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Research Article

Coal Permeability Variation during the Heating Process considering Thermal Expansion and Desorption Shrinkage

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In order to explore the influence of coal deformation caused by temperature and desorption on seepage characteristics in the process of heat injection mining of coalbed methane, the permeability test, thermal expansion, and constant temperature adsorption desorption of coal samples under different temperature and stress states were carried out using the high temperature multifunctional triaxial test system, and the influence of thermal expansion and desorption deformation effect on coal permeability in the process of temperature increase is studied. The results show that (1) with the increase of temperature, the sensitivity of coal thermal expansion deformation to temperature decreases gradually. The thermal expansion deformation makes the coal matrix expand, and the seepage channel is squeezed and the permeability decreases. (2) The effect of thermal expansion deformation is related to the porosity of coal. When the porosity of coal is high, the thermal expansion deformation reduces the permeability; on the contrary, the inward expansion of thermal expansion deformation is limited, and the effect on permeability is weakened. (3) The desorption of coal cause matrix shrinkage. The higher the desorption amount, the more obvious the shrinkage and the higher the permeability. Increasing temperature promotes desorption deformation of coal and increases permeability. (4) In the process of increasing temperature, the change of coal permeability is affected by thermal expansion deformation and desorption deformation. With the increase of temperature, when the influence of thermal expansion deformation on coal permeability is dominant, the permeability decreases gradually, and when desorption deformation is dominant on coal permeability, the permeability increases gradually. (5) With the increase of axial pressure, confining pressure, and pore pressure, the decrease of coal porosity is smaller. When the temperature increases, the temperature corresponding to the minimum permeability point is smaller. The research conclusion provides a basis for the technology of heat injection mining coalbed methane.

1. Introduction

In China, the geological resources of shallow coal bed methane (CBM) with a depth of 2,000 meters are 30 trillion cubic meters, and the reserves of CBM resources are large. In 2019, the newly confirmed geological reserves of CBM were 6.4 billion cubic meters [1, 2]. CBM is not only a kind of clean energy but also the exploitation of CBM can avoid its pollution to the environment and reduce the risk of gas explosion, so the exploitation of CBM is of great significance. CBM production by heat injection refers to the process of coal mining by injecting heat into the coal seam to promote the desorption of adsorbent gas and the change of coal seam skeleton, so as to improve permeability and achieve the effect of increasing production [3]. In this paper, the influence of thermal expansion deformation effect and desorption deformation effect on permeability of coal in the process of heating is studied to provide theoretical support for the exploitation of coalbed methane by heat injection. Scholars at home and abroad have carried out a lot of research work on the seepage characteristics of coal body and achieved fruitful results. Feng et al. studied permeability characteristics of anthracite and gas coal at high temperature (normal temperature -600°C) and found that permeability existed threshold temperature and peak temperature, which were related to coal rank. With the increase of temperature, permeability first decreased, then increased, and finally decreased again [4]. Through experiments, Wang et al. found that permeability of coal is jointly determined by thermal stress and effective stress. When the current value is greater than the latter, permeability increases with the increase of temperature, and conversely decreases [5]. Zhou et al. proposed that there is a correlation between permeability and deformation of coal body [6]. Li et al. found through experiments that the permeability of nitrogen and methane firstly decreased, then increased and then decreased with the increase of temperature, and the variation trends of the permeability of nitrogen and methane were obviously different. With the increase of effective stress, the deformation of coal was restricted, resulting in the decrease of permeability [7]. Lin and Kovscek experimentally measured the adsorption, volumetric strain, and permeability of the same core with the same instrument and found that the permeability decreased with the increase of effective stress, and the permeability of coal was affected by the adsorption and desorption of gas [8]. Harpalani and Schraufnagel studied the influence of coal desorption deformation and coal deformation caused by pore pressure changes on permeability and found that matrix shrinkage caused by desorption would lead to an increase in permeability [9]. Li et al. found that the average pore radius decreases with the increase of coal rank. With the increase of coal rank, the pore structure becomes more complex. The more developed the pores are, the more obvious the coal deformation is. The influence of temperature on coal pores is much higher than that of rock types. With the combined influences of effective stress, matrix swelling/shrinkage, and gas slippage, the permeability decreases first and then increases with the decrease of pore pressure. With the decrease of pore pressure and the increase of confining pressure, the combined influence of the three factors on coal permeability gradually weakens [10–12].

In the process of heat injection mining, the deformation of coal body is mainly thermal expansion deformation caused by temperature and shrinkage deformation caused by gas desorption, which directly affect the seepage characteristics of coal body. However, there are few reports on the influence of thermal expansion deformation and desorption deformation on permeability in the process of heating. Therefore, through the permeability test, thermal expansion, and constant temperature adsorption and desorption of coal samples under different temperature and stress states, this paper studies the influence of thermal expansion deformation and desorption deformation on permeability of coal in the process of heating at 30-150°C, providing a basis for the exploitation of coalbed methane by heat injection.

2. Experimental Section

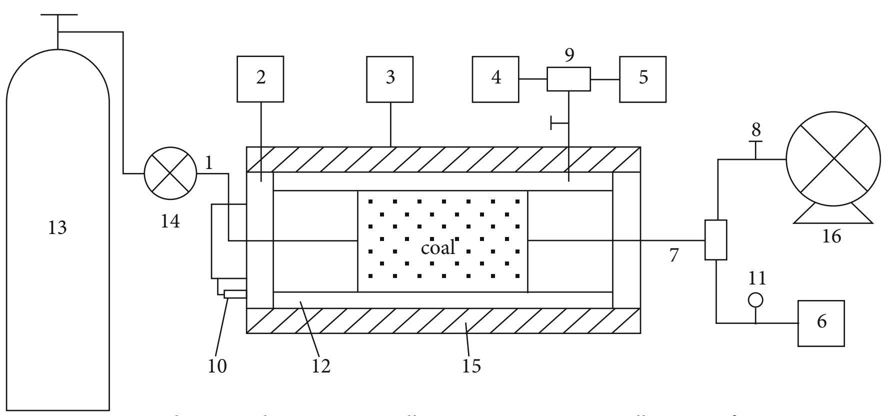
2.1. Sample. Coal sample from the Hedong coal Field Hanzui coal mine, with raw coal specimen as the research object, after the sand line cutting machine and sandpaper grinding, get 50 mm × 100 mm standard sample, and then use the drying box to keep drying at 90°C for 24 h, and then seal and save, numbered 1#, 2#, and 3#, for use in the test. The specimen is of good integrity, good quality, and no obvious cracks.

2.2. Test System. The high-temperature multifunctional triaxial test system independently developed by the Key Laboratory of In-Situ Properties-Modified Mining of Ministry of Education of Taiyuan University of Technology was used to carry out the test. The axial pressure and confining pressure are loaded and controlled by the testing machine. The maximum load of the testing machine is 75 MPa, and the accuracy is 0.01 MPa. The accuracy of the heating device can reach ±1°C. The axial deformation was measured by a displacement sensor with an accuracy of 1 μm. Radial deformation and volume deformation are measured by HTMT-II volume deformation meter [13]. Figure 1(a) is the experimental system diagram, and Figure 1(b) is the principle diagram of the high-temperature triaxial percolation meter.

2.3. Test Method and Procedure. A large number of experiments show that under the same adsorption pressure, the adsorption capacity of methane by coal is higher than that of nitrogen, and the deformation caused by methane adsorption is twice that of nitrogen, but the deformation of the two is similar with the change of adsorption pressure [14]. Considering the safety of the test, high-purity nitrogen was used as the test gas. First, the permeability is carried out to analyze the evolution of coal permeability under the joint action of temperature and pore pressure; second, thermal expansion test is carried out to analyze the influence mechanism of thermal expansion deformation on permeability of coal; the influence mechanism of desorption deformation on permeability was analyzed by adsorption desorption test; finally, the evolution mechanism of coal permeability in the process of heating is analyzed based on the deformation of coal in thermal expansion deformation, desorption deformation, and permeability. The specific test steps are as follows.

Connect the system according to Figure 1 and then conduct debugging. High-pressure nitrogen is used for air tightness detection first, the free volume of the system is calculated, and the test starts after completion. First, the permeability test was carried out. The specimen was installed first, the vacuum pump was used to make the pressure lower than 70 Pa, and the vacuumization was stopped. Then, the axial pressure and confining pressure were applied to 8 MPa and 4 MPa, respectively (hereinafter represented by low stress state). After the coal deformation is stabilized, continued into the nitrogen of 0.8 MPa, and keep the pore pressure constant for 3 h, after the coal deformation is stabilized, take the gradient of 30°C to heat, the temperature reached Table 1 set temperature insulation 2 to 3 h, after the coal deformation is stabilized, with steady state method measuring permeability, and amount of deformation temperature and after cooling, repeat the above steps, complete the permeability tests under other stress states as shown in Table 1. Then, the thermal expansion test is carried out to measure the thermal expansion deformation of coal under different stress states. Finally, under the constant temperature of 30°C and low stress state, the pore pressure of

(a) Test system



1-Pore pressure inlet; 2-Axial pressure controller; 3-Temperature controller; 4-Confining pressure controller; 5-Volume deformation meter; 6- Drainage gas collection device; 7-Pore pressure outlet; 8-Valves; 9-Three links; 10-Displacement sensor; 11-Back pressure valve; 12-Triaxial pressure chamber; 13-Nitrogen vessel; 14-Pressure reducing valve; 15-Heater band; 16-Vacuum pump

(b) Schematic diagram of high-temperature triaxial percolation meter

Figure 1: High temperature multifunctional triaxial test system.

Table 1: Test scheme.

Test	Pore pressure/MPa	Stress state/MPa	Temperature/°C
Permeability	0.8, 2, 3.2	$\sigma_2 = \sigma_3 = 4$, $\sigma_1 = 8$	30, 60, 90, 120, 150
	3.2	$\sigma_2 = \sigma_3 = 5$, $\sigma_1 = 10$	
Thermal expansion	/	$\sigma_2 = \sigma_3 = 4$, $\sigma_1 = 8$	30, 60, 90, 120, 150
		$\sigma_2 = \sigma_3 = 5$, $\sigma_1 = 10$	
Adsorption and desorption	3, 2.5, 2, 1.5, 1, 0.5	$\sigma_2 = \sigma_3 = 4$, $\sigma_1 = 8$	30

3 MPa was introduced and adsorbed at constant pressure for 48 h. Then, the air inlet was closed, and the back pressure valve was adjusted with 0.5 MPa as a gradient. The desorption and deformation of coal body under different pore pressures were measured. Replace the specimens in turn and complete the control group test in the same way as above. See Table 1 for specific test schemes.

3. Results and Discussion

3.1. Deformation Characteristics of Coal Body

3.1.1. Thermal Expansion Deformation. After collating the thermal expansion test data, the thermal expansion deformation of coal body under different stress states (expansion is negative, and contraction is positive) was obtained as shown in Figure 2 (ε_a represents axial strain, ε_r represents radial strain, and ε_V represents volumetric strain). It was found that the axial strain of the specimen showed an increasing trend with the increase of temperature, and there was no significant difference in the deformation amount. Under the condition of low stress, the radial strain and volumetric strain of specimen 1# decrease gradually with the increase of temperature at low temperature (30-60°C) and medium temperature (60-120°C), but increase somewhat at high temperature (120-150°C). The radial deformation rate increases by 8.54%, and the volume deformation rate increases by 7.75%. With the change of temperature, specimen 2# and specimen 3# first underwent expansion deformation, and the deformation rate gradually decreased and then began to contract. As the temperature rises, the elastic modulus of coal decreases [15], and due to the constraints of external stress (axial pressure and confining pressure), the coal body is squeezed and shrinks. With the increase of external stress, the radial strain and volumetric strain decrease obviously. Because with the increase of external stress, the thermal expansion of coal body is limited, and the inward expansion is more obvious. In conclusion, the sensitivity of thermal expansion deformation of coal body to temperature decreases gradually in the process of heating.

3.1.2. Desorption Deformation. According to the adsorption desorption test results of the ideal gas state equation [16], the relationship curve between desorption strain and desorption capacity was obtained, as shown in Figure 3. It can be seen from Figure 3 that there is a positive correlation between desorption strain and desorption amount. The higher the desorption amount is, the more obvious the desorption deformation is. When the desorption amount is the same, the strain of specimen 3# is the highest, and that of specimen 2# is the smallest, so specimen 3# is the most sensitive to desorption effect, followed by specimen 1# and 2#.

3.1.3. Deformation of Coal during Heating. The relation curve between coal deformation and temperature under different stress states is shown in Figure 4.

According to Figures 4(a)–4(c), it can be seen that the relationship between axial strain and temperature of coal body increases approximately linearly. According to Figures 4(d) and 4(g), it can be seen that in the low stress state, the radial strain and volumetric strain of specimen 1# increase rapidly in the low temperature section, slow down in the medium temperature section, and increase rapidly in the high temperature section. When the pore pressure is 0.8 MPa, the percentage of deformation in the total deformation at each temperature segment is 59.53%, 6.87%, and 33.60%, respectively; when the pore pressure is 2 MPa, the percentage is 52.52%, 23.19%, and 24.29%, respectively; when the pore pressure is 3.2 MPa, the percentage of deformation in the total deformation is 59.53%, 6.87%, and 33.60%, respectively, 28.6%, 25.13%, and 46.27%, respectively. Under high stress, the coal deformation increases.

3.2. Permeability Evolution of Coal during Heating Process.

The permeability of coal is calculated according to Darcy's law [7]

$$K = \frac{2P_0 q\mu L}{A\left(P_1^2 - P_2^2\right)}, \quad (1)$$

where K is the permeability of coal sample, 10^{-16} m^2; P_0 is the standard atmospheric pressure, MPa; q is the velocity through the coal sample, cm^3/s; μ is the dynamic viscosity of seepage gas, 10^{-12} MPa·s; L is the length of coal sample, cm; A is the cross-sectional area of the fluid flowing through the coal sample, cm^2; P_1 is the absolute pressure of inlet gas, MPa; P_2 is the absolute pressure of the outlet gas, MPa.

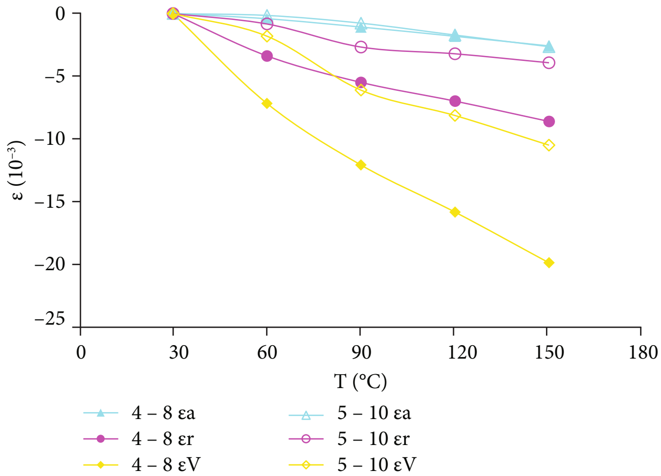
Where the dynamic viscosity of gas changes with temperature can be approximated by the Suslan relation [17]:

$$\mu = \mu_0 \frac{273 + S}{T + S}\left(\frac{T}{273}\right)^{3/2}, \quad (2)$$

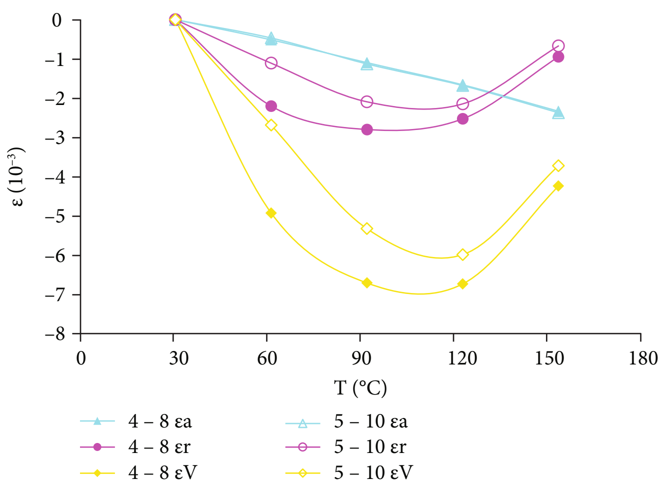
where μ is the dynamic viscosity of gas at T; μ_0 is the dynamic viscosity of gas at 0°C, N_2 is 16.606×10^{-12} MPa · s. S is the Suslan constant, N_2 is 104 K; T is the thermodynamic temperature of the gas, K.

The data are sorted out, and the evolution of coal permeability with temperature under different stress states is shown in Figure 5 (4-8-0.8 represents confining pressure of 4 MPa, axial pressure of 8 MPa, and pore pressure of 0.8 MPa).

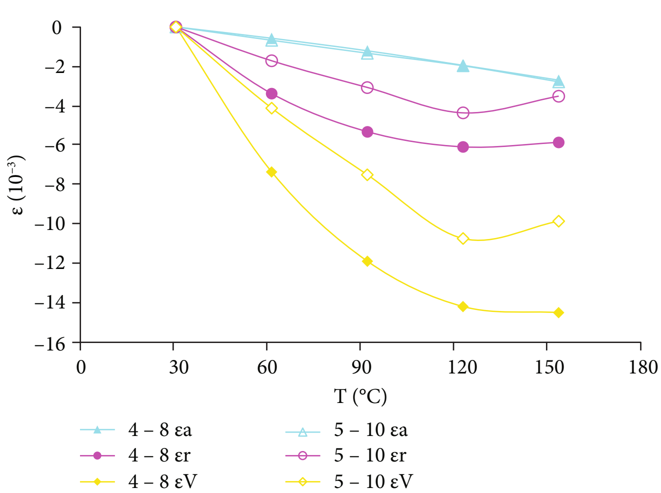
It can be seen from Figure 5 that permeability of specimen 1# decreases first and then increases with temperature under low stress state, which is consistent with the relationship between permeability and temperature in the experimental results of Jia et al. [18]. The temperature corresponding to the minimum permeability point decreases with the increase of pore pressure. When the pore pressure is 0.8 MPa, the permeability reaches the minimum value at 90°C; when the pore pressure is 2 MPa and 3.2 MPa, the permeability reaches the minimum at 60°C. Under high stress, the permeability increases with temperature when the pore pressure is 3.2 MPa. In the low-stress state of specimen 2#, when the pore pressure was 0.8 MPa, the permeability first decreased and then increased with the change of temperature; when the pore pressure is 2 MPa, the permeability



(a) 1#



(b) 2#



(c) 3#

Figure 2: Relationship between thermal expansion deformation and temperature under different stress states.

increases first and then decreases with the change of temperature; when the pore pressure is 3.2 MPa, the permeability decreases monotonically with the increase of pore pressure. Under high stress, permeability decreases monotonically with temperature. Under different stress states, the permeability of specimen 3# increases with the change of temperature. The experimental results show that the permeability is affected by temperature, external stress, and pore pressure.

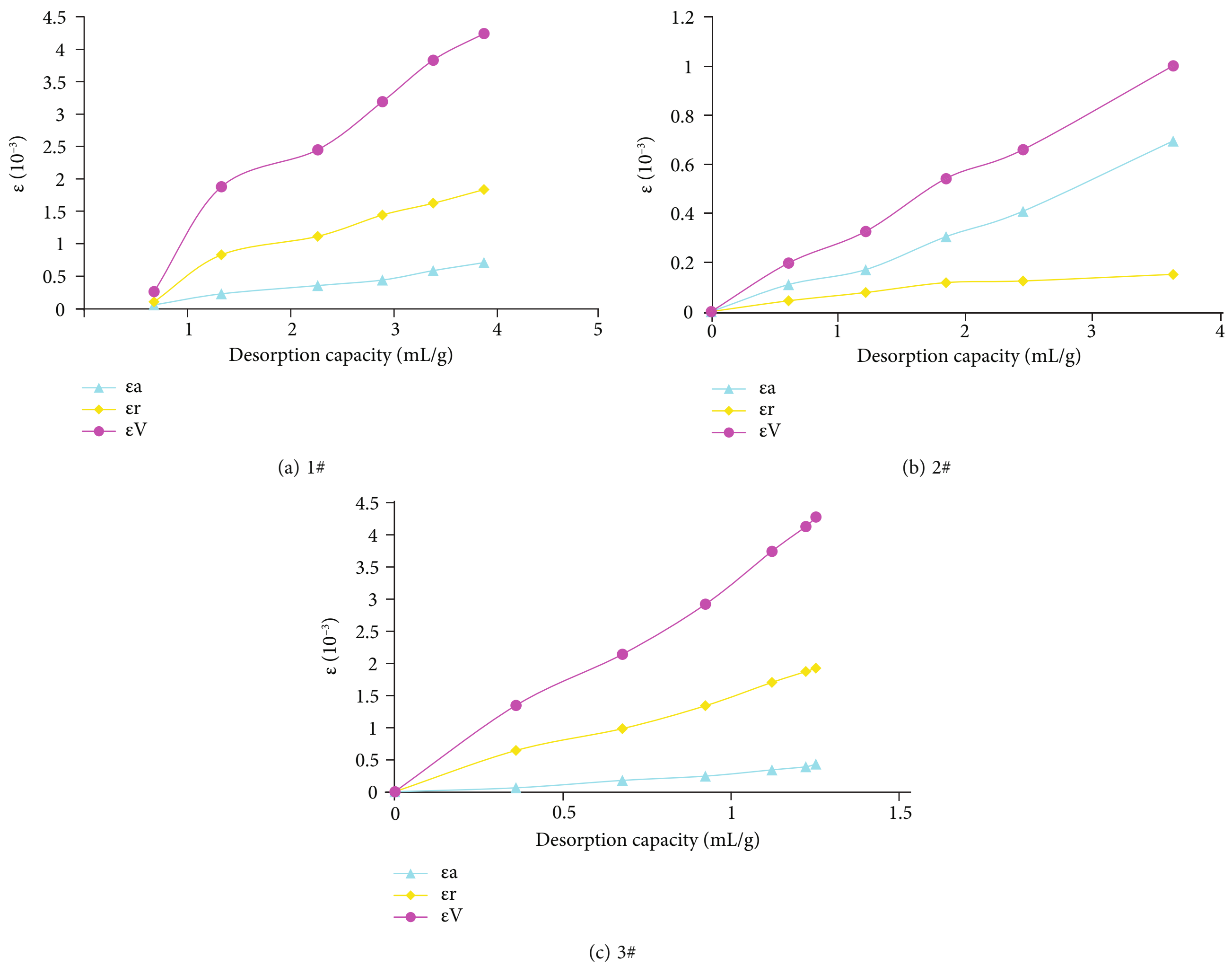
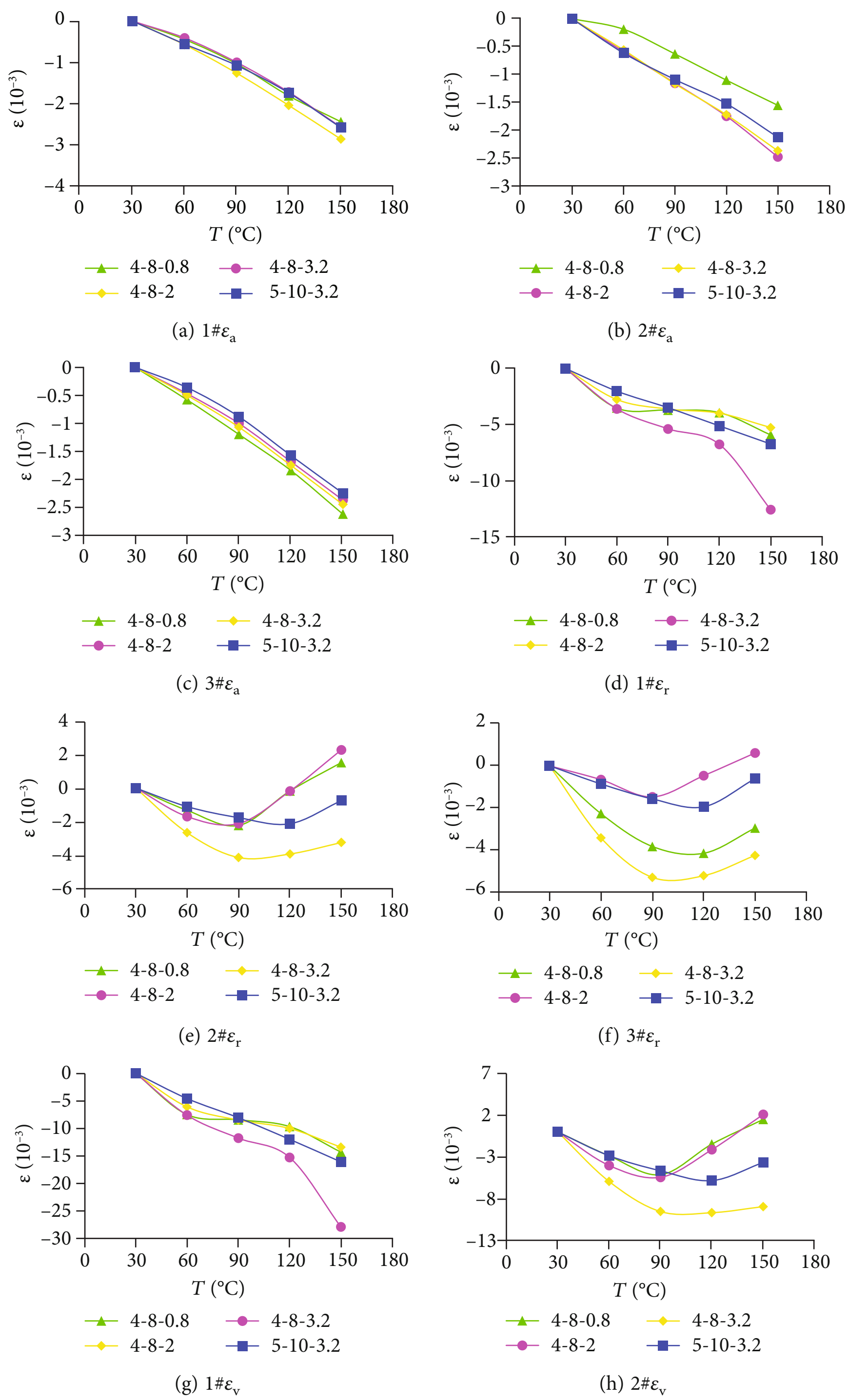


Figure 3: Relationship between desorption strain and desorption capacity.

4. Analysis of Permeability Evolution of Coal Body

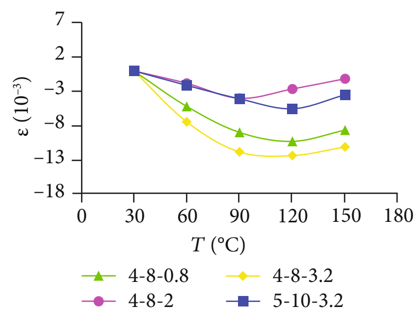
4.1. Influence of Thermal Expansion Deformation on Permeability of Coal Body. Due to the constraint of external stress, the thermal expansion of coal squeezes the seepage channel inward, resulting in the decrease of permeability. According to Figure 5, when the external stress and temperature are the same, when the pore pressure is 0.8 MPa, and at 30-90°C, the relationship between the permeability of the three specimens is 1#>2#>3#; when 120-150°C, 1#>3#>2#; when the pore pressure is 0.8 MPa and the temperature at 30°C-90°C, the relationship between the permeability of the three specimens is 1#>2#; with the increase of temperature, the relationship between the minimum permeability points of the three specimens is 1#>2#>3#. When the pore pressure is 2 MPa and 3.2 MPa, the relationship between the permeability of the three specimens is 2#>1#>3#, and the temperature corresponding to the minimum point is 2#>1#>3#. As the porosity of coal is positively correlated with permeability [19], that is, the smaller the permeability is, the smaller the porosity of coal is. Therefore, the smaller the porosity of coal, the lower the temperature when the permeability of coal reaches the minimum point in the heating process. That is because when the porosity of coal is high, the coal matrix expands and deforms with the increase of temperature, but due to the constraint of external stress, the coal expands and compresses the seepage channel internally, resulting in the decrease of permeability. However, when the porosity of coal is small, with the increase of temperature, the effect of the seepage channel of coal is more obvious and the permeability decreases to the minimum quickly, which is basically consistent with the conclusion of literature [20]. Therefore, thermal expansion deformation reduces permeability. The higher the porosity of coal, the more obvious the effect of thermal expansion deformation on permeability.

4.2. Influence of Desorption Deformation on Permeability of Coal Body. As adsorption and desorption can be approximately regarded as a reversible process [21], the coal desorption capacity and desorption deformation obtained in this paper are the coal adsorption capacity and adsorption expansion capacity, and the relationship curve between adsorption capacity and adsorption deformation capacity and pore pressure can be obtained. The influence of



(a) 1#ε_a (b) 2#ε_a (c) 3#ε_a (d) 1#ε_r (e) 2#ε_r (f) 3#ε_r (g) 1#ε_v (h) 2#ε_v

Figure 4: Continued.



(i) 3# ε_v

Figure 4: Relationship between coal deformation and temperature under different stress states.

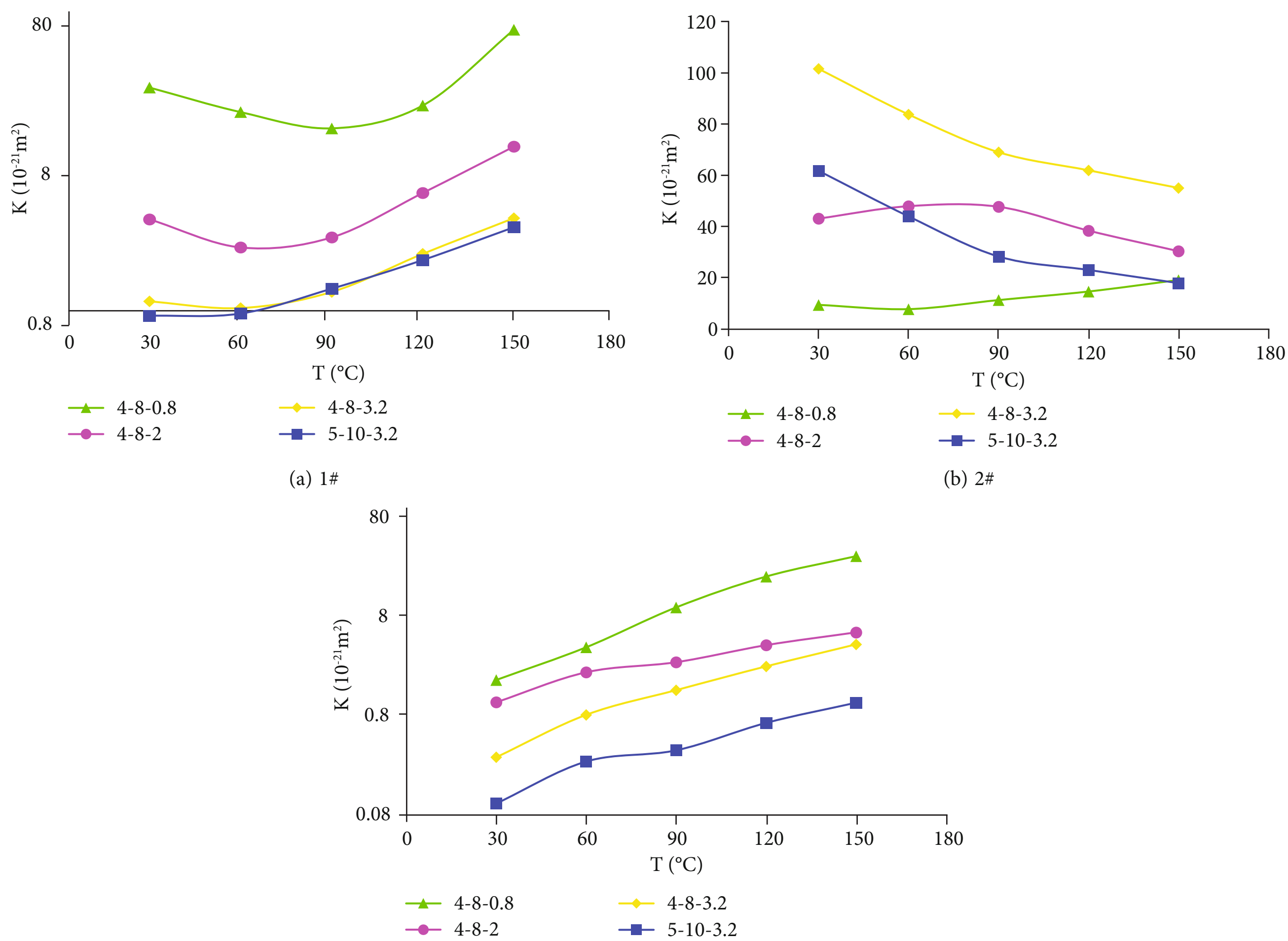
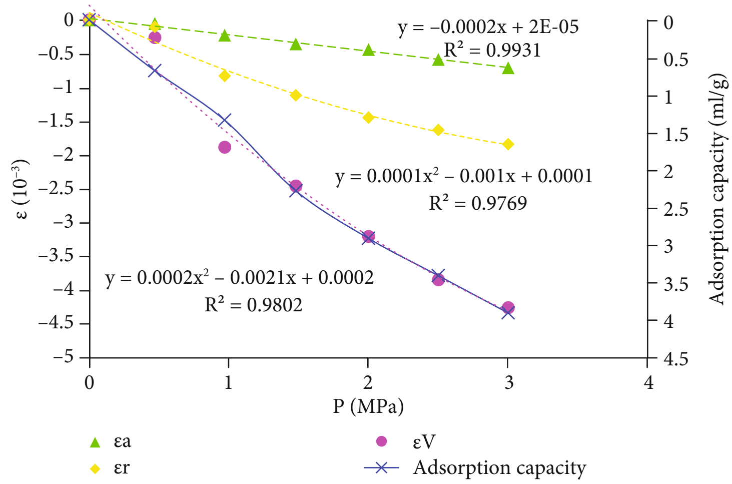


Figure 5: Relationship between coal permeability and temperature under different stress states.

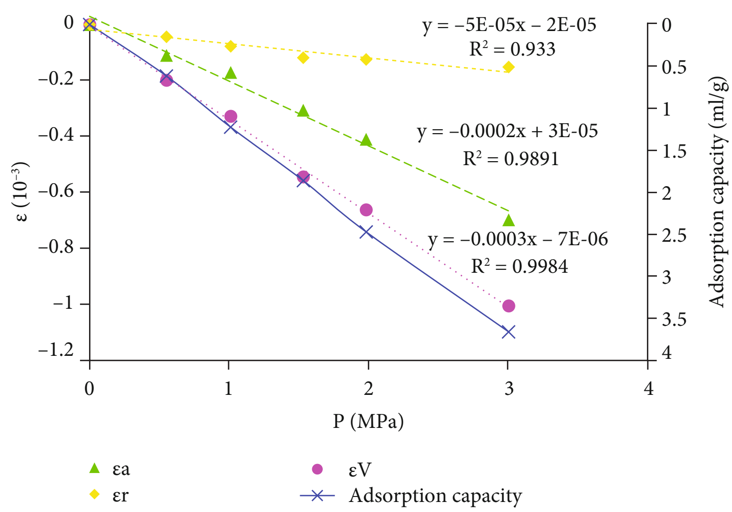
adsorption deformation on coal permeability and desorption deformation on coal permeability can be obtained by analyzing the evolution of permeability with temperature pore pressure under the same external stress and temperature.

Figure 6 shows the relationship between adsorption capacity, adsorption deformation, and pore pressure. According to Figures 6(a) and 6(c), during the adsorption process, the axial strain of specimens 1# and 3# changed linearly with pore pressure, while the radial strain and volume strain increased logarithmically with pore pressure; the adsorption capacity first increases rapidly with the increase of pore pressure, and then the increment becomes smaller and smaller. As can be seen from Figure 6(b), strain and adsorption amount of specimen 2# both changed linearly with pore pressure. The variation of coal adsorption capacity and strain with pore pressure is consistent.

After collating the permeability results, the relation curve between coal permeability and pore pressure under low



(a) 1#



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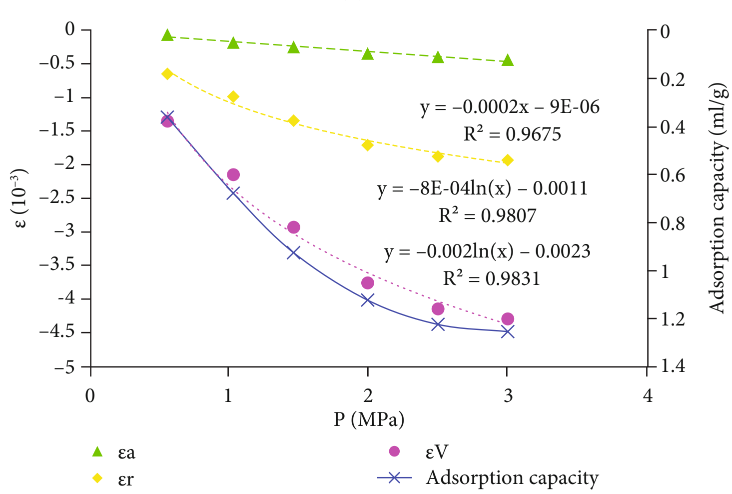

(c) 3#

FIGURE 6: Relationship curve between adsorption capacity, adsorption deformation, and pore pressure.

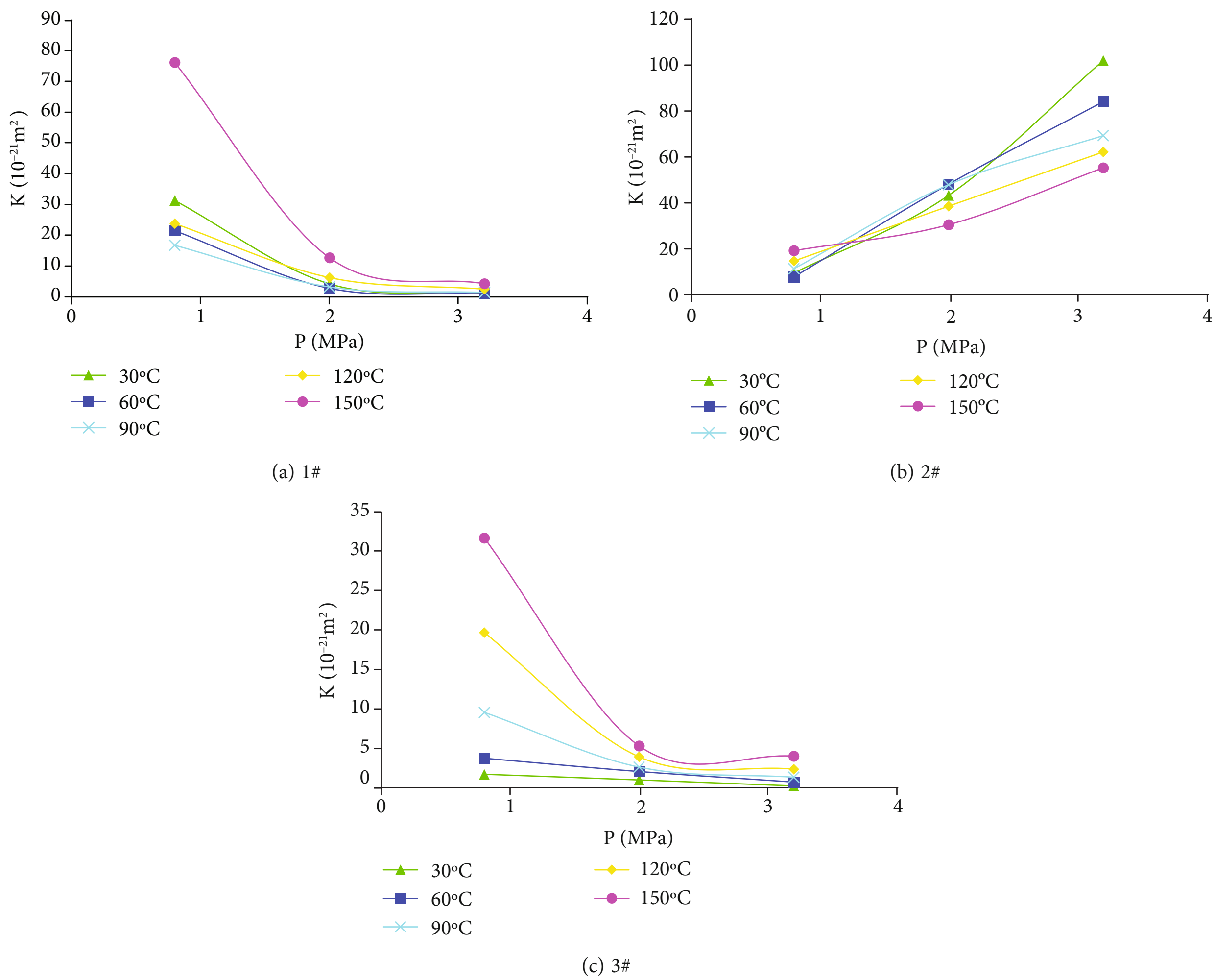

FIGURE 7: Relationship curve between coal permeability and pore pressure.

stress state was obtained, as shown in Figure 7. At different temperatures, with the increase of pore pressure, the permeability of specimens 1# and 3# declined rapidly at first and then slowly, and the permeability of specimens 2# increased gradually.

Combined with the analysis in Figure 6, it can be seen that at the same temperature, with the increase of pore pressure, the coal adsorption capacity gradually increases and the matrix expansion becomes more obvious, leading to the compression of seepage channels and the decrease of coal permeability. However, with the increase of pore pressure, the increment of adsorption expansion strain decreases gradually, the effective stress on coal decreases, and the attenuation rate of permeability slows down. The permeability of specimen 2# increases gradually with the increase of pore pressure, because the increase of pore pressure leads to the decrease of effective stress, which increases the permeability of coal body. In addition, according to Figure 6, the adsorption expansion capacity of specimen 2# is weak, and the radial strain is 8.23% and 7.1% of specimen 1# and 3#, respectively, when the pore pressure is 3 MPa. The volume strains are 23.52% and 21.34%, respectively, so the effect of effective stress reduction on permeability is much higher than that of adsorption in the process of pore pressure increase. In conclusion, with the increase of pore pressure, the permeability of coal is affected by both gas adsorption and pore pressure. Adsorbed gas makes coal matrix expand, which leads to the decrease of seepage channel and permeability. The increase of pore pressure also leads to the decrease of effective stress, which makes the seepage channel open and the permeability of coal increase.

Because adsorption and desorption can be approximately regarded as a reversible process, it can be seen from the relationship between adsorption deformation and permeability that coal desorption causes matrix shrinkage. The higher the desorption amount is, the more obvious the shrinkage deformation is and the larger the permeability is. In addition, desorption is an endothermic process [22], so in the process of heating, the absorption of heat by coal promotes desorption, thus, causing shrinkage and deformation of coal matrix and improving permeability of coal.

4.3. Analysis of Coal Permeability Evolution in Seepage Process. In the permeability experiment, with the increase of temperature, the change of permeability of coal is affected by thermal expansion deformation and desorption

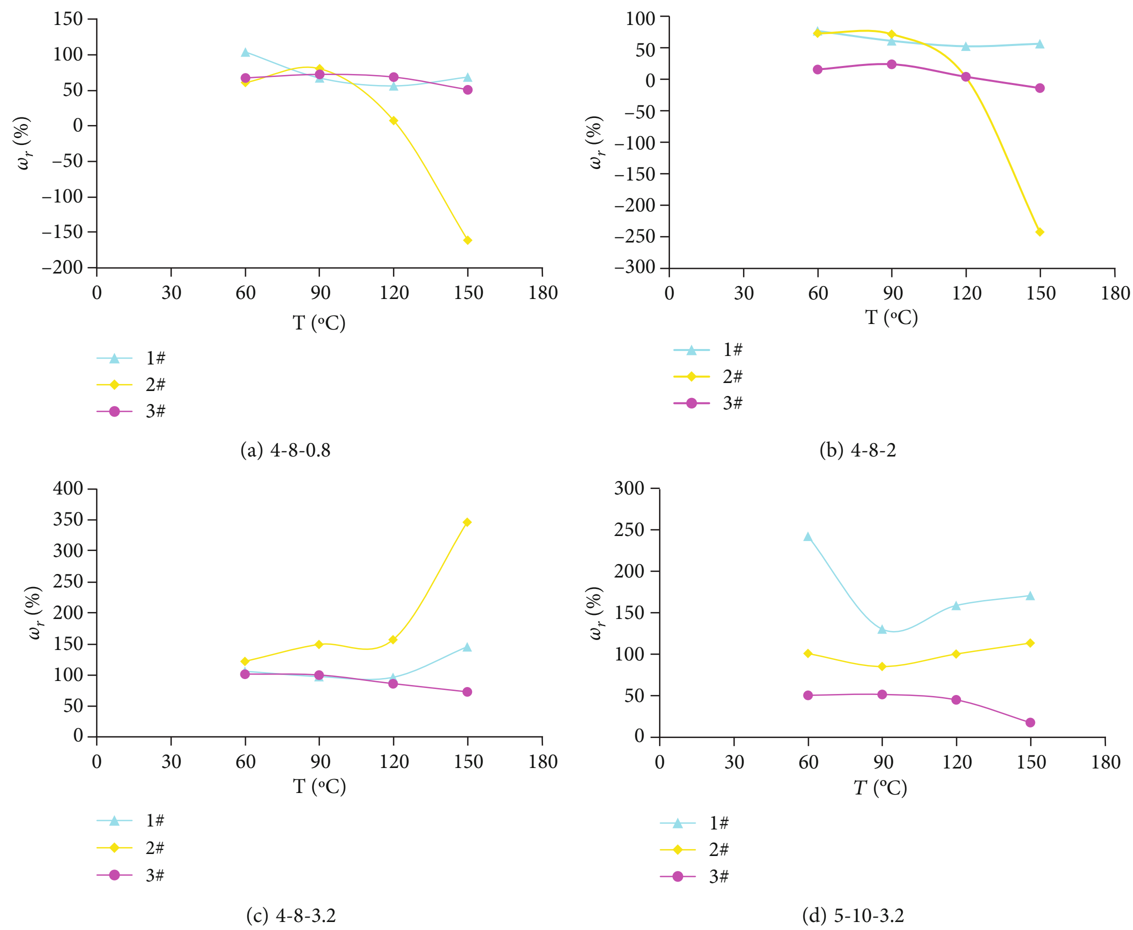

Figure 8: Relationship between ω_r and temperature under different stress states.

deformation. The permeability evolution is analyzed by combining the deformation, thermal expansion effect, and desorption deformation effect of coal in permeability experiment.

Under the same stress state, the ratio of the strain ($\varepsilon_{\text{permeability}}$) under the action of temperature and pore pressure and the thermal expansion strain ($\varepsilon_{\text{thermal expansion}}$) under the action of temperature alone is defined as ω, as shown in the following equation:

$$\omega = \frac{\varepsilon_{\text{permeability}}}{\varepsilon_{\text{thermal expansion}}} \times 100\%. \quad (3)$$

It can be seen from Figures 4(a)–4(c) that there is no significant difference in axial strain of coal body, and permeability of coal body is much more sensitive to radial strain than axial strain [23]. Therefore, this paper mainly considers the influence of coal radial deformation on coal permeability and analyzes the evolution of coal permeability through ω_r (coal radial strain ratio).

In the process of heating seepage, coal deformation is mainly composed of thermal expansion deformation and desorption deformation, that is, $\varepsilon_{\text{permeability}}$ is the superposition of $\varepsilon_{\text{thermal}}$ expansion and $\varepsilon_{\text{desorption}}$. It is assumed that the thermal expansion deformation in the process of heating seepage is the same as that in the thermal expansion test under temperature alone. Therefore, it can be seen that the coal deformation in the process of heating seepage is less than the thermal expansion deformation under the effect of temperature alone. According to equation (3), when ω_r is higher than 100%, it is because pore pressure reduces the effective stress of coal body and the coal body expands outward obviously when heated. When ω_r is less than 100%, the smaller the desorption deformation is more obvious.

Figure 8 shows the relationship between ω_r direction and temperature under different stress states.

It can be seen from Figures 8(a) and 8(b) that, with the increase of temperature, ω_r direction basically shows a decreasing trend when pore pressure is 0.8 MPa and 2 MPa, indicating that desorption deformation becomes more and more obvious and promotes permeability increase. It can be seen from Figures 8(c) and 8(d) that when the pore pressure was 3.2 MPa, with the increase of temperature, the ω_r of specimen 1# gradually decreased in the medium-low temperature section and increased rapidly after the high-temperature section. Specimen 2# increases slowly in the medium-low temperature segment but also increases rapidly after the high-temperature segment, and specimen 3# gradually decreased. Combined with Figure 6, it can be seen that with the increase of pore pressure, the growth rate of adsorption capacity of coal slows down gradually, while the decrease of effective stress causes the outward expansion and deformation of coal to increase, so the ω_r decline rate slows down or even rises back.

According to the evolution of coal permeability in Figure 5, the influence of thermal expansion deformation and desorption deformation on permeability is affected by the porosity of coal in the process of heating seepage. When the porosity of coal is high, the influence of thermal expansion deformation on permeability is dominant with the increase of temperature, and permeability decreases gradually. When the porosity of coal is small, the inward expansion of thermal expansion deformation is limited, and its effect on permeability is weakened. With the increase of temperature, the desorption deformation plays a dominant role in permeability and permeability increases gradually.

In addition, in the process of heating, with external stress, the seepage channel extrusion, when the temperature rises, the adsorption desorption gas is heated, due to poor permeability of coal is not spread in time free from inside the coal, the pore pressure increases, which makes the coal decreases, and the effective stress by heat outward expansion of coal is obvious. The outward expansion of coal body and the matrix contraction caused by desorption open the seepage channel of coal body, and the permeability increases with the increase of temperature. This shows that for the coal seam with large buried depth and high gas content, the utilization of heat injection mining technology can effectively improve the permeability of the original coal seam and strengthen the desorption, so as to realize the efficient exploitation of coalbed methane.

5. Conclusion

(1) With the increase of temperature, the sensitivity of coal thermal expansion deformation to temperature gradually decreases. Thermal expansion deforms and compresses the seepage channel, resulting in the decrease of permeability

(2) The influence of thermal expansion on coal permeability is related to the porosity of coal. When the porosity of coal is high, the permeability decreases due to thermal expansion deformation. When the porosity of coal is small, the inward expansion of thermal expansion deformation is limited, and the influence on permeability is weakened

(3) Coal desorption causes matrix shrinkage. The higher the desorption amount is, the more obvious the shrinkage deformation and permeability will be. At the same time, increasing temperature will promote the desorption deformation of coal and increase permeability

(4) In the process of heating, the permeability of coal is affected by thermal expansion deformation and desorption deformation. When the influence of thermal expansion deformation on permeability is dominant, permeability decreases gradually with temperature increasing. On the contrary, when the desorption deformation is dominant, the permeability increases with the increase of temperature

(5) The smaller the porosity of coal is, the smaller the temperature corresponding to the minimum permeability point is with the increase of temperature

Data Availability

The data used to support the findings of this study are included within the article.

Additional Points

Innovation of This Paper. Through the permeability test, thermal expansion, and adsorption desorption under different stress and temperature conditions, the evolution of coal axial strain, radial strain, volumetric strain, and permeability are analyzed, so as to explore the influence of thermal expansion and desorption deformation on coal permeability and provide a basis for heat injection mining of coalbed methane.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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