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Research Article

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Experimental Study on Permeability of Hot Water Injection into Coal at Different Temperatures

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Abstract: In order to study the effect of temperature on the permeability of coal body during hot water injection, the experiments of hot water injection into coal under different water temperature conditions were carried out using the self-developed hot water injection seepage test device. The results show that with the increase of hot water temperature, the permeability of coal body shows the trend of increasing and then decreasing with time. When the thermal stress on coal body is greater than the effective stress, the permeability of coal body increases, and when the thermal stress is less than the effective stress, the permeability of coal body decreases. The formation and lifting of water-locking effect is the reason for the pulsating change of permeability. The results of the study can provide theoretical support for the practical application of hot water injection to promote the extraction of coal seam gas.

Keywords: permeability; temperature; thermal gas extraction; heat injection.

1. Introduction

The main component of coal seam gas is methane, which mainly appears in the coal seam in two forms, one is free within the pore cracks of the coal seam, and the other is adsorbed in the coal matrix [1]. Among them, the adsorbed state of gas accounts for up to 90%, but affected by the low permeability of the coal seam, this part of the coal seam gas is difficult to extract and difficult to be efficiently utilized. Intensive extraction of coal seam gas can not only effectively reduce the occurrence of mine gas disaster accidents but also improve the supply capacity of clean energy. Therefore, it is of great theoretical significance and practical value to explore the evolution of permeability of heat-injected coal bodies under different temperature conditions to promote the extraction and utilization of coal seam gas.

In recent years, many scholars have carried out a series of studies on the technology of heat injection for gas extraction in coal seams, and it has been proved that heat injection can promote the desorption of coal seam gas by injecting hot fluid into coal seams [2][3], heating coal seams by microwave [4], and heating by electricity [5][6]. Li Weikang [7] investigated the effect of hot steam on the gas transport law of coal seam and found that heat injection can effectively improve the gas transport area. Zhang Fengjie [8] and Zhang Yongli [9] established a coupled heat-flow-solid mathematical model for heat injection to extract coalbed methane from low-permeability coal seams, and simulations found that heat injection can effectively improve the permeability of coal seams and the recovery rate of coalbed methane.

Although the heat injection technology can effectively promote the desorption and seepage of gas in the coal seam, there are fewer studies in the hot water injection technology that focus on the effect of heated temperature on the permeability of the coal body, and the relevant laws and mechanisms need to be supplemented.

Therefore, this paper carries out an experimental study on the permeability of hot water injection in coal under different water temperature conditions to investigate the effect of temperature on coal permeability.

2. Experimental Methods

Coal sample preparation

The experimental coal samples were selected from the mining area of Inner Mongolia, China, and were sampled along the stratification using a rock corer. After sampling, the coal samples were processed into cylindrical cores with a diameter of 50 mm and a length of 100 mm, and the shape of the coal samples is shown in Fig. 1.

Figure 1: Experimental samples

Experimental setup and program

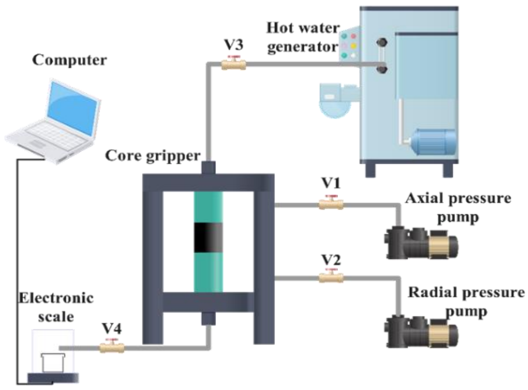


Figure 2: Diagram of experimental equipment

The device used in the experiment is shown in Fig. 2, the coal sample is put into the coal core gripper after drying treatment. Open valves V1 and V2 and use the axial pressure pump and radial pressure pump to load axial pressure to 6MPa and confining pressure to 4MPa, respectively. Open the hot water generator, set the water supply pressure to 3MPa and the temperature to 30 ℃, and open the valve V3 after the pressure and temperature are stabilized and the hot water will be passed into the coal core gripper. Open the valve V4 and use the electronic scale to record the amount of liquid out of the downstream end in real time. The computer receives and processes the data, and the experiment time is 30 min. After the experiment is completed, change the hot water temperature to 50°C, 70°C, 90°C, 110°C, and 130°C, and repeat the above operation.

3. Experimental results

Data processing

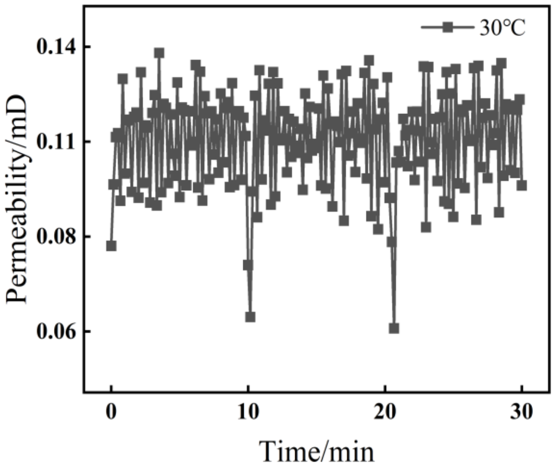
The experiments were carried out to determine the permeability using the steady state method and the permeability was calculated using the formula:

$$k = \frac{Q\mu L}{S\rho_0(P_1 - P_2)}$$

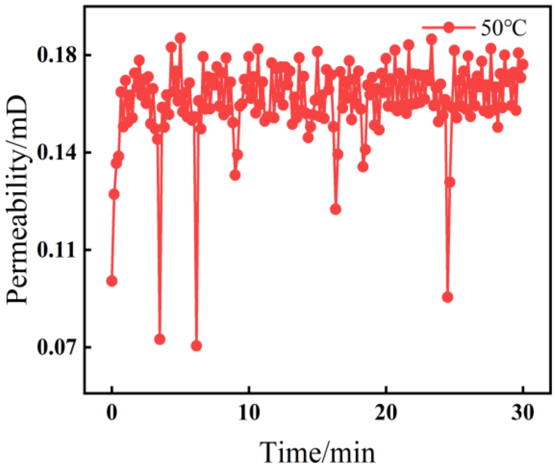
Where k is the liquid-measured permeability, mD; Q is the liquid-measured flow rate, g/s, collected by the electronic scale in real time; μ is the dynamic viscosity coefficient of water, Pa·s; L is the length of the coal sample, cm; S is the cross-sectional area of the coal sample, cm^2; ρ_0 for the density of water, g/cm^3; P_1 for the inlet pressure, MPa, collected by the sensor in real time from the upstream pressure; P_2 for the outlet pressure, MPa, take the atmospheric pressure 0.1 MPa.

Analysis of the pattern of experimental results

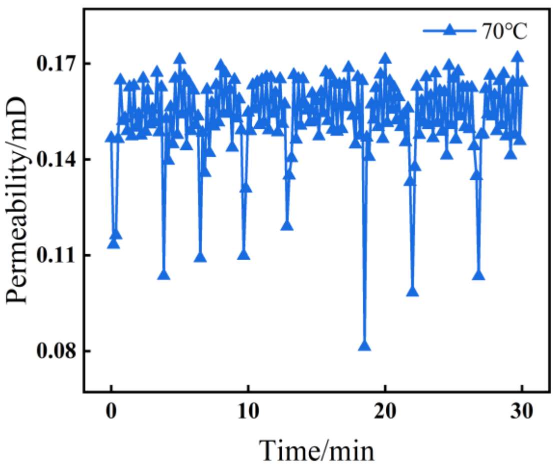
Under the condition of different water injection temperature, the trend of liquid-measured permeability of the coal body with time is shown in Fig. 3.



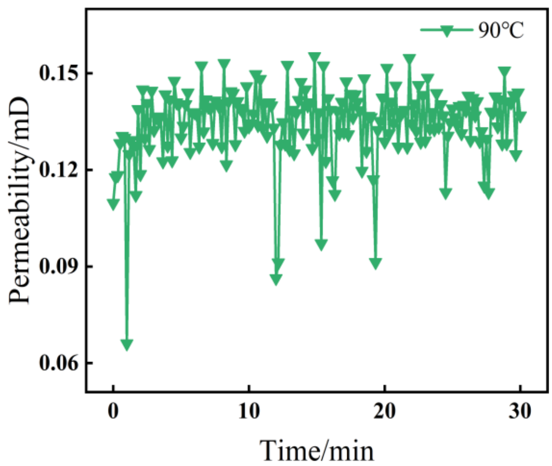
(a) 30℃



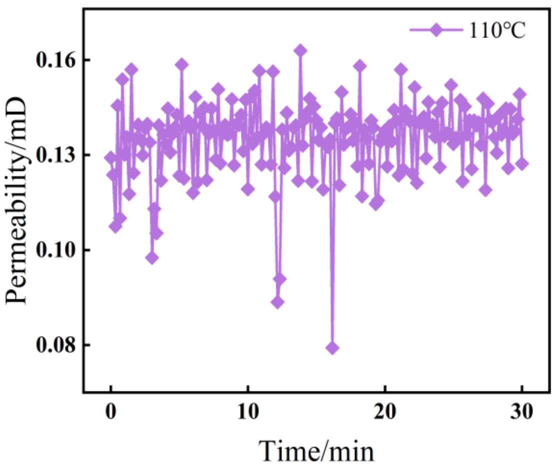
(b) 50℃



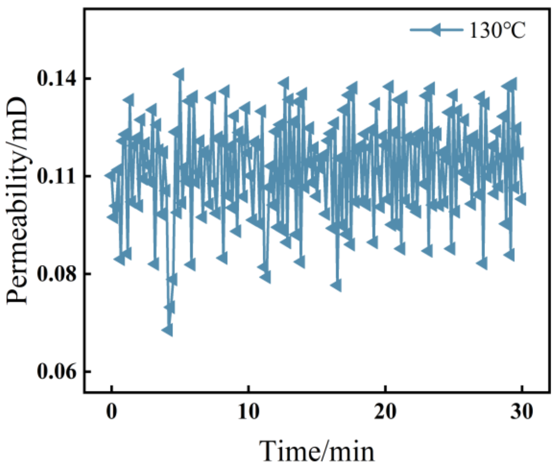
(c) 70℃



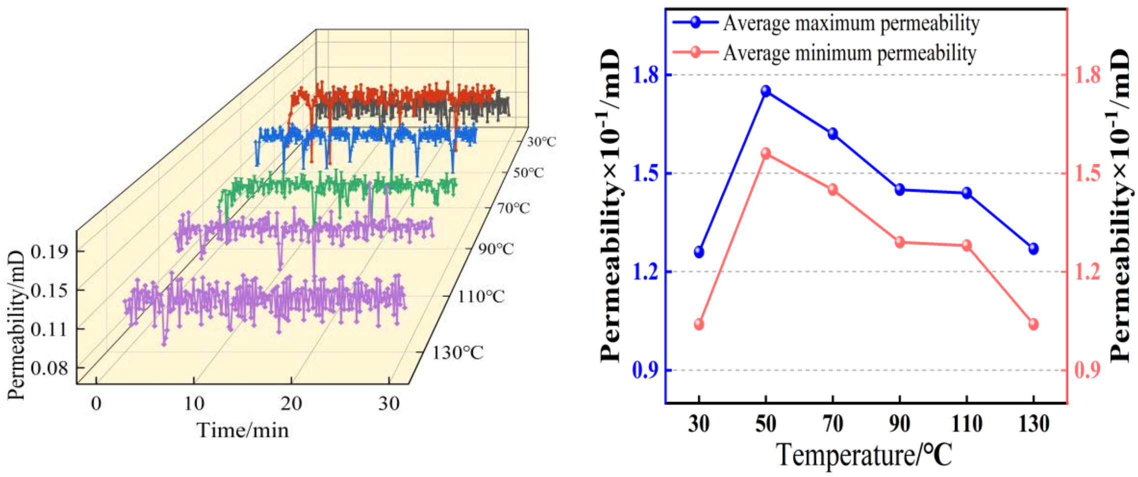
(d) 90℃



(e) 110℃



(f) 130℃



(g) Pooled penetration rate *(h) Average extreme penetration rate*

Figure 3: Trend plot of liquid measured permeability over time

As shown in Fig. 3, when the injected temperature is 30℃, the liquid permeability is centrally distributed between 0.09~0.12mD, and the maximum value of liquid permeability is 0.13mD. When the injection temperature increases to 50℃, the liquid permeability is centrally distributed between 0.15~0.17mD, and the maximum value of liquid permeability is 0.19mD. When the injection temperature is 70℃, the liquid permeability is centrally distributed between 0.15~0.16mD, and the maximum value of liquid permeability is 0.17mD. When the water injection temperature is 70℃, the liquid permeability is centrally distributed between 0.15~0.16mD, and the maximum value of liquid permeability is 0.17mD. When the water injection temperature is 90℃, the liquid permeability is centrally distributed between 0.13~0.14mD, and the maximum value of liquid permeability is 0.16mD. When the water injection temperature is 110℃, the liquid permeability is centrally distributed between 0.12~0.14mD, and the maximum value of liquid permeability is 0.15mD. When the injection temperature is 130℃, the liquid permeability is centrally distributed between 0.1~0.12mD, and the maximum value of liquid permeability is 0.14mD.

It can be seen that with the continuous injection of hot water, the measured permeability at different temperatures changes irregularly with time. With the increase of the injection temperature, the maximum value of the measured permeability shows a trend of increasing and then decreasing, and the maximum value is at 50℃.

As shown in Fig. 3(h), with the increase of water injection temperature, both the average maximum value permeability and the average minimum value permeability show the trend of increasing and then decreasing, and both reach the maximum value at 50℃.

Mechanism analysis of experimental results

Temperature is an important factor affecting the permeability of the coal body, the injection of hot water into the coal will increase the temperature of the coal body, the coal body is heated to produce thermal stress, and then expansion changes. Whether this expansion change affects the permeability of the coal body positively or negatively depends on the contrasting relationship with the thermal stress and effective stress that the coal body is subjected to [10].

When the thermal stress is greater than the effective stress, the effective stress on the coal body can not restrict the coal body to expand outward, the internal pores of the coal body will expand outward, and the permeability of the coal body increases. On the contrary, when the thermal stress is less than the effective stress, the coal body can not expand outward by the constraints of the effective stress, but can only expand inward and squeeze the pores, which makes the permeability of the coal body decrease.

When the hot water temperature rises from 30℃ to 50℃, the thermal stress on the coal body is greater than the effective stress, the internal pores of the coal body are expanded, and the permeability rises. When the hot water temperature continues to rise, the thermal stress on the coal body has been increasing but it is always smaller than the external effective stress on the coal body, so that the coal body can only be expanded inward, and the permeability continues to decrease.

Influenced by the pore structure of the coal body, hot water injection in the coal is easy to form the hydrolock effect. When the liquid section plug is formed, the liquid permeability of the coal body is extremely small. When the liquid section plug is broken through, the liquid permeability is extremely large. The formation and breakthrough of the liquid segment plug is the reason for the pulsation change of the liquid permeability of the coal body.

4. Conclusion

In this paper, we studied the change rule of permeability in the process of injecting hot water at different temperatures into the coal body, analyzed the mechanism of its generation, and obtained the following main conclusions:

(1) With the increase of injected temperature of water, the liquid-measured permeability of coal body shows the trend of increasing first and then decreasing. This is mainly affected by thermal stress and effective stress. When the thermal stress is greater than the effective stress, the coal body expands outward and the permeability becomes larger. When the effective stress is greater than the thermal stress, the coal body expands inward and the permeability decreases.

(2) In the process of hot water injection, the formation and release of water lock effect inside the coal body is the reason for the pulsating change of permeability.

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