Research Article

Coal Seam Gas Extraction by Integrated Drillings and Punchings from the Floor Roadway considering Hydraulic-Mechanical Coupling Effect

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Owing to the exhaustion of shallow coal resources, deep mining has been occupied in coal mines. Deep buried coal seams are featured by the great ground stress, high gas pressure, and low permeability, which boost the risk of gas disasters and thus dramatically threaten the security about coal mines. Coal seam gas pressure and gas content can be decreased by gas extraction, which is the primary measure to prevent and control mine gas disasters. The coal mass is simplified into a continuous medium with dual structure of pores and fractures and single permeability. In consideration of the combined effects of gas slippage and two-phase flow, a hydraulic-mechanical coupling model for gas migration in coals is proposed. This model involves the equations of gas sorption and diffusion, gas and water seepage, coal deformation, and evolution of porosity and permeability. Based on these, the procedure of gas extraction through the floor roadway combined with hydraulic punching and ordinary drainage holes was simulated, and the gas extraction results were used to evaluate the outburst danger of roadway excavation and to verify the engineering practice. Results show that gas extraction can reduce coal seam gas pressure and slow down the rate of gas release, and the established hydraulic-mechanical coupling model can accurately reveal the law of gas extraction by drilling and punching boreholes. After adopting the gas extraction technology of drilling and hydraulic punching from the floor roadway, the remaining gas pressure and gas content are reduced to lower than 0.5 MPa and 5.68 m³/t, respectively. The achievements set a theoretical foundation to the application of drilling and punching integrated technology to enhance gas extraction.

1. Introduction

As the depth of coal mining increases, the gas pressure and content in coals have increased. Gas accidents such as coal and gas outbursts and gas explosions have occurred frequently, which threaten coal mine safety production [1, 2]. Gas extraction can reduce coal seam gas pressure and gas content, eliminate outburst hazards, and seems significant to forestall gas accidents [3]. Reasonable drainage borehole layout parameters can avoid drainage blind areas between boreholes, increase gas extraction volume, decrease the amount of drilling, and lower the capital expenditure of gas extraction engineering projects. The rule of gas migration in coal seam is figured out, which is critical to determine rational drainage drilling arguments [4].

With regard to the gas migration in coals, the interaction between coal and gas has been explored by numerous scholars. They believe that changes in coal seam forces and changes in gas pressure will deform the coal body, causing changes in porosity and permeability, and proposed many gas-solid coupling models. For instance, the gas-solid coupling model of coal and gas under different stress conditions was demonstrated by Wang et al. [5], Yang et al. [6], and Connell [7]. After that, the effect of gas sorption on coal deformation was illustrated to the gas-solid coupling responses [8, 9]. Xia et al. [10, 11] and Wang et al. [12]
proposed a coupled model of coal deformation and compositional flow for the premining coal seam gas extraction. Yang et al. [13] combined the evolution of stress, damage, and gas permeability with the deformation of coal and rock. Gao et al. [14] and Liu et al. [15] considered the thermal effect for extraction of coal seam gas with slotted boreholes. Zhao et al. [16] simulated the in situ gas desorption behavior of the coal seam gas. The research results have guiding significance for the optimization of drainage hole layout.

2. Hydraulic-Mechanical Coupling Model for Gas Extraction from Coal Seams

In accordance with the gas storage environment in coals, some hypotheses are proposed [10, 21–23]. (1) Coal mass is an elastic continuous medium with dual structure of pores and fractures and single permeability. (2) Water only occurs and migrates. The adsorbed and desorbed gas exists within both pores and fractures, while water is only transported in the fracture. The process of gas adsorption/desorption is consummated in a moment. (3) Gas migration seems to closely correlate with the microcromic structure of coals. It can be divided into three steps in series: firstly, the adsorbed gas desorbs into the space of pores satisfying the Langmuir law; then, the gas diffuses from the pores to fractures satisfying Fick’s law; finally, the gas seeps from the fracture into the gas well satisfying Darcy’s law. (4) Gas seems in accord with the equation of ideal gas. (5) The volume force of the gas is ignored.

2.1. Controlling Equation of Seepage Field. Coal seam is a porous organic mineral buried in the rock stratum. Coal seam is not only the gas source of coalbed methane but also the storage reservoir for coalbed methane. It is featured by pore-fracture dual structure. The gas mass in the coal matrix seems comprised of adsorbed and free gas, which can be defined as [24]

\[ m_m = \phi_m \rho_g + V_{sg} \rho_s \rho_{mg}, \]

where \( \phi_m \) is the matrix porosity, \( \rho_g \) is the density of the gas (kg/m\(^3\)), \( V_{sg} \) is the adsorbed gas content (m\(^3\)/kg), \( \rho_s \) is the density of the coal skeleton (kg/m\(^3\)), and \( \rho_{mg} \) is the density of gas under standard conditions (kg/m\(^3\)).

In accordance with the ideal gas equation of state, the density of gas is

\[ \rho_g = \frac{M_g}{RT} p, \]

where \( M_g \) is the gas molar mass (kg/mol), \( R \) is the gas molar constant (/mol-K), \( p \) is the gas pressure (MPa), and \( T \) is the coal bed temperature (K).

Considering the modified Langmuir law, the adsorbed gas in the coal matrix can be illustrated [10]:

\[ V_{sg} = \frac{V_L p_m}{p_L + p_m}, \]

where \( V_L \) is the Langmuir volume constant (m\(^3\)/kg), \( p_L \) is the Langmuir pressure constant (Pa), and \( p_m \) is the CBM pressure in the matrix (MPa).

In the initial state, the gas desorption rate equals the gas adsorption rate in the coal matrix, namely, the equilibrium state of sorption. The gas pressure in pores is the same with that in the fractures. The operation of gas extraction will break this equilibrium state. As a result, the adsorbed gas desorbs and migrates to the fractures by means of gas diffusion. Based on Fick’s law and mass conservation law, the equation of gas transport in the matrix is [19]

\[ \frac{\partial m_m}{\partial t} = -\frac{M_g}{\tau RT} \left( p_m - p_{fg} \right), \]

where \( p_{fg} \) is the gas pressure in the fissure (MPa) and \( \tau \) is the gas desorption time, which equals the time it takes for the matrix to desorb 63.2% of the adsorbed gas and can be acquired through the desorption experiment of coal samples.

Submitting equations (1)–(3) into equation (4), the gas transport equation in the coal matrix can be acquired:

\[ \frac{\partial}{\partial t} \left( \frac{V_L p_m}{p_L + p_m} \rho_s \frac{M_g}{RT} p_m + \phi_m \frac{M_g}{RT} p_m \right) = -\frac{M_g}{\tau RT} \left( p_m - p_{fg} \right). \]

Groundwater and gas exist in the fracture system at the same time, and the fluid migration is a two-phase flow. The desorbed gas from the coal matrix acts as the mass...
source of fractures. The governing equations for gas transport in the fracture can be defined as [25]

\[ \frac{\partial (s_f \varphi_f \rho_g)}{\partial t} + \nabla \cdot (\rho_g \varphi_f \mathbf{q}_g) = (1 - \varphi_f) \frac{M_g}{\tau RT} (\rho_m - \rho_g), \] (6)

\[ \frac{\partial (s_w \varphi_w \rho_w)}{\partial t} + \nabla \cdot (\rho_w \varphi_w \mathbf{q}_w) = 0, \] (7)

where \( S_g \) is the gas phase saturation, \( \varphi_f \) is the fracture porosity, \( \mathbf{q}_g \) is the gas flow velocity (m/s), \( S_w \) is the water phase saturation, \( \rho_w \) is the water density (kg/m\(^3\)), and \( \mathbf{q}_w \) is the water flow velocity (m/s).

In consideration of the slippage effect, combined with the generalized Darcy’s law of gas-water two-phase seepage, the flow velocity of gas and water in the fracture is [25, 26]

\[ q_g = -\frac{kk_{fg}}{\mu_g} \left( 1 + \frac{b_1}{P_{fg}} \right) \nabla P_{fg}, \] (8)

\[ q_w = -\frac{kk_{rw}}{\mu_w} \nabla P_{tw}, \] (9)

where \( k \) is the absolute permeability of the fracture (m\(^2\)), \( k_{fg} \) is the relative permeability of the gas phase, \( \mu_g \) is the gas phase dynamic viscosity (Pa·s), \( b_1 \) is the slip factor (Pa), \( \mu_w \) is the water phase dynamic viscosity (Pa·s), and \( P_{tw} \) is the pressure of the fracture in the fissure (MPa).

Incorporating equation (8) into equation (6) and equation (9) into equation (7), the control equation of the gas and water seepage field can be obtained:

\[ \frac{\partial}{\partial t} \phi_i \frac{M_g}{RT} P_{fg} + \nabla \cdot \left( -\frac{M_g}{RT} \left( \rho_m + \frac{b_1}{RT} kk_{rw} \right) \nabla P_{fg} \right) = (1 - \varphi_f) \frac{M_g}{\tau RT} (\rho_m - \rho_g), \] (10)

\[ \frac{\partial}{\partial t} \left( s_w \varphi_f \rho_w \right) + \nabla \cdot \left( -\frac{kk_{rw}}{\mu_w} \nabla P_{tw} \right) = 0. \] (11)

2.2. Controlling Equation of Stress Field. The coal deformation is caused by the combination of stress, gas and water pressure, and gas sorption. Thus, the strain of coal mass is presented as [23]

\[ \varepsilon_{ij} = \frac{1}{2G} \sigma_{ij} - \left( 1 - \frac{1}{9K} \right) \sigma_{kk} \delta_{ij} = \frac{\alpha_m P_m + \alpha_i P_i}{3K} \delta_{ij} + \frac{\varepsilon_s}{3} \delta_{ij}, \] (12)

where \( \delta_{ij} \) is the Kronecker symbol; \( D \) is the equivalent coal elastic modulus (GPa), and \( D = 1/(1/E_s + 1/(aK_s)) \); \( G \) is the coal shear modulus (GPa), and \( G = D/2(1 + v) \); \( K \) is the bulk modulus of coal (GPa), and \( K = D/(1 - 2v) \); \( K_s \) is the bulk modulus of the coal skeleton (GPa), and \( K_s = E_s/(1 - 2v) \); \( E_s \) is the elastic modulus of the coal skeleton (GPa); \( K_e \) is the fracture stiffness (GPa); \( v \) is Poisson’s ratio; \( a_m \) and \( a_i \) are the Biot effective stress coefficients corresponding to pores and cracks, respectively, \( a_m = 1 - K/K_s \), and \( a_i = 1 - K/(aK_s) \); \( \varepsilon_s \) is the adsorbed gas strain of the framework; \( P_i \) is the pressure of the fracture fluid (MPa); and \( a \) is the width of the coal matrix (m).

The adsorbed gas strain of the skeleton is proportional to the adsorbed amount [19]:

\[ \varepsilon_s = a_g V_{sg}, \] (13)

where \( a_s \) is the gas adsorption capacity (m\(^3\)/kg) and \( V_{sg} \) is the gas adsorption capacity (m\(^3\)/kg).

Obeying the elastic mechanics theory, the following equations can be obtained:

\[ \begin{cases} \varepsilon_{ij} = \frac{1}{2} (u_{ij} + u_{ji}), \\ \sigma_{ij} + P_i = 0, \end{cases} \] (14)

where \( F_i \) is the volume force (MPa) and \( u_i \) is the displacement in the \( i \) direction (m), where \( i = x, y, z \).

Combining equations (12) and (14), the modified Navier equation that considers pore pressure, changes, and adsorption, that is, the stress field governing equation is obtained:

\[ G \varepsilon_{ij} + \frac{G}{1 - 2v} u_{ij} - \alpha_m P_{mj} - \alpha_i P_{ij} - K e_{ax} + F_i = 0. \] (15)

2.3. Porosity and Permeability Equation. Porosity and permeability are the critical arguments for gas migration in the procedure of extraction and closely correlate with the stress and the mechanical properties of coals. The mesostructure of coal mass with the conceptual model is shown in Figure 1. The variation of the width of the matrix and fracture will change the magnitude of porosity and permeability in coal, resulting in the evolution of mass transport in coal seam.

The porosity in the coal matrix can be described as [27]

\[ \varphi_m = \frac{1}{1 + S} \left( \varphi_{m0} (1 + S_0) + \alpha_m (S - S_0) \right), \] (16)

where \( S = e_v + P_{mj}/K_s - e_s - e_a \), \( e_v \) is the volumetric strain of coal, and subscript “0” means the initial state of variables.

The fracture porosity can be defined as [27]

\[ \varphi_i = \varphi_{i0} \left( -3 \varphi_{i0} (\Delta e_a - \Delta e_v) / \varphi_{i0} + 3K_i/K \right), \] (17)

where \( K_i \) is the improved fracture stiffness, \( K_i = bK_s \) (GPa), and \( b \) is the width of the fracture (m).
The cubic law is used to express the association between the coal seam fracture permeability ratio and the porosity ratio [28, 29]:

$$\frac{k}{k_0} = \frac{\phi_f}{\phi_{f0}}^{3/6}$$

Substituting equation (17) into equation (18), the fracture permeability can be acquired:

$$k = k_0 \left(1 - \frac{3(\Delta e_\text{a} - \Delta e_\text{f})}{\phi_{f0} + 3K_f/K} \right)^3$$

where $k_0$ is the initial permeability ($m^2$).

Combining equations (5), (10), (11), and (15), the hydraulic-mechanical coupling model for gas migration in
coal seams is established. These equations can be programmed into COMSOL Multiphysics to simulate gas extraction through boreholes from the floor roadway.

3. Geometric Model and Definite Solution Conditions

3.1. Research Background. The studied coal mine is located at Pingdingshan, with about 4 km in length and 3 km in width. The area is about 12.87 km², and the approved production capacity is 1.4 Mt/a. The dynamic disaster phenomenon transpired 28 times in this mine. The maximum volume of outburst gas is 25704 m³, and the maximum outburst coal is 293 t. As the shallow coal resources are exhausted, mining operation has been moving into deep seam. The deep buried coal seams show the characteristics of complex occurrence conditions, large in situ stress, high gas content, and low penetrance. Gas extraction becomes more difficult and the outburst risk increases.

The panel 31020 is located in the upper part of the west wing of the third level (Figure 2). It is adjacent to the panel 17220 that has been mined to the south and the panel 31040 that has not yet been mined to the north. Panel 31020 is mining the coal seam. The coal seam is relatively stable and the structure is simple. The inclination angle of the coal seam is 8°-11°, with an average of 10°. The thickness of the coal seam is about 3.2 m~4.5 m, the average coal thickness is 3.3 m, the original gas content is 14.97 m³/t, the original gas pressure is 1 MPa, and the original ground temperature is 29.4°C~32.2°C. The roadway 31020 for air intake has a strike length of 761 m and is driven along the roof of coal seam C15, with a distance of 11 m to 14 m from the overlying coal seam C14 and 1.5 m to 12 m from the underlying coal seam C16-17. The construction of roadway 31020 was carried out at a position staggered 20 m outside the floor gas extraction roadway, and the distance between the two roadways was 18 m. The elevation of the roadway 31020 is -630 m to -696 m, and the vertical buried depth is 880 m to 976 m. The cross section of the roadway is 4.6 m × 3.4 m, and it is supported by rectangular anchor mesh cable beams, and the row spacing is 700 mm.

3.2. Geometric Model Construction. The roadway 31020 for air intake needs to adopt effective gas extraction measures to reduce gas pressure and ensure safe operation of roadway advancing. Therefore, the gas extraction plan of drilling through the floor roadway is adopted to prevent outburst in the area of the roadway 31020. Starting from the opening of the floor roadway at 35 m inward, a set of drilling holes are designed every 6 m. Each set of designed drilling holes has a diameter of 89 mm, and the hole depth is 0.5 m from the roof of C15 coal seam. 127 sets of predrainage drilling boreholes were constructed in the floor roadway, including 1143 ordinary drillings and 318 punchings. In addition, hydraulic punching begins at the 462 m distance from the opening of the floor roadway (15 m ahead of the roadway 31020), and 54 sets of hydraulic punchings were constructed in the direction of roadway 31020, with an interval of 6 m for each group. 6 punchings with an average hole depth of 28 m and a drilling with diameter of 89 mm are arranged. Figure 3 shows the layout plan of gas extraction by integrated drillings and punchings from the floor roadway. Among them, section A-A has 3 hydraulic punchings and 6 ordinary drillings [30], and section B-B has 6 hydraulic punchings, respectively, as shown in Figure 4.
In accordance with the gas extraction plan of roadway 31020, a geometric model was established to research the gas extraction effect and gas migration characteristics of the air intake roadway driving face, as shown in Figure 5. In order to observe the changes in gas pressure in the coal seam, two reference lines are set in the geometric model. They are the reference line C-D located in the middle of coal seam and the reference line E-F of the axis of roadway 31020.

3.3. Determination of Solution Conditions. The definite solution conditions of numerical simulation include boundary conditions and initial conditions. For the boundary conditions for the simulation of gas extraction by drilling through the floor roadway, the overburden gravity of 15.3 MPa in the z direction, horizontal stress of 18.8 MPa in the x direction, and horizontal stress of 12.8 MPa in the y direction are applied to the model. The bottom side of the geometry model is set as fixed boundary with zero of horizontal and vertical displacements, and the other two horizontal directions are the sliding boundaries that limit the horizontal displacement. The model is surrounded by an impermeable boundary. There is no flow of gas and water at the boundary. The external seepage boundary of the model is a gas non-permeable boundary. The drainage borehole wall is set as Dirichlet boundary conditions, and the drainage negative pressure is 20 kPa. Aimed at the initial conditions for the simulation of gas extraction by drilling through the floor roadway, the initial gas pressure of the coal seam is 1.0 MPa and the initial permeability is $1.8 \times 10^{-17}$ m$^2$. Relevant parameters are shown in Table 1.

4. Simulated Results of Gas Extraction before and after Roadway Excavation

4.1. Gas Pressure Distributions in Coal Seam before Roadway Excavation. As extraction time prolongs, the gas pressure decreases in coal seam, and the reduction range gradually expands until it extends to the entire coal seam. In the early stage of extraction, the gas pressure decreases in a small range after being extracted for 10 days. When gas extraction is operated for 120 days, the gas pressure decreased more significantly, and the gas pressure in most areas of coal seam decreased from the initial gas pressure of 1 MPa to less than 0.4 MPa. The effect of hydraulic punching seems significantly effective compared to that of ordinary drilling. There exist several dominant reasons. Firstly, hydraulic punching punches the coal body out of the borehole, which extends the touch area between the hole wall of the borehole and the coal seam. Secondly, the stress in coal seam around the hydraulic punchings is released after the coal mass is washed out, which increases the permeability of the coal seam and accelerates the rate of gas migration to the borehole; in consequence, the gas extraction productiveness is promoted.

4.2. Gas Pressure Distributions in Coal Seam after Roadway Excavation. The coal seam gas pressure distribution after different extraction times is taken as the initial pressure of gas in the coal seam during roadway excavation, which is imported into the outburst hazard simulation model to reevaluate the danger of coal and gas outburst after different

### Table 1: Relevant parameters for numerical simulation.

| Parameter                                | Value         | Parameter                                | Value         |
|------------------------------------------|---------------|------------------------------------------|---------------|
| Coal seam initial gas pressure ($p_0$, MPa) | 1.0           | Formation temperature ($T_0$, K)          | 300           |
| Gas adsorption volume constant ($V_1$, m$^3$/kg) | 0.0266        | Adsorption gauge factor ($\epsilon_{\text{max}}$, kg/m$^2$) | 0.06          |
| Gas adsorption pressure constant ($P_1$, MPa) | 0.568         | Gas molar mass ($M_g$, g/mol)             | 16            |
| Gas dynamic viscosity ($\mu_g$, Pa·s)     | $1.84 \times 10^{-5}$ | Molar gas constant ($R$, J/(mol·K))      | 8.314         |
| Hydrodynamic viscosity ($\mu_d$, Pa·s)    | $1.03 \times 10^{-3}$ | Standard temperature ($T_a$, K)           | 273.5         |
| Gas desorption time ($\tau$, d)          | 1.21          | Standard atmospheric pressure ($p_0$, kPa) | 101           |
| Initial coal porosity ($\phi_{\text{ini}}$) | 0.035         | Coal density ($\rho_c$, kg/m$^3$)         | 1410          |
| Initial fissure degree of coal ($\phi_{\text{fl}}$) | 0.012         | Initial permeability ($k_{\text{ini}}$, m$^2$) | $1.8 \times 10^{-17}$ |
| Slippage factor ($h_s$, MPa)             | 0.36          | Coal Poisson’s ratio ($\nu$)              | 0.35          |
extraction times. Figure 8 shows the distribution of gas pressure in the coal seam when the roadway is driven 60 m after 10, 30, 60, and 120 days of gas extraction.

After being extracted 10 days, the gas pressure in the coal seam is greater than 0.8 MPa, the gas in the coal seam before the excavation work quickly moves to the roadway, and the gas pressure decreases greatly. As the extraction time prolongs, the gas pressure gradient between the roadway wall and the coal seam decreases, the gas migration speed in the square coal body before the tunneling work decreases, and the amount of gas transported in a short time is greatly reduced. When the drainage time is 120 days, the gas pressure in the coal seam is reduced to about 0.3–0.4 MPa, the outburst risk is eliminated, and the outburst can be effectively controlled.

5. Drainage Effect during Field Application

The in situ experimental method is adopted to evaluate the remaining gas content and gas pressure. The remaining gas content and pressure are measured by setting gauges through the cross-layer boreholes in the floor roadway of
the roadway 31020 for air intake. It is judged that the regional outburst prevention measures are effective when the remaining gas content and the residual gas pressure are less than 6 m³/t and 0.6 MPa, respectively. If the remaining gas content is greater than or equal to 6 m³/t or the remaining gas pressure is greater than or equal to 0.6 MPa, continue to implement regional outburst prevention measures until the regional standard is reached. A set of test boreholes are

Table 2: Measured results of gas pressure and gas content.

| Drilling position | Drilling number | Vertical depth of measuring point (m) | Measuring point elevation (m) | Maximum pressure (MPa) | Gas content (m³/t) |
|-------------------|-----------------|--------------------------------------|------------------------------|------------------------|------------------|
| 50 m inward from the opening of the floor roadway | B1-1  | 904 | -654 | 0.3 | 5.0667 |
|  | B1-2  | 904 | -654 | 0.35 | 4.7032 |
| 100 m inward from the opening of the floor roadway | B2-1  | 906 | -656 | 0.25 | 4.8338 |
|  | B2-2  | 906 | -656 | 0.3 | 4.1869 |
| 150 m inward from the opening of the floor roadway | B3-1  | 909 | -659 | 0.4 | 5.4853 |
|  | B3-2  | 909 | -659 | 0.5 | 4.733 |
| 200 m inward from the opening of the floor roadway | B4-1  | 910 | -660 | 0.35 | 4.8716 |
|  | B4-2  | 910 | -660 | 0.3 | 5.229 |
| 250 m inward from the opening of the floor roadway | B5-1  | 911 | -661 | 0.3 | 5.0219 |
|  | B5-2  | 911 | -661 | 0.4 | 5.6859 |
| 300 m inward from the opening of the floor roadway | B6-1  | 913 | -663 | 0.45 | 4.5965 |
|  | B6-2  | 913 | -663 | 0.4 | 4.3454 |
| 350 m inward from the opening of the floor roadway | B7-1  | 915 | -665 | 0.3 | 5.1005 |
|  | B7-2  | 915 | -665 | 0.3 | 4.8301 |
| 400 m inward from the opening of the floor roadway | B8-1  | 918 | -668 | 0.4 | 5.0038 |
|  | B8-2  | 918 | -668 | 0.5 | 4.9156 |
| 450 m inward from the opening of the floor roadway | B9-1  | 918 | -668 | 0.3 | 5.2622 |
|  | B9-2  | 918 | -668 | 0.4 | 5.0408 |
| 500 m inward from the opening of the floor roadway | B10-1 | 920 | -670 | 0.3 | 5.2569 |
|  | B10-2 | 920 | -670 | 0.35 | 5.1177 |

Figure 8: Gas pressure distribution when roadway drives 60 m with different extraction times.
constructed every 50 m at the opening of the low-level gas extraction roadway from 50 m to 300 m. 10 groups are arranged. The remaining gas content and pressure are shown in Table 2.

In the measured results, the coal seam gas pressure is reduced by ~75%, and the gas content is reduced by ~70.27% after implementing the integrated drillings and punchings from the floor roadway. The maximum gas pressure and maximum gas content are reduced to 0.5 MPa and 5.68 m³/t, respectively. There was no gas dynamic phenomenon during the excavation of the roadway 31020. This proves the established hydraulic-mechanical model and its application in numerical simulation of gas extraction by integrated drillings and punchings from the floor roadway in underground coal mines.

6. Conclusions

(1) A hydraulic-mechanical coupling model of gas migration in coal seams was established, including the governing equations of the gas seepage field, water seepage field, and stress field, as well as porosity and permeability evolution equations. The influence of gas slippage effect and gas-water two-phase seepage was considered comprehensively.

(2) The process of gas extraction through the floor roadway through the integrated drillings and punchings was simulated, and the drainage results were used to reevaluate the outburst risk of roadway excavation. Results show that gas extraction can reduce coal seam gas pressure, slow down the rate of gas release, and effectively prevent outbursts.

(3) The integrated drillings and punchings from the floor roadway were adopted for engineering practice. The gas pressure in coal seam is lower than 0.5 MPa, while the gas content in coal seam is smaller than 5.68 m³/t.

In future works, the effect of geological structure and heterogeneity of mechanical properties of coal seam on the efficiency of gas extraction by integrated drillings and punchings from the floor roadway may be considered in the hydraulic-mechanical coupling model.

Data Availability

The data used in this article were from the simulation results by COMSOL Multiphysics. The data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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