [22] and Tang et al. [23], in order to verify whether the static cracking agent can act on the hard roof, used the triaxial rock mechanics experiment. Liu [24], Du [25], Chen [26] and Mathias [27] et al. established the crack propagation model through elastic mechanics to monitor the crack evolution law during the experiment and obtained the crack force and crack propagation relationship. A relationship between crack force and crack ductility radius was obtained. Zheng [28], Xu [29], Zhao [30] and Garcia Calvo et al. [31]. studied and analyzed the principle of static expansive agent and its influencing factors. It is concluded that static blasting technology is suitable for deep mining and coal mines with poor permeability and complex coal seam conditions. On the basis of this study, the prospect of static blasting agent in the direction of coal mining is put forward. Li [32] and Luo [33] prepared the static crushing agent suitable for coal mines, and finally determined the optimal ratio through experimental research to achieve the ideal effect of coal rock crushing. Xie et al. [34,35] solved the problem of poor gas extraction effect in low permeability coal seam, analyzed the influencing factors of expansion and cracking of static expansion agent, and found that under the condition of reasonable ratio of hole spacing to hole diameter, static expansion agent can make the inner wall of extraction hole produce a large number of macro cracks. Xiao et al. [36] found that the static blasting technology was applied to promote the efficiency of gas extraction in coal engineering, but it lacked understanding of the monitoring changes of gas in the process of static blasting. Therefore, changes in gas adsorption rates both prior to and secondary to static blasting were monitored and analyzed by scanning electron microscopy, infrared spectroscopy and gas chromatography. The results show that the static blasting will produce micro cracks, resulting in porosity increases and gas pressure decreases rapidly. Mahes [37,38], Liu [39] and Shobeir et al. [40] used the finite element method to predict the expansion pressure generated in the static blasting process and analyzed and compared the predicted blasting pressure results and the mathematical model results. To address the lack of understanding of the crack development pattern during the use of static blasting technology, Xie et al. [41,42] investigated the evolution pattern of cracks in coal seams during static blasting using numerical simulation software and experimental studies. It is concluded that static blasting will cause numerous cracks, and these cracks will be widely spread and extended throughout the whole process. Finally, a large number of radial cross-fracture networks are formed between boreholes. An impact from static blasting on seams depends on the increase of permeability caused by coal seam cracking caused by expansion pressure. Compared with traditional gas extraction, the use of this technology in gas extraction under specific mine environments has great safety and environmental protection advantages and certain progress advantages. However, the current research has insufficient understanding of the changes in gas migration during static blasting and influenced the factors of gas extraction, which will result in the reduction of gas extraction efficiency. In this study, a mathematical model of Darcy's law, the ideal gas equation and the deformation and damage equation of the coal rock body is developed. The gas migration and permeability evolution in the static blasting process are studied by COMSOL simulation software, which is beneficial to the field guidance of gas extraction from low permeability seams.

2. Method

2.1. Basic Assumptions

To establish the coal seam gas migration model, we make the following basic assumptions:

(1) Coal is homogeneous continuous porous medium, and coal rock is isotropic, coal skeleton is linear elastic material;

(2) Gas is simplified to ideal gas and follows conservation of mass equations;
(3) The temperature of coal seam is constant and does not take into account the effects of temperature field changes during the extraction process. At the same time, the transport of gas through the fissure is a seepage process and satisfies Darcy's law.
(4) Coal failure criterion follows Mohr-Coulomb.

2.2. Gas Flow Equation

The gas flow in coal seam follows the law of conservation of mass, and the continuity equation can be expressed as:

$$\frac{\partial Q}{\partial t} + \nabla \cdot \left(\rho_g v_g\right) = 0 \tag{1}$$

where ρ_g is gas density; v_g is gas seepage velocity; Q is gas content per unit volume of coal; t is time.

Assuming that gas flow in coal seam is regarded as horizontal radial flow, follows Darcy's Law, expressed as:

$$V_g + \frac{k}{\eta_g} \nabla p = 0 \tag{2}$$

where V_g is gas seepage rate; η_g is gas dynamic viscosity coefficient; k is coal seam permeability; ∇ Gas pressure gradient.

Due to the poor permeability of Wangjialing mine, the Klingberg formula can be used to correct the permeability of the coal body, expressed as:

$$V_g + \frac{k}{\eta_g} \left(1 + \frac{b_p}{p}\right) \nabla p = 0 \tag{3}$$

2.3. Equation of Permeability Change

Conventional gas extraction mainly depends on the permeability change caused by the stress sensitivity of coal and rock mass caused by the decrease of gas pressure during borehole extraction. The permeability change under static blasting depends on the obvious increase of cracks and the gradual formation of a penetrating fracture network after the expansion of the fractured coal seam. The fracture system around these boreholes is the main channel of coal seam gas migration. Due to the compressibility of cracks, the width of cracks varies with stress.

Changes of coal rock permeability and effective stress:

$$k = k_0 \cdot e^{-\beta \sigma'} \tag{4}$$

where k is the permeability under certain stress conditions; k_0 is the permeability under stress-free conditions; β is the pore-fracture compression coupling coefficient of coal; σ'—effective stress.

2.4. Stress Balance Equation

The momentum conservation equation of coal under effective stress and pore pressure is:

$$\sigma_{12,2} + f_1 - \left(\alpha \delta_{12} p_e\right)_{,2} = 0 \tag{5}$$

where $\sigma_{12,2}$ is effective stress components; p_e is pore pressure component; δ_{12} is the Kroneker symbol; α is Biot effective stress coefficient; f_1 is volume component.

2.5. Deformation Control Equation of Coal Body

The geometric equation for the deformation of the coal body is the equation of strain versus displacement, and the geometric equation of coal deformation is:

$$\varepsilon_{12} = \frac{1}{2}(u_{1,2} + u_{2,1}) \tag{6}$$

where ξ_{12} is volumetric strain; $u_{1,2}$ is the positive displacement component; $u_{2,1}$ is the shear displacement component.

Deformation of the coal body generates strain and effective stress, the relationship between them obeying the generalized Hooke's law. The instantonal equation is:

$$\sigma_{12} = D_{12kl}\xi_{12kl} \tag{7}$$

The total strain of coal is based on the sum of the strain caused by stress and the change of gas pressure in cracks and changes in coal matrix shrinkage due to matrix porosity and gas desorption and adsorption. The equilibrium equation in elastic condition expressed by displacement is obtained:

$$G\nabla^2 u + f - [\nabla(\alpha p_e) + (\lambda + G)\nabla(\nabla u)] = 0 \tag{8}$$

The differential is obtained:

$$G\nabla^2 u_1 + f_1 - \left[(\lambda + G)\frac{\partial \xi_v}{\partial x_1} + \partial\frac{\partial p_e}{\partial x_1}\right] = 0 \tag{9}$$

where σ is effective stress; f_1 is volume force; e is strain; u is displacement; p_e is pore pressure; α is the effective stress coefficient.

3. Engineering Background and Physical Model Establishment

3.1. Engineering Background

In Figure 1, Wangjialing Coal Mine was located at Hejin City, Yuncheng City, Shanxi Province, China, with an annual design production capacity of 6 million tons, belonging to super large modern mines. The No.2 coal seam lies at 12,316 working face, the mining gas content is about 4~6 m^3/t, and absolute gas gush from the mine is 12~15 m^3/min, which is a typical high-strength mining coal seam with low gas emission. As the depth and intensity of mining increases, conventional gas extraction can no longer meet requirements of safe operation. Extraction effect is not good and the gas is still easy to overrun. This paper takes the No. 2 coal seam of the 12,316 comprehensive mining face of Wangjialing coal mine as the engineering background, and after establishing a mathematical model to study the effect of enhanced extraction by static blasting, analyzes these factors affecting the ability of static blasting to improve gas extraction by adjusting parameters, which provides theoretical support in the field of high efficiency gas extraction in low permeability coal seam.

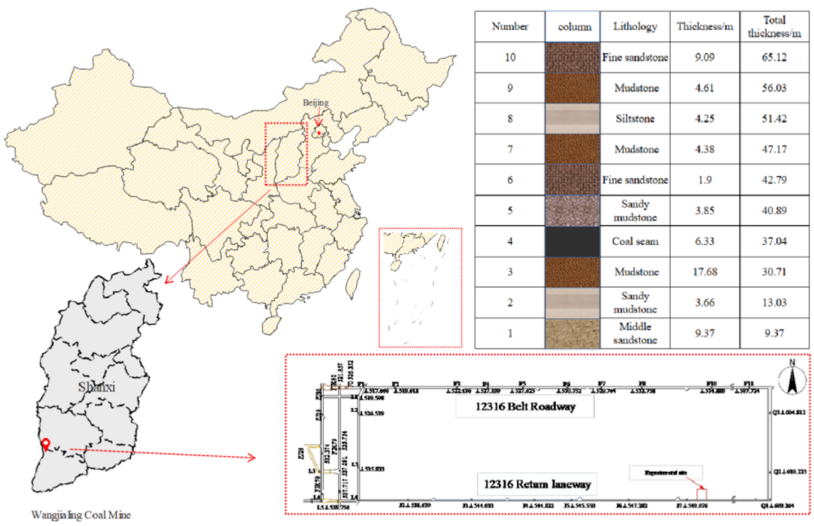


Figure 1. General situation and stratigraphic distribution map of Wangjialing Mine in China.

3.2. Establishment of Physical Model and Setting of Boundary Conditions

To investigate the influences of static blasting on gas extraction, a numerical model of fluid-solid coupling was developed by COMSOL Multiphysics software. When building the model, elastic-plastic mechanics and gas seepage equations were used as the theoretical basis, and the solid mechanics module was selected as the mechanics module for enhanced extraction by static blasting in mines, and the PDE module was set up to simulate the radial flow of gas. Based on the mechanical properties of the No. 2 coal seam and the actual situation of the coal mine gas deposit, we define the parameters of the coal rock body and set the initial and boundaries conditions, and the mathematical model is solved by using the appropriate solver.

For the convenience of calculation, the three-dimensional seepage process is simplified into two-dimensional radial flow, and the geometric model is established according to the actual situation. As shown in Figure 2. Three boreholes (one blasting hole and two extraction holes) are arranged along the central line of the roadway, drill hole spacing of 1.5 m, observation point set at 0.5 m from the extraction drill hole on the right. The surrounding of the model is assumed to be zero flow boundary, the top and bottom of the mined layer are impervious strata, the left and right roll support is set, model top is free boundary, the drilling boundary is free boundary, fixed constraints are set at the model bottom. At model top, 10 MPa overburden pressure is set up, the coal seam gas pressure is 0.2 MPa, extraction negative pressure is 20 kPa, and borehole diameter is 75 mm. For other parameters used, see Table 1.

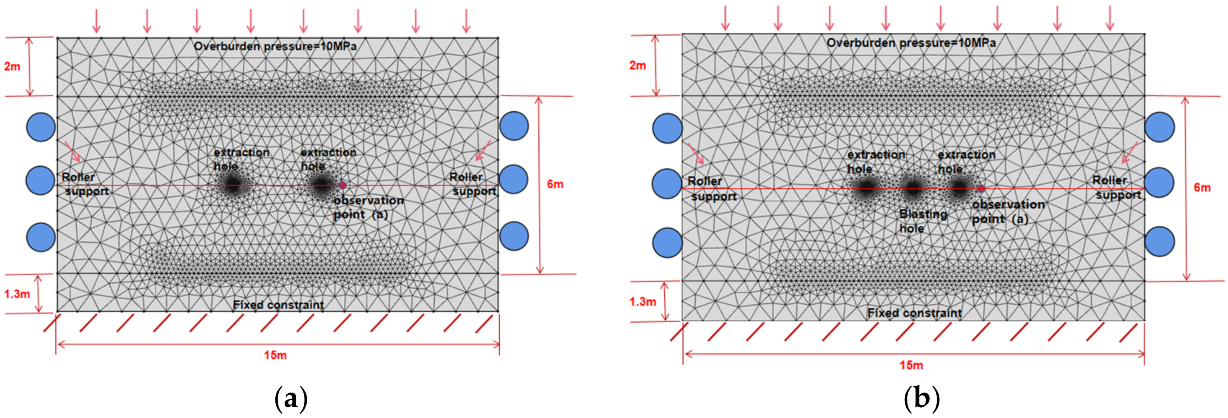


Figure 2. Geometric physical model. (**a**) Physical model of conventional extraction. (**b**) Enhanced Extraction Model.

Table 1. Modeling Basic Parameters.

Parameters	Numerical	Unit
Initial gas pressure	0.2	MPa
Initial gas content	3.3	m^3/t
Klingberg coefficient	0.35	MPa
Elastic modulus	3.0	GPa
Poisson's ratio	0.35	
Dynamic viscosity	1.08×10^{-5}	Pa·s
Negative pressure of extraction	20	kPa
Initial permeability of coal seam	2×10^{-15}	m^2
Porosity	4.3	%
Adsorption constant a	29.24	a m^3/t
Adsorption constant b	0.95	b MPa^{-1}
Expansion pressure	40	MPa

4. Results and Discussion

4.1. Simulation Results Analysis of Conventional Extraction and Static Blasting Enhanced Extraction

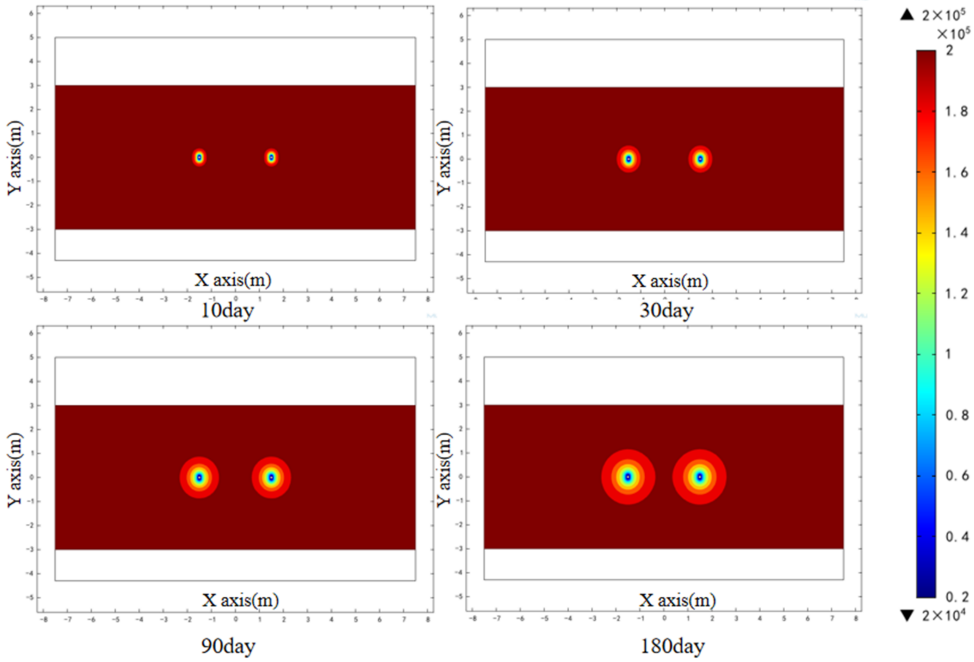
4.1.1. Gas Pressure Change

Figure 3 is the conventional gas extraction and uses static blasting to enhance permeability and promote extraction in 10 d, 30 d, 90 d, 180 d coal seam gas-pressure-change cloud map. In Figure 3a, the gas pressure around the extraction borehole gradually lowers as the number of extraction days increases. In the early stage of extraction, the gas pressure decreased with the increase of time, and pressure drop coefficient was large. The influence range of pressure relief increases with time but the decline rate of gas pressure tends to be slow with time, and the speed of decline decreases and tapers off. In Figure 3b, the decline rate of gas pressure around the extraction hole is significantly higher than that of conventional gas extraction after using static blasting technology to increase permeability and promote extraction. With the increase of extraction time, the gas pressure around the extraction boreholes on both sides of the blasting hole is continuously reduced, and the range of extraction and pressure relief is gradually expanded and started to conduct, with obvious pressure relief effect. In the early stage of extraction, the pressure relief area of the two extraction holes was circular, and gradually evolved into "∞" distribution after 90 days. More effective pressure relief close to the side of the blasting hole was more obvious. After 180 days, more effective pressure relief is further expanded, and the coal seam surrounding borehole is influenced by the pressure relief and permeability enhancement of the blasting hole.

Figure 4 shows the radial gas pressure versus distance in the borehole at 10 d, 30 d, 90 d and 180 d. Figure 4a shows changes in gas pressure over distance for conventional gas extraction. The gas pressure in the seam gradually decreases over time, with the greatest reduction in gas pressure between 10 d and 30 d. As the mining time increases, the gas pressure drop decreases and the rate of gas pressure drop becomes slower. Figure 4b shows the variation of gas pressure with distance when using static blasting for enhanced gas extraction. The rate of gas pressure drop is significantly higher for enhanced gas extraction using static blasting than for conventional gas extraction. The reason is that the surrounding rock is cracked by the expansion pressure generated by static expansion material acting on the boreholes. At the same time, the porosity and permeability increase greatly with internal fracture of seams and the development of a large number of fractures in coal and rock mass, and the permeability is significantly enhanced. It provides a channel for gas extraction, and the gas extraction efficiency is significantly improved. The gas pressures measured at the observation points of conventional gas extraction at 10, 30, 90 and 180 d were 0.199 MPa, 0.197 MPa, 0.187 MPa and 0.178 MPa, respectively. The gas pressures measured at the observation points at the 10, 30, 90 and 180th days of static blasting enhanced gas extraction were 0.178 MPa, 0.166 MPa, 0.153 MPa and 0.143 MPa, respectively. It is obvious that compared with conventional gas extraction, the extraction efficiency of enhanced gas extraction is significantly improved.

4.1.2. Gas Content Change

Figure 5 is the conventional gas extraction and use static blasting to enhance permeability and promote extraction in 10 d, 30 d, 90 d, 180 d coal seam gas content change cloud map. Figure 5a shows the change of gas content after conventional gas extraction. The area of reduced gas content is progressively expanded from the center of the extraction hole, but the decreasing area and the decreasing speed are slow. Conversely, in Figure 5b, the scope and reduction rate of gas content in the same period are significantly improved by using static blasting technology. At 30 d, the gas pressure relief range under conventional gas extraction has not yet been penetrated, and it began to penetrate gradually to the inside of the extraction hole after 90 d. The pressure relief range of static blasting enhanced extraction has been penetrated at 30 d, and the pressure relief area around the two extraction holes has been fully penetrated after 90 d. This is because in the borehole pressure relief ring after static blasting, the permeability is significantly enhanced by connection between artificial fracture and primary cutting and structural fracture of coal body. Under the negative pressure, free gas in fracture circle is quickly pumped to the ground through the fracture to the direction of the extraction borehole. The original balance of the seam is broken, the adsorbed gas is quickly desorbed and diffused from the surface of the coal matrix. Finally, it is continuously poured into the extraction system through the fracture network.



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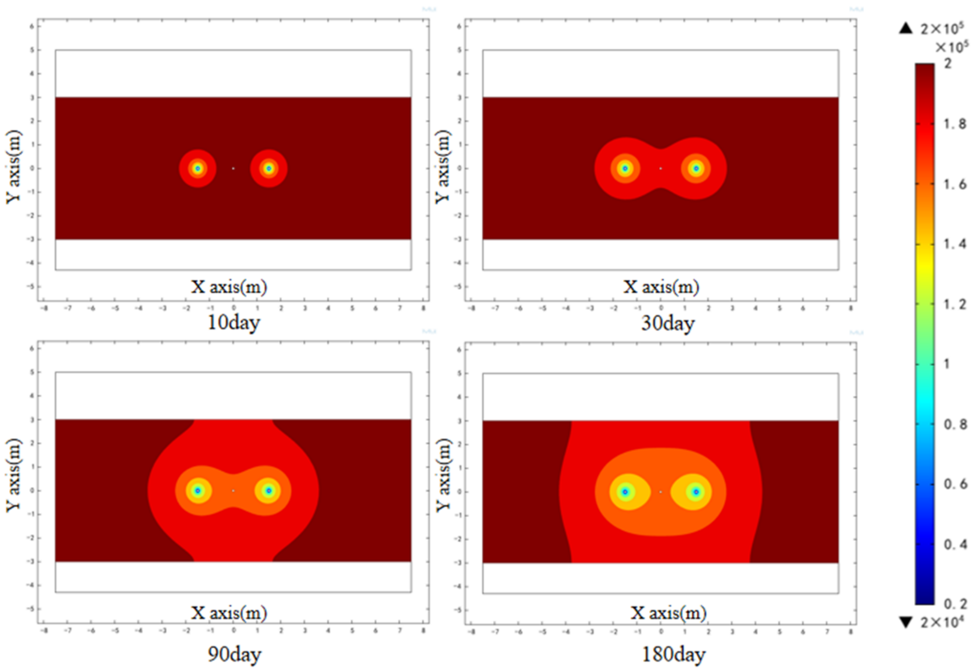
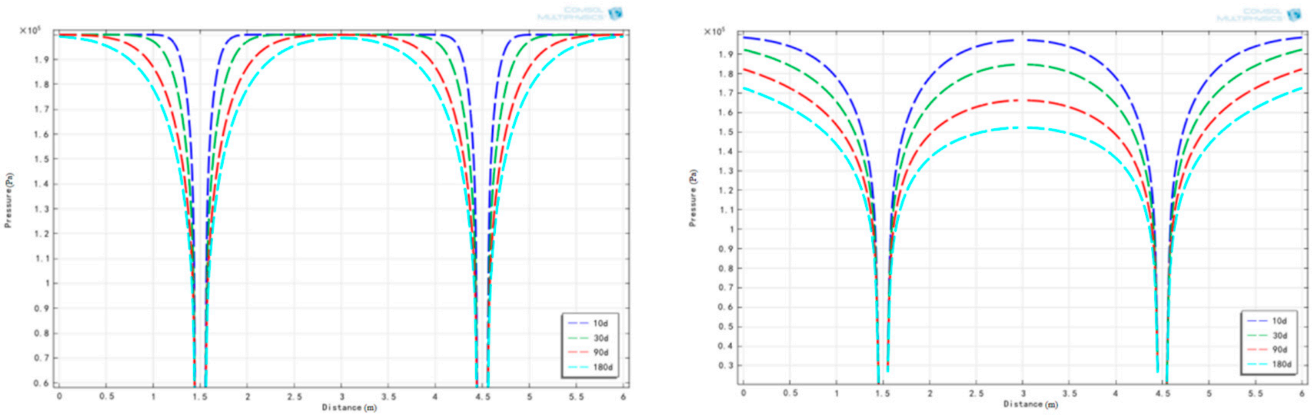


(**b**)

Figure 3. Gas pressure distribution under conventional extraction and static blasting enhanced extraction. (**a**) Gas pressure distribution map under conventional gas extraction. (**b**) Distribution map of gas pressure under gas extraction enhanced by static blasting technology.



(**a**) (**b**)

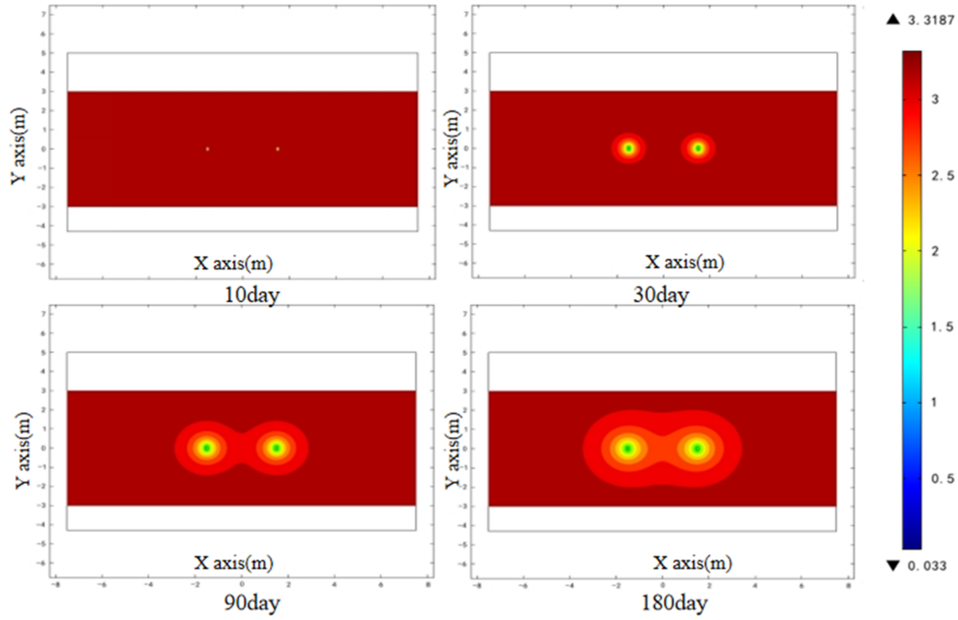
Figure 4. Gas pressure curve of conventional gas extraction and static blasting enhanced gas extraction with distance. (**a**) Conventional gas extraction. (**b**) Static blasting enhanced gas extraction.

4.1.3. Strain of Coal Plastic Zone

Figure 6 shows the change of coal plastic zone under conventional gas extraction and static blasting. After drilling in the seam, when the stress around the borehole exceeds the yield limit, the seam around the borehole changes from elastic state to plastic state, and coal rock mass in the plastic state is the plastic zone. Figure 6a shows the change of plastic zone of coal after conventional gas extraction. The shape of the butterfly wing is regular around the extraction hole, and the influence radius of the plastic zone is 0.12 m. Figure 6b shows the change of the plastic zone of coal mass after blasting using static blasting technology. The change of the plastic zone around the blasting hole presents a nearly symmetrical spindle shape. The plastic zone expands about 0.430 m along the horizontal sides of the borehole and extends 1.455 m up and down in the vertical direction. This is because the stress of coal and rock in the borehole will be redistributed after static blasting. Stress in the local area of coal rock around the borehole exceeds coal strength. Compared to conventional gas extraction, the plastic zone of seam and rock will produce greater damage. The range of the plastic strain zone will further increase, and the expansion of cracks will increase. The range of the plastic zone and pressure relief zone will gradually increase with the generation of expansion pressure. For the gas extraction process, the larger the plastic zone created by the coal body around the borehole, the wider the range of fissures created and the greater the permeability, the more conducive to gas extraction and the increase in extraction rate.

4.1.4. Changes of Permeability and Porosity

Figure 7 shows the variation of coal permeability and porosity during conventional gas extraction and static blasting. Figure 7a shows the changes of permeability and porosity after conventional gas extraction. As seen in Figure 7a, as gas pressure gradually decreases with gas extraction of coal rock masses, coal stresses skeleton increases, the reservoir pressure of coalbed methane decreases, coalbed methane desorption, coal matrix shrinkage, the internal permeability and porosity of the coal body will gradually increase with the gas extraction. It increased rapidly from 10 d to 60 d, and the increasing speed gradually tended towards flat after 60 d. Figure 7b shows the variation of permeability and porosity after permeability enhancement by static blasting. Compared with the low increase of permeability and porosity for processes of conventional gas extraction and its weak anti-reflection effect, it can be clearly seen that the increase of permeability and porosity of the coal body after static blasting is much larger than that of conventional gas extraction, and its growth rate shows multiple growth. At 180 d, 7.26 times increase in permeability and porosity compared to starting permeability and porosity. The reason is that expansion pressure of static expansive agent is used to make cracks efficiently in the borehole, and the fracture pressure relief ring filled with complex fracture network system is formed in the seam. In the fracture relief ring, the strain of the coal body increases and the effective stress in seam changes owing to the failure of the crack on the seam and the diversion and permeability increase of the gas, which causes the change in the pore space and fractures within the seam. Due to the increase of surface free energy of the matrix micro pores, new pores and cracks will be produced, so that the permeability and porosity increase.



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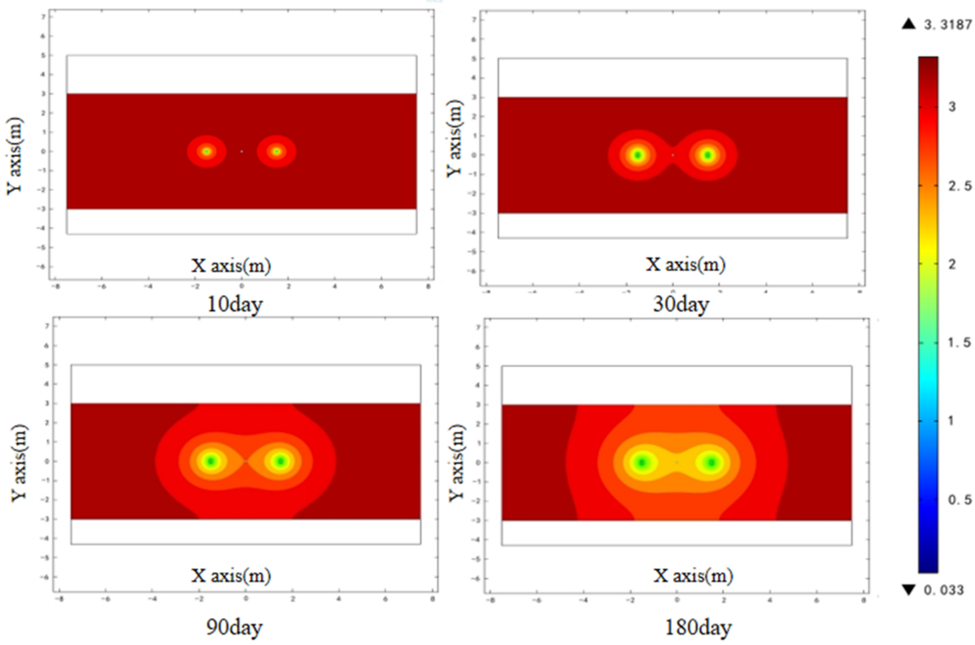
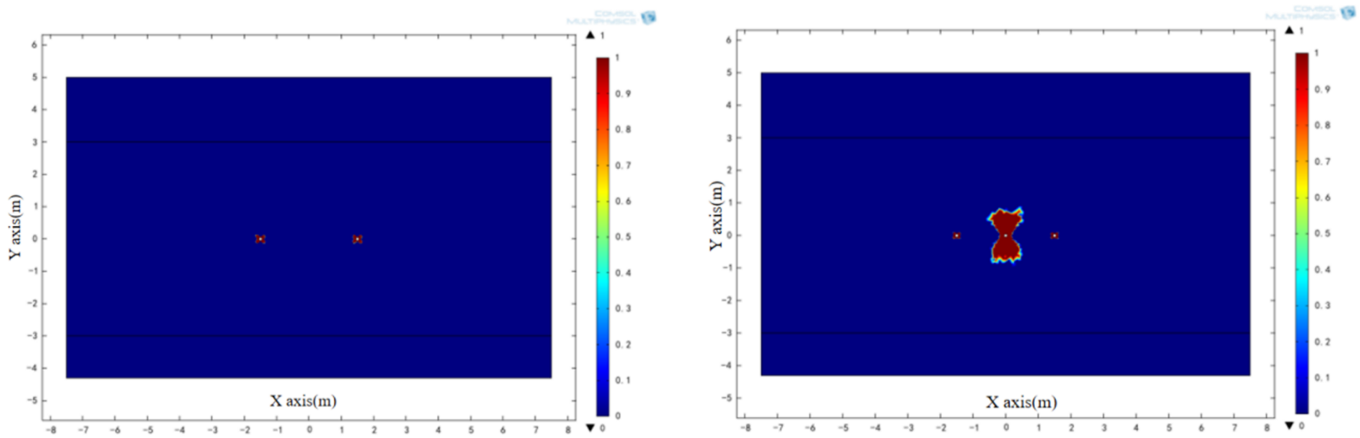


(**b**)

Figure 5. Changes of gas content under conventional gas extraction and static blasting enhanced gas extraction. (**a**) Gas content change under conventional gas extraction. (**b**) Gas content change under static blasting.



(**a**) (**b**)

Figure 6. Plastic strain zone of conventional gas extraction and enhanced gas extraction. (**a**) Conventional gas extraction plastic strain zone. (**b**) Enhanced gas extraction plastic strain zone.

4.2. Effect of Different Influence Factors on Enhanced Extraction

For exploring the different factors influencing the use of static blasting technology for enhanced gas extraction for low permeability coal seams, the control single variable method was used to analyze the influence of different expansion pressures, extraction negative pressures, overburden pressures, spacing of extraction holes and the number of blasting holes on the change of gas pressure. The specific implementation plan is shown in Table 2.

Table 2. Implementation Scheme of Numerical Simulation under Different Parameters.

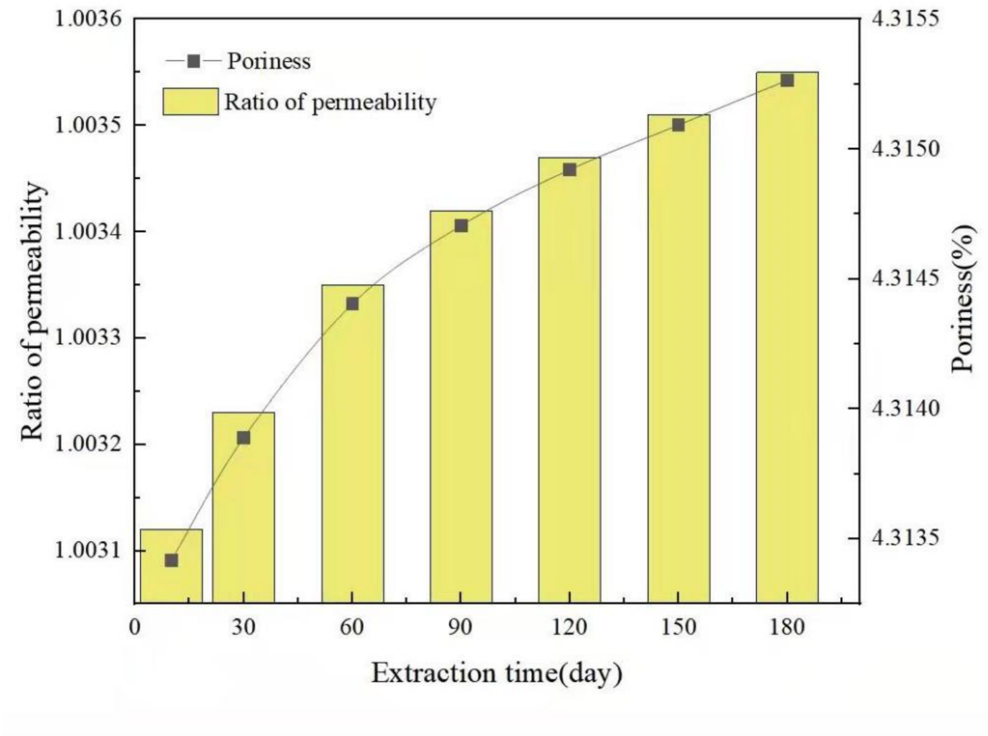
Parameters	Variable	Actual Conditions
Expansion pressure	20 MPa; 30 MPa; 40 MPa	40 MPa
Negative pressure of extraction	15 kPa; 20 kPa; 25 kPa	20 kPa
Overburden pressure	6 MPa; 10 MPa; 12 MPa	10 MPa
Spacing of extraction holes	3 m; 4 m; 5 m	3 m
Number of blasting holes	1; 2; 3	1

4.2.1. Expansion Pressure

Figure 8 is a curve of the change in gas pressure at the reference point at different expansion pressures for enhanced gas extraction using static blasting techniques to enhance gas extraction. As seen in the Figure 8, the higher the expansion pressure generated by static blasting, the faster the gas pressure drop rate of coal seam. Under the same conditions, high expansion pressure would create a significant amount of cracking, and the range of plastic strain zone of coal will further expand, and the range of pressure relief will increase.

4.2.2. Extraction Negative Pressure

Figure 9 is a curve of gas pressure variation at different extraction negative pressures. It can be seen from the diagram that the change in negative pressure in the extraction hole has a very weak influence on seam gas pressure as the duration of gas extraction time is from 10 d to 30 d. The greater the negative pressure of the extraction hole, the greater the decline of the gas pressure, but the overall change is not obvious relative to other influencing factors. The change of the negative pressure of the extraction hole has a weak influence on the decline of the gas pressure of whole coal seam.



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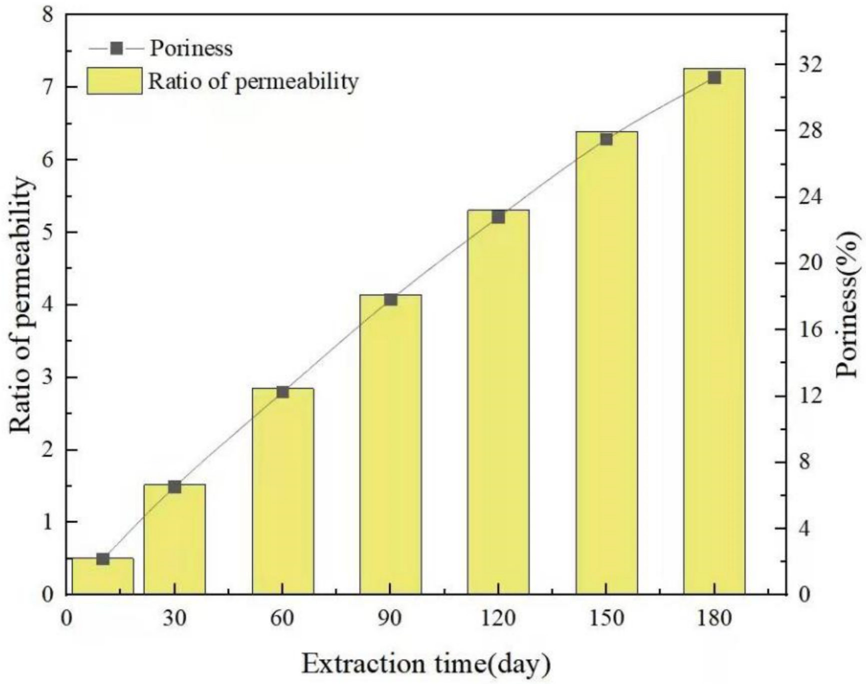

(**b**)

Figure 7. Changes of permeability ratio and porosity under conventional extraction and enhanced gas extraction. (**a**) Change of permeability ratio and porosity under conventional gas extraction. (**b**) Changes in permeability ratio and porosity under enhanced gas extraction.

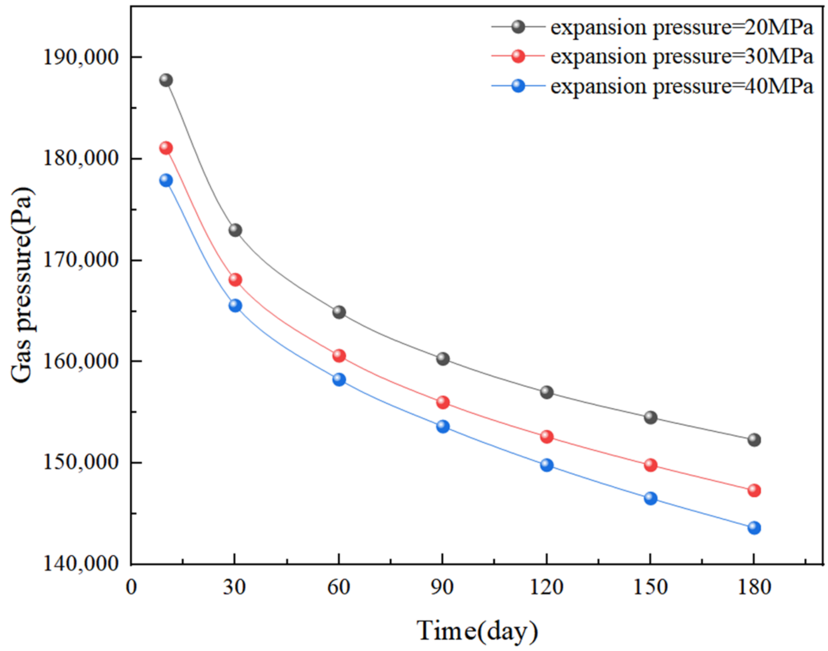

Figure 8. Gas pressure changes under different expansion pressures.

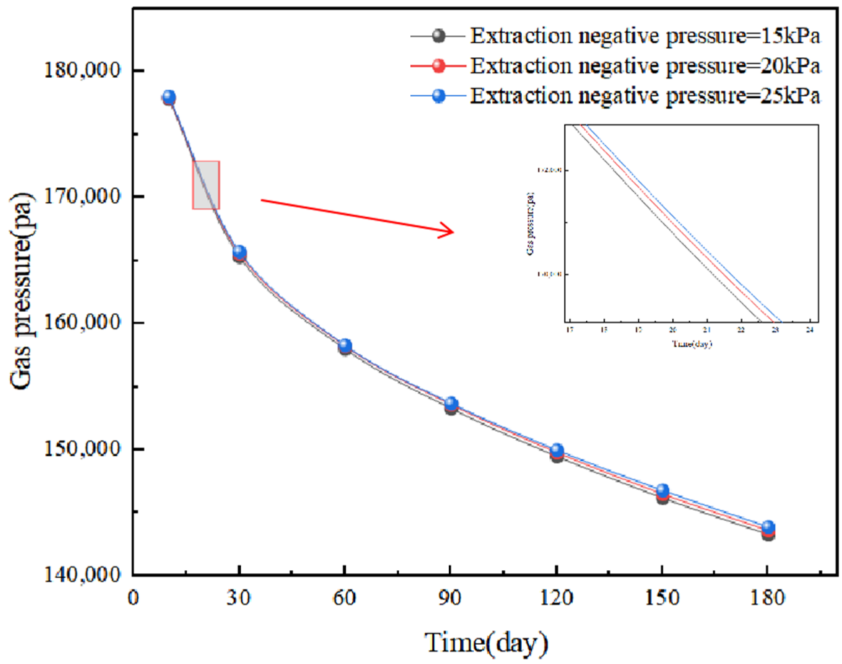

Figure 9. Gas pressure changes under different extraction negative pressures.

4.2.3. Overburden Pressure

Figure 10 is a curve of gas pressure variation at different overburden pressures. From Figure 10 it is evident that the different ground stresses have a very significant effect on extraction: when the overburden pressure on the coal body is small, the extraction effect is better, the drop in gas pressure within the coal seam is very significant; when the overburden pressure of coal body is large, gas pressure decreased slowly, the decline decreased, and the decline curve of gas pressure gradually tends to be gentle after 120 days. This is due to overburden pressure causing difficulties in gas flow within the coal seam, increased difficulty in extracting gas from extraction holes and slow reduction in gas pressure. It follows that the trend of gas pressure decrease under high ground stress conditions is significantly less than that under low ground stress conditions.

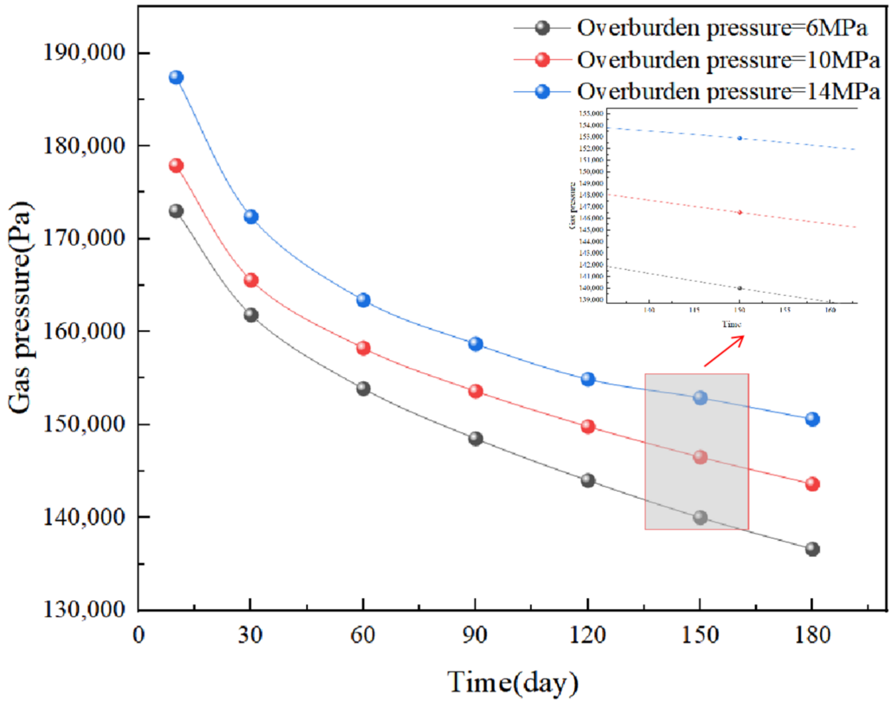

Figure 10. Gas pressure changes under different overburden pressures.

4.2.4. Spacing of Extraction Holes

Figure 11 is the gas pressure change curve of different spacing of extraction holes. When gas is extracted for 10 d to 60 d, the gas pressure drops more rapidly at the measurement points near the center of the borehole, the gas pressure changes sharply, and the decrease is large. However, the difference in the initial gas extraction effect was not obvious under different spacing of extraction holes conditions. After 60 days, the gas pressure drop curve began to slow down compared with the early extraction, and gas extraction effect began to gradually widen the gap. At various extraction drill hole spacing conditions, as the extraction drill hole spacing increases, the effect of extraction stacking on gas pressure in the vicinity of extraction boreholes is reduced. The effect of gas extraction is influenced by the spacing between extraction boreholes. When the distance between two extraction boreholes is 3 m, the gas pressure decreases with the extension of extraction time and the gas extraction effect is the best. As the spacing increases, the gas pressure decreases at a slower rate with time, and the effect of gas extraction decreases. It can therefore be argued that adjacent boreholes will have an overlapping. The closer the drill holes are to each other, the better the gas extraction effect.

4.2.5. Number of Blasting Holes

Figure 12 is a curve of gas pressure variation for different numbers of blasting holes. During gas extraction, plastic failure will occur when blasting holes are set for expansion cracking and permeability enhancement, but the influence range of multiple blasting holes is much higher than that of single hole blasting. It is evident from Figure 12 as the number of blasting holes is increased to three, the decline rate and amplitude of gas pressure are higher than that of setting one blasting hole and two blasting holes. This is due to the change of coal body stress and the increase of cracks after porous blasting. After blasting, as the cracks generated by expansion pressure in the middle area of the blasting hole appear through cracks developed along the vertical direction of the blasting hole connection, there is a rapid increase in effective stress in coal, and cracks in a certain area of rock mass between blasting holes develop secondary. The degree of damage and fragmentation of coal increases, the plastic strain zone increases, and plastic damage is strong. The mine permeability has improved significantly, and gas extraction has improved significantly.

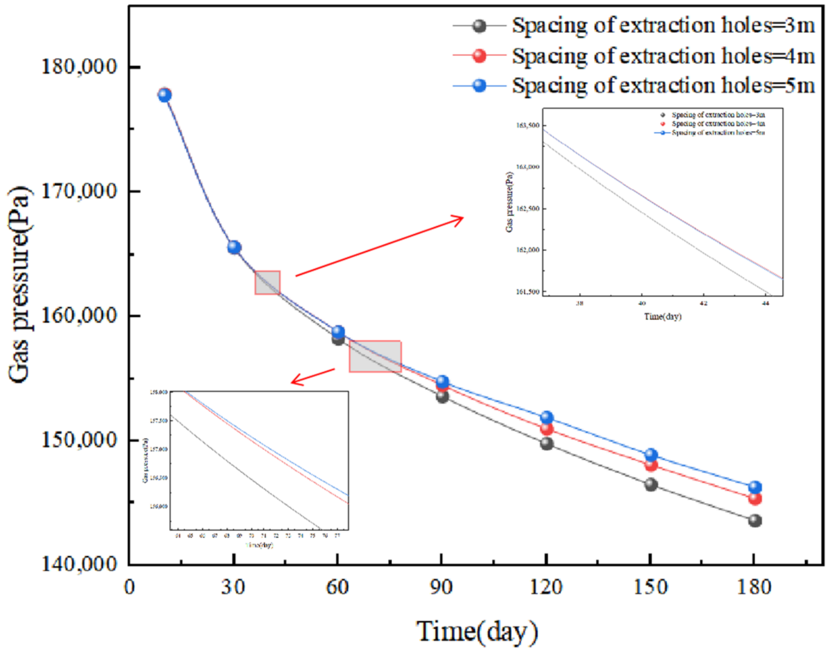

Figure 11. Changes of gas pressure with different spacing of extraction holes.

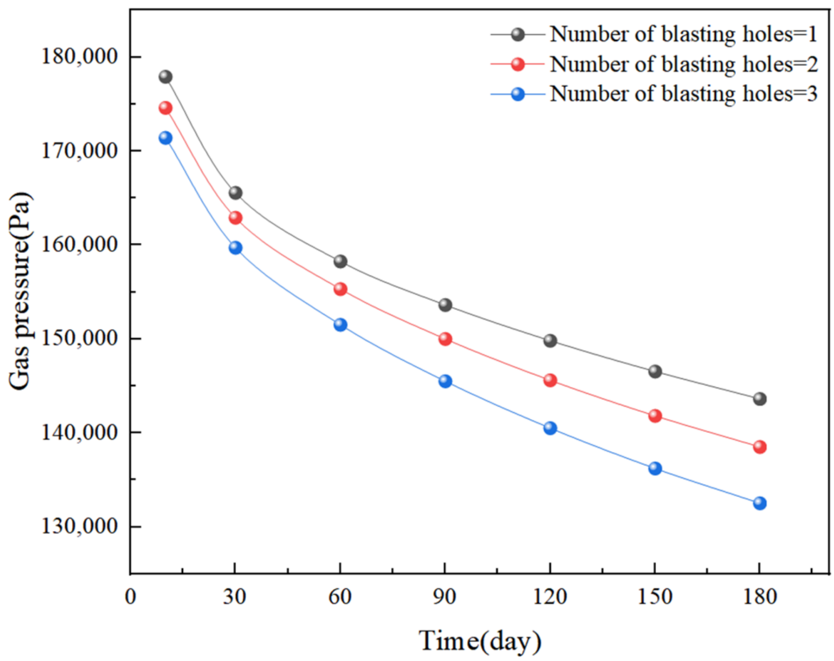

Figure 12. Changes of gas pressure with 1, 2 and 3 blasting holes.

5. Conclusions

This study has developed a new technology for enhanced mine gas extraction using static blasting, using the No. 2 coal seam of Wangjialing Mine as the engineering background, which differs from previous knowledge on the lack of gas monitoring and changes during the process of increasing permeability and promoting extraction. The study compares the effect of gas extraction after conventional gas extraction and static blasting and discusses the influencing factors in the static blasting process. The conclusion are:

(1) By means of numerical simulation, gas pressure changes under conventional extraction and static blasting enhanced extraction are studied. It is found that the gas pressure measured by static blasting technology at the observation point position is 0.178 MPa, 0.166 MPa, 0.153 MPa and 0.143 MPa at 10, 30, 90 and 180 d, respectively, which is 1.241 times the efficiency of conventional gas extraction.
(2) During static blasting, cracks develop rapidly due to effects of blast hole expansion stresses on the cracking of the coal body, the influence range of plastic zone is expanded, the permeability and porosity are increased by 7.26 times compared with conventional gas extraction, and the permeability is significantly improved.
(3) For the exploration of different influencing factors in the static blasting process, gas extraction by static blasting is primarily affected by the expansion pressure produced by blasting agent, overburden pressure, spacing of extraction holes and the number of blasting holes, and the effect of extraction negative pressures is small. These influencing factors can be appropriately adjusted to improve the extraction effect.

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