Research Article

Experimental Study on Reynolds Number Evolution of Gas-Filled Coal

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The flow state of gas in coals is very complicated. We should pay attention to whether the permeability calculated by Darcy's law is in accordance with the actual situation. We conducted an experiment on coal permeability and deformation under fixing confining pressure and increasing axial stress conditions. The objective is to investigate the variation of Reynolds number Re . In this study, the dynamic evolution of the Reynolds number is calculated under the relevant assumptions. The Reynolds number increases with an increase in the axial stress. In addition, the larger the value of initial Reynolds numbers, the greater the value of Re in the postpeak, and the possibility of nonlinear flow state is higher. Further, if the mass density (ρ) and fluid viscosity (μ) are constant, the decrease in the amplitudes of the flow rate is less than the increase in the equivalent diameter of the seepage path. Moreover, the tensile stress generated around the pores and fractures parallel or nearly parallel to the axial stress direction with increase in the axial stress results in an increase in the Reynolds numbers and equivalent diameter of the seepage path increase due to the development, expansion, and penetration of the cracks.

1. Introduction

In the process of underground mining, in situ stress, gas pressure, and coal deformation are changing constantly. Under the combined effect of various factors, the engineering geological disaster, such as coal and gas outburst, is very prone to occur. The migration characteristic of gas in coals is closely related to the occurrence of gas disasters. However, the dynamics of the Reynolds number reflect the flow state of the gas in coals under different stress arrangement. Accordingly, the Reynolds number is of great significance for preventing gas disaster. Therefore, it is very necessary to study the variation of Reynolds number for gas-bearing coal.

Vidhya et al. [1] concluded that Reynolds number has the effect of increasing axial velocity skin friction, axial velocity, normal velocity skin friction, and heat transfer rate both in the case of impermeable plate and porous plate. Under the condition of increasing confining pressure, Ranjith and Darlington [2] conducted an experimental study on the flow of single-phase water and airflow through a rock joint to

evaluate the linear or nonlinear relationship between Reynolds number and pressure change. In addition, the applicability of Forchheimer's relation was tested. Kovscek et al. [3] experimentally studied the flow characteristics of nitrogen, water, and aqueous foam through a transparent replica with a naturally rough-walled rock fracture. The hydraulic aperture of the fracture was about $30\ \mu\text{m}$. By analogizing the flow between parallel plates, the authors described the single-phase flow of nitrogen and water. With the Reynolds number close to one, the inertial effects caused by fracture roughness become important in single-phase flow. Mohan et al. [4] calculated the Reynolds number under the hydrodynamic conditions and concluded that the flow of fluid in the reservoir fractures is laminar flow. The hydraulic conductivity of rock joints under normal load without shearing or after shear displacements was tested by Boulon et al. [5]. They built a mesoscale model to describe flow changes. The model is locally based on the cubic law and considers the reduction of roughness. Using this model, they give the maximum Reynolds number of the

FIGURE 1: Servo-controlled seepage equipment for thermal-hydrological-mechanical coupling of coals and rocks.

flow. App et al. (2002) concluded that the effective relative permeability of the gas for the single-phase cases depends upon three variables, capillary number, Reynolds number, and saturation, which all varied throughout the core. These studies show that the identification of the fluid flow state can independently be done without using Darcy's law. Moreover, Darcy's law is not applicable in any case. However, researchers use Darcy's law to calculate permeability of coals and rocks [6–11], which indicates inconsistency with the practice, and therefore, further study is needed.

In summary, despite the Reynolds number being an important dimensionless parameter for discriminating the flow fluid behavior, the research on the evolution of the Reynolds number in the process of loading axial stress on gas-filled coal is rarely reported. Given that, in order to reveal the gas flow state, it is necessary to study the Reynolds number evolutions by carrying out the gas permeability experiment under triaxial compression conditions. The study also provides a useful reference to select an appropriate model (based on Darcy's law and non-Darcy's law) for the permeability calculation.

2. Experimental Setup and Scheme

2.1. Experimental Setup. The experiments were conducted with the newly developed servo-controlled seepage apparatus for thermal-hydrological-mechanical (THM) coupling of gas-infiltrated coals [12, 13]. The apparatus is composed of the following main components: a servo loading system, a pressure chamber, a gas pressure control system, a data acquisition and storage system, and an auxiliary system. The accuracy of this measurement system is $\pm 1\%$ for stress, $\pm 1\%$ for deformation, and $\pm 0.1^\circ\text{C}$ for temperature control. The setup can simulate the experimental study of multifield

TABLE 1: In situ stress of the fully mechanized working face 2461.

In situ stress	Magnitude (MPa)	Dip angle ($^\circ$)	Azimuthal angle ($^\circ$)
Maximum principal stress	26.6	-6.7	90.1
Intermediate principal stress	19.4	-16.8	358.1
Minimum principal stress	8.5	-71.8	201.1

coupling conditions of porous media under different in situ stresses, mining stresses, and fluid pressures.

The experimental setup and loading cell are shown in Figure 1.

2.2. Experimental Specimens. Coals were obtained from the fully mechanized working face 2461 of outburst coal seam C_1 in Baijiao Coal Mine of Sichuan Coal Industry Group. Its buried depth is about 582.5 m. The in situ stress in the field is shown in Table 1. The measured average moisture content and density of coal specimens in the same coal seam were 1.866% and 1.507 kg/m^3 , respectively. The uniaxial compressive strength of raw coal is 25.82 MPa, the elastic modulus is 2.29 GPa, the tensile strength is 2.06 MPa, the initial porosity is 0.0538, and the initial permeability is $0.0193 \times 10^{-3} \mu\text{m}^{-2}$. Poisson's ratios are 0.14 (axial stress is normal to bedding planes) and 0.22 (axial stress is normal to bedding planes). Coals were drilled, cut, and polished into cylindrical specimens with a height of 100 mm and a diameter of 50 mm. The two ends of the cylindrical specimen were finally ground to meet the requirements of the ISRM [14] suggested methods for the parallelism of the end faces. The prepared specimens can be seen in Figure 2.

2.3. Experimental Scheme. In the first stage of the experiments, the specimens were placed into the loading cell with

FIGURE 2: Coal samples.

FIGURE 3: The stress path of coal sample loading.

the bedding plane parallel to the axis (Figure 1). Methane (CH_4) was used to be the injection gas at a pressure of 3 MPa during the whole experiment.

The experiment was performed in the following three steps.

Step 1. Axial stress and confining pressure were simultaneously increased to 20 MPa of hydrostatic pressure at the rate of 0.05 MPa/s. The pressure was maintained for 48 hours to balance the adsorption of coals.

Step 2. By keeping the confining pressure unchanged, the axial pressure is switched from force control to displacement control and the coal specimens were loaded at a rate of 0.01 mm/min until the coal specimens are in the residual stress region.

Step 3. End the experiment.

The stress path as obtained from the experiment is shown in Figure 3.

3. Results and Analysis

3.1. Reynolds Number Derivation. To characterize the flow behavior of the gas in the above experiment, knowledge of the Reynolds number is important. The Reynolds number Re is a dimensionless parameter that characterizes the fluid flow state as follows [3, 4, 15]:

$$Re = \frac{\rho v r}{\mu}, \quad (1)$$

where Re is the Reynolds number, which is the ratio of the inertial forces to the viscous force, and quantifies the relative importance of these two types of forces for the given flow conditions. In equation (1), ρ is the mass density of the fluid

in g/m^3 , v is the characteristic velocity in m/s , r is the characteristic dimension or equivalent diameter of the seepage path in m , and μ is the fluid viscosity in $\text{N}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

In this study, Reynolds number Re is used to determine whether the seepage follows Darcy's law and its calculation formula is

$$\text{Re} = 5.71 \times 10^{-2} \frac{\rho \sqrt{k}}{\varphi^{1.5} \mu} v. \quad (2)$$

Combining equations (1) and (2), we have the following:

$$r = 5.71 \times 10^{-2} \frac{\sqrt{k}}{\varphi^{1.5}}, \quad (3)$$

where φ is the porosity of coal under the current stress state.

Based on the designed stress path, the coal is always in the prepeak state and the flow of CH_4 in the coal can be characterized by Darcy's law. The permeability equation is as follows [12, 13, 16–18]:

$$k = \frac{2q\mu LP_2}{A(P_1^2 - P_2^2)}, \quad (4)$$

where k is the permeability in m^2 , q is the exit flow rate of CH_4 in m^3/s , P_2 is one standard atmospheric pressure in MPa , μ is the kinematic viscosity of CH_4 in $\text{MPa}\cdot\text{s}$, at the temperature of the test according to Sutherland's formula, L is the specimen length in m , P_1 is the entrance pressure in MPa of CH_4 at the test temperature, and A is the cross-sectional area of the coal specimens in m^2 .

In an extremely short period, the change in the equivalent diameter of seepage path is

$$\Delta r = dr = d \left(5.71 \times 10^{-2} \frac{\sqrt{k}}{\varphi^{1.5}} \right). \quad (5)$$

In particular, “an extremely short period” refers to the adjacent time interval when the data acquisition and storage system records the data (the system records the data once per 0.22 s). Compared with the time used for experiment, the period can be considered as instantaneous.

Using equation (5), we have the following:

$$\Delta r = dr = \left(2.855 \times 10^{-2} \frac{dk}{k} - 8.565 \times 10^{-2} \frac{d\varphi}{\varphi} \right) \frac{k^{0.5}}{\varphi^{1.5}}. \quad (6)$$

Therefore, the change rate in the equivalent diameter of seepage path is

$$\frac{\Delta r}{r} = \frac{dr}{r} = \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \frac{d\varphi}{\varphi}. \quad (7)$$

The experimental time used for maintaining the confining pressure and increasing the axial pressure is shorter than that of the adsorption equilibrium; therefore, the deformation induced by the adsorption and desorption

of coal matrix is not considered. Accordingly, the change rate of the porosity is as follows [19]:

$$\frac{d\varphi}{\varphi} = -\frac{1}{K_p} \left(\frac{\sigma_1 + 2\sigma_3}{3} - \beta p \right) + \frac{1}{K} \left(\frac{\sigma_1 + 2\sigma_3}{3} - \alpha p \right), \quad (8)$$

where $\alpha = 1 - K/K_m$, $\beta = 1 - K_p/K_m$, and $K = E/3(1 - 2\nu)$. Here, α is the Biot coefficient, K is the bulk modulus of coal in MPa , E is Young's modulus in MPa , ν is Poisson's ratio, K_m is the bulk modulus of coal matrixes/grains in MPa , K_p is the bulk modulus of fracture system in coals in MPa , p is the gas pressure in MPa , and β is the effective stress coefficient of fractures in coal.

Combining equations (7) and (8), we have the following:

$$\frac{dr}{r} = \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \left[-\frac{1}{K_p} \left(\frac{\sigma_1 + 2\sigma_3}{3} - \beta p \right) + \frac{1}{K} \left(\frac{\sigma_1 + 2\sigma_3}{3} - \alpha p \right) \right]. \quad (9)$$

Herein, the coal matrix is considered as a rigid body, so $\alpha = \beta = 1$. Accordingly, equation (9) can be rewritten as

$$\frac{dr}{r} = \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \left(\frac{1}{K} - \frac{1}{K_p} \right) \left(\frac{\sigma_1 + 2\sigma_3}{3} - p \right). \quad (10)$$

In the absence of the gas sorption effect, the volumetric variation of the porous media satisfies the Betti-Maxwell reciprocal theorem [20, 21] and we have the following:

$$K_p = \frac{\varphi}{\alpha} K = \varphi K. \quad (11)$$

Incorporating equation (11) into equation (9), we obtain

$$\frac{dr}{r} = \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \left(1 - \frac{1}{\varphi} \right) \frac{1}{K} \left(\frac{\sigma_1 + 2\sigma_3}{3} - p \right). \quad (12)$$

Raw coal is always subjected to confining pressure in the process of increasing axial pressure, so triaxial compression experiment is very different from the uniaxial compression experiment and the deformation modulus and Poisson's ratio are given as follows:

$$\begin{aligned} B &= -\frac{\varepsilon_3}{\varepsilon_1}, \\ \nu &= \frac{(B\sigma_1 - \sigma_3)}{[\sigma_3(2B - 1) - \sigma_1]}, \\ E &= \frac{(\sigma_1 - 2\nu\sigma_3)}{\varepsilon_1}, \end{aligned} \quad (13)$$

where ε_1 and ε_3 are the axial and radial strains, respectively, and σ_1 and σ_3 are the major and minor principal stresses in MPa .

The permeability of gas reservoirs is a key performance factor in gas production. Permeability directly affects the gas extraction and shale gas yield. Therefore, it is of

FIGURE 4: Change of Reynolds number rate $d \text{ Re}/\text{Re}$ with axial strain ε_1 in the loading.

paramount interest to study the permeability [16, 22]. A typical relationship between porosity and permeability is the cubic law and defined as [20, 23–25]

$$k = k_0 \left(\frac{\varphi}{\varphi_0} \right)^3, \quad (14)$$

where φ_0 is the initial porosity of coals, φ is the porosity under current state, k_0 is the initial permeability of coal in m^2 , and k is the permeability under current state in m^2 .

Incorporating equation (14) into equation (12), we have the following:

$$\frac{dr}{r} = \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \left(1 - \frac{1}{\varphi_0 (k/k_0)^{1/3}} \right) \frac{1}{K} \left(\frac{\sigma_1 + 2\sigma_3}{3} - p \right). \quad (15)$$

In each ultrashort period ($[t_i, t_i + 1]$), the velocity of the flow of gas through coal is considered as constant, that is, $v_i = v_{i+1}$. In that case, using equation (1), we have the following:

$$\Delta \text{Re} = d \text{Re} = \frac{\rho v_{i+1} r_{i+1}}{\mu} - \frac{\rho v_i r_i}{\mu} = \frac{\rho}{\mu} v_{i+1} (r_{i+1} - r_i) = \frac{\rho}{\mu} v_{i+1} dr, \quad (16)$$

where v_i and v_{i+1} are the velocity of flow through coal at i^{th} and $(i+1)^{\text{th}}$ moments, respectively. r_i and r_{i+1} are the corresponding equivalent diameter of the seepage path. It should be noted that i^{th} moment is an arbitrary time recorded by the data acquisition and storage system during the experiment and $(i+1)^{\text{th}}$ moment is the adjacent time of i^{th} moment.

Therefore, the change rate of the Reynolds number is

$$\begin{aligned} \frac{\Delta \text{Re}}{\text{Re}} &= \frac{d \text{Re}}{\text{Re}} = \frac{dr}{r} \\ &= \frac{1}{2} \frac{dk}{k} - \frac{3}{2} \left(1 - \frac{1}{\varphi_0 (k/k_0)^{1/3}} \right) \frac{1}{K} \left(\frac{\sigma_1 + 2\sigma_3}{3} - p \right). \end{aligned} \quad (17)$$

Equation (17) indicates that the change rate of Reynolds number is related to the stress field and permeability. The change rate of Reynolds number ($d \text{ Re}/\text{Re}$) versus axial strain ε_1 in the loading is shown in Figure 4. We can observe that ($d \text{ Re}/\text{Re}$) increases with the increase in the axial strain ε_1 . Moreover, fitting $d \text{ Re}/\text{Re}$ and ε_1 in polynomial form is as follows:

$$\frac{d \text{Re}}{\text{Re}} = 830.53 \varepsilon_1^2 + 16.537 \varepsilon_1 - 0.1363. \quad (18)$$

The correlation coefficient is $R^2 = 0.9835$.

Accordingly, we assume a quadratic polynomial relationship between the change rate of Reynolds number ($d \text{ Re}/\text{Re}$) and axial strain ε_1 :

$$\frac{d \text{Re}}{\text{Re}} = a \varepsilon_1^2 + b \varepsilon_1 + c, \quad (19)$$

where a , b , and c are the fitting coefficients.

From equation (19), we have the following:

$$\Delta \ln(\text{Re}) = d \ln(\text{Re}) = \frac{d \text{Re}}{\text{Re}} = a \varepsilon_1^2 + b \varepsilon_1 + c. \quad (20)$$

For the experimental data, a , b , and c in equation (19) are 830.53, 16.537, and -0.1363, respectively. Further, we have the following:

$$\begin{aligned} \Delta \ln(\text{Re}) &= \ln(\text{Re}_{i+1}) - \ln(\text{Re}_i) \\ &= (a \varepsilon_{1-i+1}^2 + b \varepsilon_{1-i+1} + c) - (a \varepsilon_{1-i}^2 + b \varepsilon_{1-i} + c) \\ &= \Delta \varepsilon_1 [a(\varepsilon_{1-i+1} + \varepsilon_{1-i}) + b], \end{aligned} \quad (21)$$

$$\ln \left(\frac{\text{Re}_{i+1}}{\text{Re}_i} \right) = \Delta \varepsilon_1 [a(\varepsilon_{1-i+1} + \varepsilon_{1-i}) + b]. \quad (22)$$

FIGURE 5: Relationship between deviatoric stress $(\sigma_1 - \sigma_3)$ and strain ε in the process of loading.

FIGURE 6: Change of permeability k with axial strain ε_1 in the process of loading.

Taking logarithm on both the sides of equation (22), we obtain the ratio of Reynolds number at the adjacent times:

$$\frac{Re_{i+1}}{Re_i} = e^{\Delta\varepsilon_1 [a(\varepsilon_{1-i+1} + \varepsilon_{1-i}) + b]}, \quad (23)$$

where Re_i and Re_{i+1} are the Reynolds number at the i^{th} and $(i+1)^{\text{th}}$ moments, respectively. ε_{1-i} and ε_{1-i+1} are the corresponding axial strains, respectively. Here, $\Delta\varepsilon_1 = (\varepsilon_{1-i+1}) - (\varepsilon_{1-i})$.

On combining equation (23) with the experiment, we get

$$\frac{Re_{i+1}}{Re_i} = e^{\Delta\varepsilon_1 [830.53(\varepsilon_{1-i+1} + \varepsilon_{1-i}) + 16.537]}. \quad (24)$$

It can be seen from equation (24) that if the Reynolds number Re_0 at the initial loading time is known, the Reynolds number for the later stages can be calculated; hence, the flow behavior of gas can also be determined. Additionally, it can provide a reference for the selection of model for the postpeak permeability calculation.

3.2. Variation of Reynolds Numbers during Loading. Figure 5 shows the deviatoric stress $(\sigma_1 - \sigma_3)$ versus strain ε (axial strain ε_1 , lateral strain ε_3 , and volumetric strain ε_v) in the process of loading, and Figure 6 shows the permeability k versus axial strain ε_1 . The raw coal undergoes the pore and fracture compaction stage, elastic deformation stage, plastic development stage, and residual stress stage (Figures 5 and 6). Accordingly, the permeability changes in a V-type are expected. Because the coal is in a high confining pressure state, there is no sudden increase in the permeability when the axial stress reaches peak stress (Figure 6).

Figure 7 shows the Reynolds number ratio (Re_{i+1}/Re_i) versus axial strain ε_1 in the process of loading. The range of Re_{i+1}/Re_i is $[0.999, 1.0015]$. Because the range of the region $\Omega \in [1, 10015]$ is larger than $\Omega \in [0.999, 1]$, so the Reynolds number is $Re_{i+1} > Re_i$. Therefore, we conclude that the Reynolds number increases with the increase of axial strain ε_1 .

It is observed that the gas flow state is a linear laminar flow if $Re < 10$ (conforms to Darcy's law) [26, 27], while $10 \leq Re \leq 100$ indicates a nonlinear laminar flow regime. Hence, a critical Reynolds number 10 determines the

FIGURE 7: Change of Reynolds number ratio Re_{i+1}/Re_i with axial strain ε_1 in the process of loading.

(a)

(b)

(c)

FIGURE 8: (a) Change of Reynolds number Re with axial strain ε_1 . (b) Change of Reynolds number Re with axial strain ε_1 in the postpeak state. (c) Change of Reynolds number Re with axial strain ε_1 in the prepeak state.

transition from linearity to nonlinearity [28]. Calculations show that, if the gas has a laminar flow before the peak stress, the initial Reynolds number satisfies $1 \leq Re_0 \leq 3.2317$ (Figure 8). Further, different initial Reynolds number (Re_0) could result in Re greater than or less than 10 in the postpeak stage. In the case of higher Reynolds number, the inertial term in Forchheimer flow equations is more significant, and the flux (Q) cannot be accurately predicted by Darcy's law [2, 29–31]. Therefore, the permeability of gas-bearing coal cannot be calculated by using equation (4) in the postpeak stage. In conclusion, a careful selection of the permeability calculation model is necessary.

Essentially, the difference in Re_0 is related to the physical characteristics of raw coal and the stress state. Coal body contains abundant pores and fractures with unique roughness, tortuosity [30], boundary conditions, number [32], and distribution of seepage channels. Besides, the in situ stress, gas pressure, and temperature of coals are significantly different [33, 34]. The internal structure of raw coal is significantly different from that of sandstone and shale. The raw coal contains not only bedding planes but also unique cleat system (face cleat and butt cleat). Moreover, the roughness of fracture surface and the tortuosity of fracture path are difficult to describe quantitatively, which makes the structure of raw coal extremely complex. The influences of face cleat, butt cleat, and bedding plane on permeability are indeed of significant importance. However, the calculation principle of permeability is closely related to the gas flow state, and the Reynolds number determines the gas state. A larger Re_0 results in a larger Re in the postpeak and the higher the probability that the gas is in a nonlinear flow state in the postpeak stage. Based on the capillary model, it is shown that the capillary aperture inside coal can expand under tensile stress on the crack surface, as shown in Figure 9.

At $(i + 1)^{th}$ moment, the Reynolds number can also be given as follows:

$$Re' = \frac{\rho(v + \Delta v)(r + \Delta r)}{\mu}, \quad (25)$$

where $(Re)'$ is the Reynolds number at $(i + 1)^{th}$ moment, Δv is the change in the characteristic velocity in an extremely short period, and Δr is the change in the equivalent diameter of the seepage path in an extremely short period.

By subtracting equation (1) from equation (25), we have the following:

$$\Delta Re = \frac{\rho}{\mu} [(v + \Delta v)(r + \Delta r) - vr], \quad (26)$$

$$\Delta Re = \frac{\rho}{\mu} (v \cdot \Delta r + r \cdot \Delta v + \Delta r \cdot \Delta v), \quad (27)$$

$$\Delta Re = Re \left(\frac{\Delta r}{r} + \frac{\Delta v}{v} + \frac{\Delta r \Delta v}{vr} \right). \quad (28)$$

FIGURE 9: Capillary model of gas flow in coal sample.

Neglecting the higher order term $((\Delta v \Delta r)/(vr))$ in equation (28) results in

$$\Delta Re = Re \left(\frac{\Delta r}{r} + \frac{\Delta v}{v} \right). \quad (29)$$

Herein, we use volume flow Q to characterize characteristic velocity v . Accordingly, we have the following:

$$\Delta Re = Re \left(\frac{\Delta r}{r} + \frac{\Delta Q}{Q} \right), \quad (30)$$

where ΔQ is the change in the volume flow Q in an extremely short period in m^3/s and ΔRe is the change in the Reynolds number Re in an extremely short period.

$(\Delta Q/Q)$ versus ε_1 is shown in Figure 10. Upon comparing Figures 4 and 10, we observe that $|\Delta Q/Q| < |\Delta r/r|$. Under the condition of constant ρ and μ , the decrease in the amplitudes of the flow rate is less than the increase in the equivalent diameter of the seepage path $((\Delta r/r) + (\Delta Q/Q) > 0)$, that is, the Reynolds number is increasing continuously ($\Delta Re > 0$). The change in the equivalent diameter of pores and fractures parallel or nearly parallel to the direction of the maximum principal stress (axial stress direction σ_1) is the main factor causing the change of the gas flow state [35]. Moreover, the equivalent diameter is also affected by the axial stress. With increasing axial stress, tensile stress is generated around the above-mentioned pores and fractures. Consequently, the equivalent diameter increases due to the cracks expand and extend along the σ_1 direction. When coals enter the plastic stage, the development, expansion, and penetration of the pores and fractures accelerate the increase in the equivalent diameter, which is manifested by the increasing Reynolds number.

4. Conclusions

We performed an experiment on coal permeability and deformation under fixed confining pressure and increasing

FIGURE 10: Change of flow rate $\Delta Q/Q$ with axial strain ε_1 in the process of loading.

axial stress conditions with the aim to select the permeability model by investigating the variation of Reynolds number. The primary conclusions are as follows:

- (i) The dynamic evolution of Reynolds number under the assumption that the coal matrix is rigid and the flow rate is constant in an extremely short period is examined. We find that the Reynolds number increases with an increase in the axial strain
- (ii) Different initial Reynolds numbers result in the Reynolds numbers being may be greater than or less than 10 in the postpeak stage. In this case, the permeability of gas-bearing coal cannot be calculated by Darcy's law. Therefore, a careful selection of the permeability calculation model is necessary
- (iii) If ρ and μ are constant, the decrease in the amplitudes of flow rate is less than the increase in the equivalent diameter of the seepage path. Furthermore, the tensile stress generated around the pores and fractures parallel or nearly parallel to the axial stress direction with increasing axial stress results in an increase in the equivalent diameter due to the development, expansion, and penetration of the cracks

Data Availability

Data available within the article or its supplementary materials.

Conflicts of Interest

We declare we have no competing interests.

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