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Research Article

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Influence Law of Helium Injection on Coal Permeability Under Different Temperature and Pressure Conditions

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Abstract Gas disasters often accompany the process of mining coal resources. Conducting pre-extraction of coal bed methane can effectively prevent the occurrence of such disasters, but the effect of coal bed methane extraction at the present stage is poor, mainly due to the low permeability of the coal seam. In this paper, we will explore the change rule of coal permeability through the experiment of injecting hot helium gas into coal to provide more theoretical basis for thermal gas extraction from coal beds. The experimental results show that: with the injection of hot helium, the coal permeability shows a rapid increase and then a slow increase in the law, mainly because of the internal and external expansion of the coal pores; at the same time, the coal permeability decreases with the increase of the injection pressure, which is due to the slippage effect in the coal body.

Keywords internal and external expansion; slip effect; permeability; thermal helium

1. Introduction

China, as a large coal-producing country, has abundant reserves of coalbed methane [1]. However, in the process of extracting CBM, the development and utilisation of CBM is constrained by the generally low permeability of coal seams and the insufficient pressure of coal seam gas [2][3]. For this reason, many scholars have proposed the method of heat injection in coal to improve the extraction efficiency of coalbed methane.

RenT [4] utilised an improved ECBM method using liquid nitrogen/hot nitrogen for alternating gas injection into coal reservoirs and found that high temperature and high-pressure nitrogen caused the coal matrix to shrink, while new fine fractures were obtained, which improved the permeability of coal reservoirs. Li Yong [5] found that the pores of bituminous coal and anthracite were expanded, opened and connected after the hot steam, and the original pores and cracks were further developed. Liang Li [6] carried out the injection of hot CO_2 in coal to drive out methane in coal, and found that the pressure and temperature of injected CO_2 had an important effect on CH_4 output and CO_2 storage, under the condition of the same injection temperature, the increase of injection pressure could increase CH_4 output by 6.7%~17.4%, and under the condition of the same injection pressure, the increase of injection temperature increased the CH_4 output rate by 40.0%~43.8%~43.8%.TengT [7] found through simulation that hot gas injection in coal can enhance gas desorption, while thermal fracturing can greatly increase the porosity and permeability of coal matrix, but the thermal expansion of coal matrix slightly reduces the porosity and permeability of coal matrix. Su [8] experimentally investigated the effects of thermal expansion and desorption deformation on coal permeability during the process of temperature increase, and found that with the increase of temperature, when thermal expansion deformation dominates the coal permeability, the permeability gradually decreases, and when desorption deformation dominates the coal permeability, the permeability gradually increases. Hong[9] proposed a damage-heat-fluid-solid multi-field coupling theory to reveal the mechanism of thermal stimulation to improve the extraction of coalbed methane,

and found that heat injection into the coal can significantly increase the desorption and diffusion of gas, as well as the rate of coalbed methane gas production and the efficiency of production It is found that heat injection in coal can significantly improve the desorption and diffusion of gas, as well as the rate of gas production and production efficiency.

However, the theoretical study for the injection of hot gas in coal is still insufficient, so this paper will elaborate the change rule of coal permeability through the experiment of injecting hot helium gas into coal and explain the mechanism after heat injection in coal.

2. Experimental samples and experimental protocol

Preparation of experimental samples

The experimental samples were selected from anthracite coal in Zhaogu, Henan Province, with a burial depth of about 400-500 m. The industrial parameters of the samples were as follows:

Table 1: Industrial parameters of coal samples

Mad (%)	Vad (%)	Aad (%)	ρ (g/cm^3)
4.22	3.79	7.64	3.43

In order to reflect the real coal seam situation, the experimental samples are directly drilled on the original coal briquettes to extract the columnar coal cores by using the coal core machine. The size of the coal sample was chosen as Φ50mm×100mm, and the sample was cut along the seam to ensure that the surface of the sample was smooth and even. The experimental samples are as follows:

Figure 1: Experimental samples

Experimental equipment

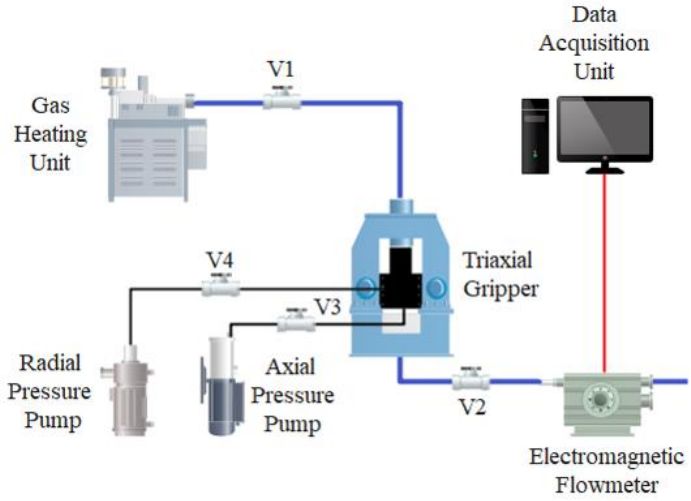

Figure 2: Diagram of experimental equipment

The experimental equipment mainly consists of a gas heating unit, an axial pressure pump, a radial pressure pump, an electromagnetic flowmeter, a data acquisition unit, a triaxial gripper and valves V1\V2\V3\V4.

The gas heating unit can heat the helium gas and inject it into the coal sample in the triaxial gripper through V1, and the gas flowing out of the downstream end of the triaxial gripper through V2 calculates the change of permeability of the coal body in the electromagnetic flowmeter, and finally transmits the obtained data to the data acquisition unit for processing. The axial and radial pressure pumps were able to pressurise the coal body to simulate the formation conditions.

Experimental programme

In order to investigate the effect of hot helium on the permeability of the coal body, the experiment will be divided into four temperatures (30℃, 60℃, 90℃, 120℃) and four pressures (0.5MPa, 1MPa, 2MPa, 3MPa) to inject hot helium into the coal samples, and at the same time, the coal samples will be loaded with an axial pressure of 7MPa and a radial pressure of 6MPa. The permeability change of the coal body was recorded in real time during the experiment.

3. Experimental results

Analysis of the law of experimental results

By injecting hot helium gas under different temperature and pressure conditions into the coal samples, the change rule of permeability of the coal body was explored.

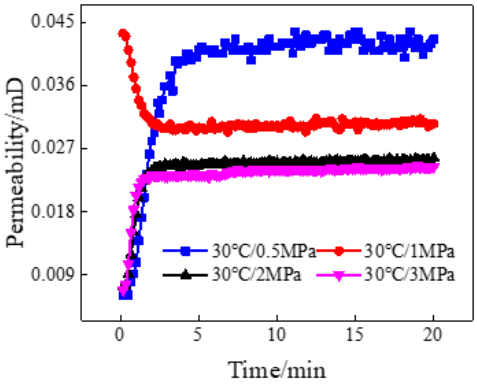

Fig. 3 Permeability of the coal body under 30°C

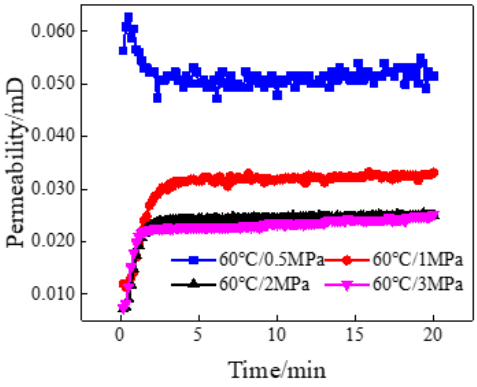

Fig. 4 Permeability of the coal body at 60°C

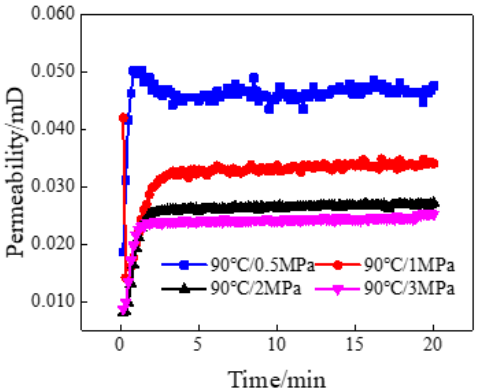

Fig. 5 Permeability of the coal body at 90°C

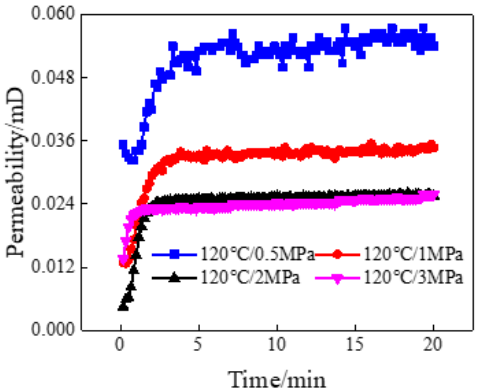

Fig. 6 Permeability of the coal body at 120°C

With the injection of hot helium gas at different temperatures and pressures into the coal, the overall coal permeability showed a trend of rapid increase followed by slow growth.

Figure 3 shows the influence of different pressures of hot helium on the coal permeability at 30℃, from which it can be seen that the coal permeability increases rapidly and then grows slowly under the conditions of gas injection pressure of 0.5MPa, 2MPa and 3MPa, but it shows the law of decreasing and then growing slowly under 1MPa. The permeability of the coal body grew from 0.0061mD to 0.06mD at 30°C/0.5MPa; the permeability decreased from 0.04mD to 0.03mD at 30°C/1MPa; the permeability increased from 0.0075mD to 0.025mD at 30°C/2MPa; and the permeability increased from 0.0068mD to 0.042mD.

Figure 4 shows the influence law of different pressure of hot helium on the permeability of the coal body under the condition of 60°C. The change law of permeability is similar to that of Fig. 3, but it shows the law of decreasing firstly and then increasing slowly under 0.5MPa. The permeability of coal body decreased from 0.0062mD to 0.051mD at 60°C/0.5MPa; the permeability decreased from 0.011mD to 0.033mD at 60°C/1MPa; the permeability increased from 0.0073mD to 0.025mD at 60°C/2MPa; the permeability increased from 0.0073mD to 0.024mD at 60°C/3MPa. to 0.024mD at 60°C/3MPa.

Figure 5 shows the influence of different pressures of hot helium on the permeability of the coal body under the condition of 90°C, from which it can be seen that the permeability of the coal body shows a sharp increase and then a slow growth with the increase of the injection pressure, but there is still a small decline in the fluctuation under the condition of 0.5MPa. The permeability of the coal body grows from 0.018mD to 0.047mD at 90°C/0.5MPa; the permeability decreases from 0.013mD to 0.034mD at 90°C/1MPa; the permeability grows from 0.0082mD to 0.027mD at 90°C/2MPa; the permeability grows from 0.0087mD to 0.025mD.

Figure 6 shows the influence pattern of different pressures of hot helium on the permeability of the coal body under the condition of 120°C. The permeability of the coal body under the condition of 120°C/0.5MPa grows from 0.032mD to 0.055mD; the permeability under the condition of 120°C/1MPa decreases from 0.013mD to 0.035mD; the permeability under the condition of 120°C/2MPa grows from 0.0045mD to 0.026 mD; permeability increased from 0.013 mD to 0.026 mD at 120°C/3MPa.

The effect of hot helium on the permeability of the coal body is mainly divided into two stages, the first stage is mainly a rapid growth or rapid decline trend. The second stage is a slow growth trend. Meanwhile, when the permeability of coal body reaches the second stage, it shows the law of 0.5MPa>1MPa>2MPa>3MPa under different temperature conditions.

Mechanistic analysis of experimental results

From the analysis of the above law, it can be seen that the change of permeability after injection of hot helium gas into coal shows the law of rapid increase and then slow growth. In the first stage, the permeability of coal body rises rapidly, which is mainly due to the result of internal and external expansion effect of coal body affected by temperature in this stage. When the thermal stress is greater than the gas pressure, the pores expand inwards; when the thermal stress is less than the gas pressure, the pores expand outwards. Although the inward expansion of the pores occurred when the gas pressure was 0.5MPa, the gas pressure was small enough to pass through the reduced pores; and after the gas pressure increased, the pores expanded outward and the pores expanded, so the permeability increased.

Meanwhile, in the first stage of injecting hot helium, the gas pressure is higher and the driving force is enough, so a large amount of gas is discharged from the coal body, and the permeability increases rapidly under the influence of the slip effect. In the second stage, the driving force decreases, so the slip effect decreases, and at the same time, the pore space expands inward again, and the pore space that was opened by the gas pressure shrinks again, and the permeability of the coal body appears to increase slowly under the joint effect of the two.

When injecting hot helium gas at 30°C/1MPa as well as 60°C/0.5MPa, the permeability of the coal body shows a trend of rapid decline followed by slow growth, mainly due to the external load, the gas pressure is not enough to hold the pores open, so the gas forms a pressure build-up in the coal, and the slipping effect increases, so the stage of rapid decline occurs. At increasing temperatures, the pores expand more inwards, so pressure build-up occurs at 60°C/0.5MPa.

As the temperature continues to rise, the pores of the coal body undergo rapid inward expansion after which the limit of inward expansion occurs and the overall pores shrink, but at the same time the increase in temperature causes rapid flow of gas molecules, so pressure build-up is difficult to occur at higher temperatures.

In the second stage of hot helium injection, the permeability will show the law that permeability decreases with the increase of gas pressure due to the increase of slip effect caused by the increase of gas pressure.

4. Conclusion

(1) With the injection of hot helium gas, the permeability of the coal body shows a pattern of rapid growth followed by slow growth. It is mainly the effect of internal and external expansion inside the coal body with the growth of temperature and pressure.

(2) When the gas injection temperature is low, the law of first rapid decrease and then slow increase appears. It is mainly because the gas pressure is not enough to hold up the pore space, forming a pressure build-up, and finally presenting a rapid decrease in permeability under the action of slip effect.

(3) The coal body shows the law that permeability decreases with the increase of pressure after the injection of hot helium gas. The permeability decreases gradually because the gas pressure increases, resulting in a more obvious slip effect.

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