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Research Article

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Study on the Influence of Coal Seam Temperature on Coal Permeability

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Abstract: The permeability of coal is mainly affected by many factors such as gas pressure, stress, temperature and so on. Through seepage test, thermal expansion test, depressurization desorption test and warming desorption test, the deformation law of coal under temperature and desorption is studied. The relationship between pore pressure and slippage effect and the influence of temperature on slippage factor are analyzed, and the evolution law of permeability of coal under temperature and desorption considering slippage effect is explored. This paper mainly summarizes the theoretical knowledge obtained by scholars through experiments and numerical simulation in recent years, analyzes the influence of thermal expansion deformation and desorption deformation on permeability respectively, and then comprehensively analyzes the influence mechanism of the two on permeability in the process of warming seepage.

Keywords: seepage test, desorption, thermal expansion test, warming seepage test, slip-off effect

1. Research Purpose and Significance

China is rich in coal resources and widely distributed. China's coal seams have the characteristics of high storage and low permeability. A large amount of gas exists in coal. Gas is an unconventional natural gas and efficient and clean energy. Promoting the development and utilization of gas in coal can reduce fossil energy consumption, increase the proportion of green energy, optimize China 's energy structure, reduce greenhouse gas emissions, and achieve the purpose of dual carbon emission reduction. Gas extraction can reduce the concentration of gas in coal, prevent gas outburst and gas explosion in the process of coal mining, ensure the safety of underground mining, and realize coal mine safety.

Although domestic and foreign scholars have carried out a lot of experimental and theoretical research on the seepage characteristics of coal, they have not clearly separated the influencing factors of permeability, and the factors will affect each other. In the process of heat injection mining, the thermal expansion deformation and desorption shrinkage deformation of coal body will directly affect the permeability, and the increase of temperature will also affect the effect of slippage effect, which will also affect the permeability of coal body. Therefore, this paper provides theoretical support for heat injection mining technology by studying the influence mechanism of thermal expansion deformation, desorption deformation and slippage effect on the evolution law of coal permeability in the process of warming.

Therefore, in order to improve the safety of the utility tunnel, it is necessary to identify its safety risks, effectively realize functions such as risk classification and hidden danger investigation in the utility tunnel and prevent the occurrence of accidents.

2. Research Status at Home and Abroad

Effect of temperature on coal deformation and permeability

In the process of heat injection mining, temperature directly affects the deformation and permeability of coal. With the increase of temperature, the coal body mainly undergoes thermal expansion deformation and deformation. The influence of temperature on coal rock is mainly reflected in three aspects, thermal expansion, thermal damage and micro cracks, which will lead to the deformation of coal rock. Because desorption is an endothermic process, with the increase of temperature, the gas desorption is promoted [1], and the coal body is desorbed and deformed, which will cause the change of coal seam permeability.

Li Zhiqiang further studied the contradictory reasons for the change of methane permeability in coal under temperature and stress conditions. The seepage experiment of coal samples was carried out by using methane and helium under different temperature and stress combinations. It was found that under different effective stress conditions, the permeability of coal samples with temperature is not monotonous. There is a turning zone, which depends on the contrast relationship between thermal stress and effective stress. Under the condition of low effective stress, the temperature increases, the coal body expands outward, and the cracks become larger, resulting in the permeability increases with the increase of temperature. Under the condition of high effective stress, the temperature increases, the coal body expands internally or the plasticity of the coal body increases. As a result, the coal body has greater compressibility, and the permeability decreases with the increase of temperature. Li Zhiqiang unified the previous contradictions through experiments and theoretical analysis [2]. Mi Xuqing obtained the same conclusion through experiments. In order to study the mechanism of permeability change, the coal samples were subjected to cyclic treatment at high temperature and low temperature. After cyclic temperature shock, the permeability of coal was affected by the number of temperature shocks, temperature gradient and thermal stress. The thermal stress caused by temperature gradient exceeded the strength of coal samples, resulting in structural damage and cracks, and the permeability increased.

In addition to the change of permeability caused by the thermal expansion deformation of the matrix, the temperature will also cause the adsorption and desorption of gas, which will cause the deformation of the coal matrix and affect the permeability [3]. Through a series of experiments, Li Bobo et al. found that the total desorption amount of coal gradually increased during the process of depressurization, and this process was also accompanied by desorption shrinkage deformation. As the pore pressure decreased, the deformation gradually increased. Taking briquette as the research object, it is found that with the increase of temperature, the radial and volume shrinkage deformation of coal body occurs, the axial shrinkage deformation occurs first, then becomes expansion deformation, and the permeability of coal body increases gradually. With the increase of pore pressure, the permeability of coal decreases rapidly and then tends to be gentle. The seepage tests of different pore pressures were carried out at 30 °C, 50 °C and 70 °C, and it was found that the decrease rate and change range of permeability were affected by temperature.

The sensitivity of permeability to temperature is affected by many factors. Perera et al. found that the sensitivity of permeability to temperature gradually increases with the increase of temperature through the seepage test of pore pressure rise at different temperatures. Li et al. found that the permeability of nitrogen and methane decreased first, then increased and then decreased with the increase of temperature, and with the increase of effective stress, the large deformation was limited, resulting in a small change in permeability. 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, the more obvious the deformation of coal rock. The influence of temperature on coal pores is much greater than the influence of coal rank on pores [4]. Under the combined action of effective stress, matrix expansion / contraction and slippage effect, 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 effect of the three on the permeability of coal rock is gradually weakened [5].

Influence of slippage effect on permeability of coal

In the process of heat injection mining, with the exploitation of coalbed methane, on the one hand, the pore pressure gradually decreases, the slippage effect gradually increases, and the influence on permeability gradually increases. On the other hand, with the increase of temperature, the kinetic energy of gas molecules increases, and the expansion deformation and absorption shrinkage deformation of the matrix will affect the

slippage factor, thus affecting the permeability. Therefore, it is of great significance to study the influence of slippage effect on permeability in the process of heat injection mining.

Xiao Xiaochun and Feng Zengchao found that there is a critical pore pressure through the seepage test of increasing pore pressure under different confining pressures. When the pore pressure is less than the critical pore pressure, the permeability is mainly determined by the slippage effect. When it is greater than the critical pore pressure, linear seepage is dominant [6]. The greater the confining pressure, the smaller the critical pore pressure at which the slippage effect disappears. In order to study the dominant role of effective stress and slippage effect on permeability in the process of coal seepage, Li Jungan et al. found that in the process of reducing pore pressure, the permeability increased first and then decreased, and the pore pressure of 1.9 MPa was the critical point. When the pressure is less than 1.9 MPa, the effective stress and slippage effect are the main factors affecting permeability. When the pore pressure is greater than 1.9 MPa, the permeability is not affected by the slippage effect, which is mainly determined by the effective stress.

Wang and Zhou et al.found that the slippage effect is determined by the average free path of gas molecules and the radius of pore throat, and the deformation of coal caused by temperature will also cause the change of slippage factor. Li Bobo et al.used briquette as the research object. At 30-60 °C, it was found that when the effective stress was constant, the slippage effect decreased rapidly with the increase of pore pressure and then tended to be gentle. The higher the temperature, the smaller the pore pressure, and the more obvious the effect of slippage effect on permeability [7]. Both temperature and pore pressure have a significant effect on the slippage effect.

Effect of pore pressure on coal deformation and permeability

With regard to the influence of desorption deformation on permeability, Zhu Jie et al. found that there was a correlation between permeability and deformation of coal through seepage tests under different stress states and different pore pressures and established a correlation equation between permeability and effective stress and deformation caused by adsorption and desorption. The decrease of gas pressure leads to an increase of effective stress, and the deformation of coal body and the deformation caused by gas desorption make the permeability of coal body gradually increase. Harpalani et al. studied the relationship between coal deformation and pore pressure and explored the influence of coal deformation on permeability. It was found that the matrix shrinkage caused by desorption would lead to the increase of permeability [8]. Yuan Mei et al. found that when the axial pressure and confining pressure are constant, the permeability of coal decreases with the decrease of pore pressure due to the effective stress, but the effective stress causes the deformation of coal to be limited. As the pore pressure continues to decrease, deformation dominates, and permeability increases.

Vishal et al. studied the comprehensive influence of pore pressure and adsorption expansion of coal rock on the permeability of coal rock. It was found that with the increase of pore pressure, the adsorption expansion deformation of coal body changed the permeability [9]. Fu Xuehai et al. used helium and methane as experimental gases respectively and carried out two sets of parallel tests that kept the effective stress unchanged. It was found that the shrinkage of coal matrix would increase the permeability, and the greater the Klinkenberg permeability, the higher the sensitivity of permeability to matrix shrinkage deformation. Lin et al used the same instrument to measure the adsorption, volume strain and permeability of the same core. It was found that the permeability decreased with the increase of effective stress, and the permeability of coal was affected by gas adsorption and desorption [10].

3. Research Status of The Relationship Between Temperature and Coal Permeability

The influence of temperature on coal permeability is related to the type and pressure of gas. It is found that the permeability of coal samples decreases with the increase of temperature when the gas pressure is low, and the influence of temperature on permeability decreases when the gas pressure is high. Perera studied the effect of temperature on the permeability of natural fractured coal. It was found that when the gas injection pressure was high, the permeability of coal seam increased obviously with the increase of temperature. When the gas injection pressure was low, the effect of temperature on permeability was not obvious. This is because the molecular weight of CO_2 adsorbed in coal matrix decreases with the increase of temperature and the decrease of gas injection pressure, resulting in the shrinkage of coal matrix and the increase of permeability. The effect of temperature on CO_2 permeability is significant at 90 °C, while temperature has no significant effect on N_2

permeability [11]. Yang Kai studied the permeability change law of coal body under the coupling effect of temperature and confining pressure and found that the increase of temperature led to the expansion of coal body, the permeability decreased, and the permeability showed the sensitivity to temperature. The change of law of coal permeability under the action of pressure and temperature is studied by wave. With the increase of temperature, the permeability of gas-bearing coal decreases due to the internal expansion of coal squeezing pores and fissures, and then the external expansion of coal leads to the increase of pores and fissures, and the permeability increases. At the same time, it is found that the reduction of pore pressure weakens the compression limit of coal matrix, and the response degree of permeability to temperature increases with the decrease of pore pressure [12].

Zhang Dandan kept the effective stress unchanged and carried out comparative experiments on the permeability of briquette and raw coal under different temperature conditions. It was found that the permeability of raw coal and briquette decreased with the increase of temperature, and the permeability of raw coal was more sensitive to temperature than that of briquette due to internal anisotropy. Cai Tingting explored the change of permeability in the creep process of coal samples under different temperature conditions. It was found that the permeability of lean coal samples decreased first and then increased due to compression and expansion, while the increase of temperature would reduce the stress value at the turning point from decrease to increase [13].

In addition to exploring the influence of temperature on the permeability of coal, many scholars have also carried out a large number of experimental studies on other rocks. Based on thermoelastic mechanics and experimental data, the mathematical expression of rock permeability and temperature is established, and the existence of temperature threshold is verified. Zhang Yuan studied the temperature rise of feldspar fine sandstone, and found that there was also a threshold temperature, and the permeability at the threshold temperature was 65 times higher than that at room temperature. Dong Fuke [14] conducted temperature experiments on oil shale and found that there was a threshold in the temperature range of 350 °C ~ 400 °C. The permeability of oil shale increased slowly below this temperature and increased rapidly above this temperature.

4. Conclusion

Although domestic and foreign scholars have carried out a lot of experimental and theoretical research on the seepage characteristics of coal, they have not clearly separated the influencing factors of permeability, and the factors will affect each other. In the process of heat injection mining, the deformation of coal body is mainly the thermal expansion deformation caused by temperature and the shrinkage deformation caused by gas desorption, which directly affect the seepage characteristics of coal body.

(1) Firstly, the influence of temperature on coal deformation is analyzed by thermal expansion test. Then, through the adsorption and desorption test at room temperature (30 °C), the influence of pore pressure on coal deformation and the relationship between desorption amount and desorption deformation were analyzed. Then, through the thermal expansion test and temperature-increasing desorption test of coal body under different stress states, the relationship between desorption deformation and temperature of coal body during temperature-increasing process is studied by comparing and analyzing two sets of tests under the same effective stress. Finally, combined with thermal expansion deformation and desorption deformation, the deformation law of coal body in the process of warming seepage is analyzed.

(2) Based on the deformation characteristics of coal body, the influence of thermal expansion deformation and desorption deformation on permeability is analyzed respectively. Combined with the evolution law of permeability of coal body in the process of temperature increase, the evolution mechanism of permeability of coal body in the process of temperature increase is analyzed.

(3) Through the seepage test under variable temperature conditions, the slippage factors at different temperatures are obtained. Then, combined with the laws of thermal expansion deformation and deformation, the influence of pore pressure and temperature on the slippage effect is analyzed. Finally, the influence of slippage effect, thermal expansion deformation and deformation on permeability during warming process is comprehensively analyzed.

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