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Research Article

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Experimental Research on Seepage of High-Temperature Hot Water Injection into Coal Under Different Pressure Conditions

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Abstract: In order to accurately characterize the evolution of permeability in hot water injection into coal, the permeability of the coal body during the injection of high-temperature hot water under different pressure conditions was measured. The results show that: with the injection of high-temperature hot water, the permeability of the coal body undergoes pulsation change with time, which is related to the formation of liquid segment plugs in the coal. The formation of liquid segment plugs leads to a small fluctuation of permeability, and the breakthrough of liquid segment plugs leads to the emergence of the peak permeability. With the elevation of the injection pressure, the peak of the permeability decreases, the amplitude of the pulsation is reduced, and the average large-value permeability decreases and the average small-value permeability increases. This is related to the elevated fluid driving force inside the coal. The results of this study can provide a theoretical basis for the application of hot water injection to extract gas.

Keywords: thermal gas recovery; hot water permeability; high temperature hot water; liquid segment plug

1. Introduction

Coalbed methane, also known as coalseam gas, is an associated resource of coal, which is highly efficient and clean, and is favored by power generation, chemical industry, fuel and other fields. Strengthening gas extraction is of great significance in reducing the occurrence of gas disaster accidents and optimizing China's energy structure.

China has abundant coalbed methane reserves, but only 10% of them are active in the form of free state in the pore and crack of coal seams. A large amount of coalbed methane is endowed with adsorption state in the coal matrix [1], which makes it difficult to extract coalbed methane in China and the effective extraction rate is low. Promoting the desorption of gas in the coal matrix is the key to improve gas extraction.

To address this key issue, many scholars have learned the formation heating technology in the field of petroleum extraction and innovatively applied the heat injection technology to the extraction of coal seam gas [2-4]. Yang Xinle et al [5] established a mathematical model for heat injection and extraction in low-permeability coal seams by considering the coupling of temperature and stress, and the simulation results proved that heat injection can effectively improve coalbed methane extraction. Teng [6] and Xue [7] established a coupled heat-liquid-solid model to simulate the process of hot water injection in coal seams, and the results showed that the hot water injection can effectively improve the recovery rate of coalbed methane. Hu Linjie, Feng Zengzhao et al [8] [9] demonstrated that hot water injection can lift the hydro-lock effect and promote methane desorption through on-site hot water injection experiments.

However, at this stage, there is less research on the evolution law and mechanism of permeability of coal body during hot water injection, for this reason, this paper carries out seepage experiments of high-temperature hot

water injection into coal body under different pressures, obtains the evolution law of permeability during the process of hot water injection into coal, and explains the mechanism of the change of permeability pulsation, which provides theoretical references for the technology of hot water injection to promote the extraction of methane gas.

2. High temperature hot water seepage experiment

Experimental setup

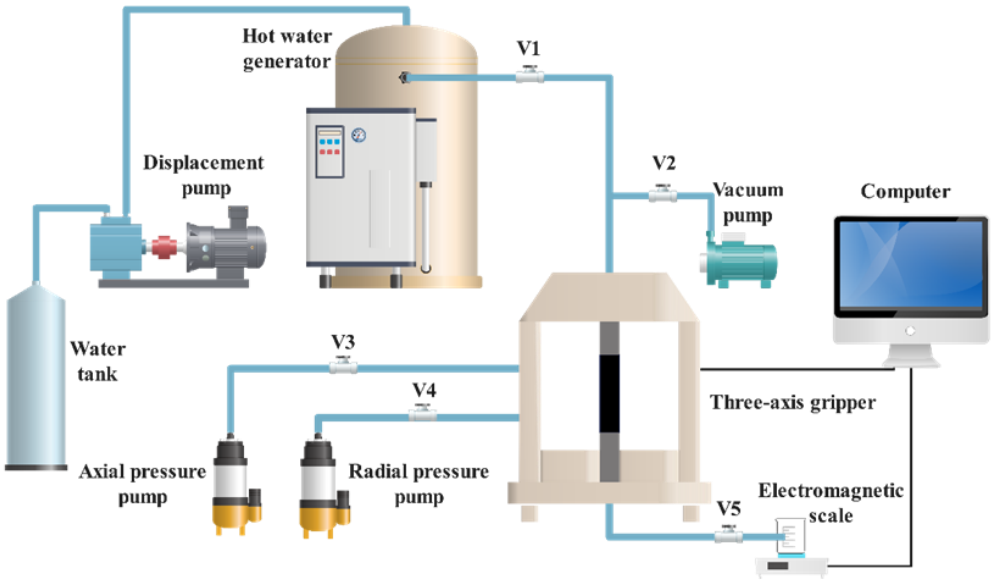


Figure 1: Experimental equipment diagram

As shown in Figure 1, the experimental setup consists of a displacement pump, a hot water generator, a triaxial gripper, an axial pressure pump, a radial pressure pump, valves V1\V2\V3\V4\V5 and a computer. Among them, the displacement pump and hot water generator are responsible for preparing the constant temperature and pressure hot water required for the experiment, the axial pressure pump and radial pressure pump complete the pressurization of the coal samples by injecting water into the triaxial gripper, the electromagnetic scale monitors the downstream end of the triaxial gripper in real time, and the computer is responsible for recording and processing the experimental data.

Coal sample preparation

The experimental coal samples were selected from Jiaozuo mining area in Henan Province, China, and were coring along the laminae by using coal sample coring machine, and the coal samples were processed into standard cylindrical coal cores of ϕ50×100mm. The basic parameters of the coal samples were measured and the results are shown in Table 1.

Table 1: Basic parameters of coal samples

Mad/%	Aad/%	Vad/%	ρ /(g/cm^3)	FCad/%
3.50	9.75	5.85	1.67	78.45

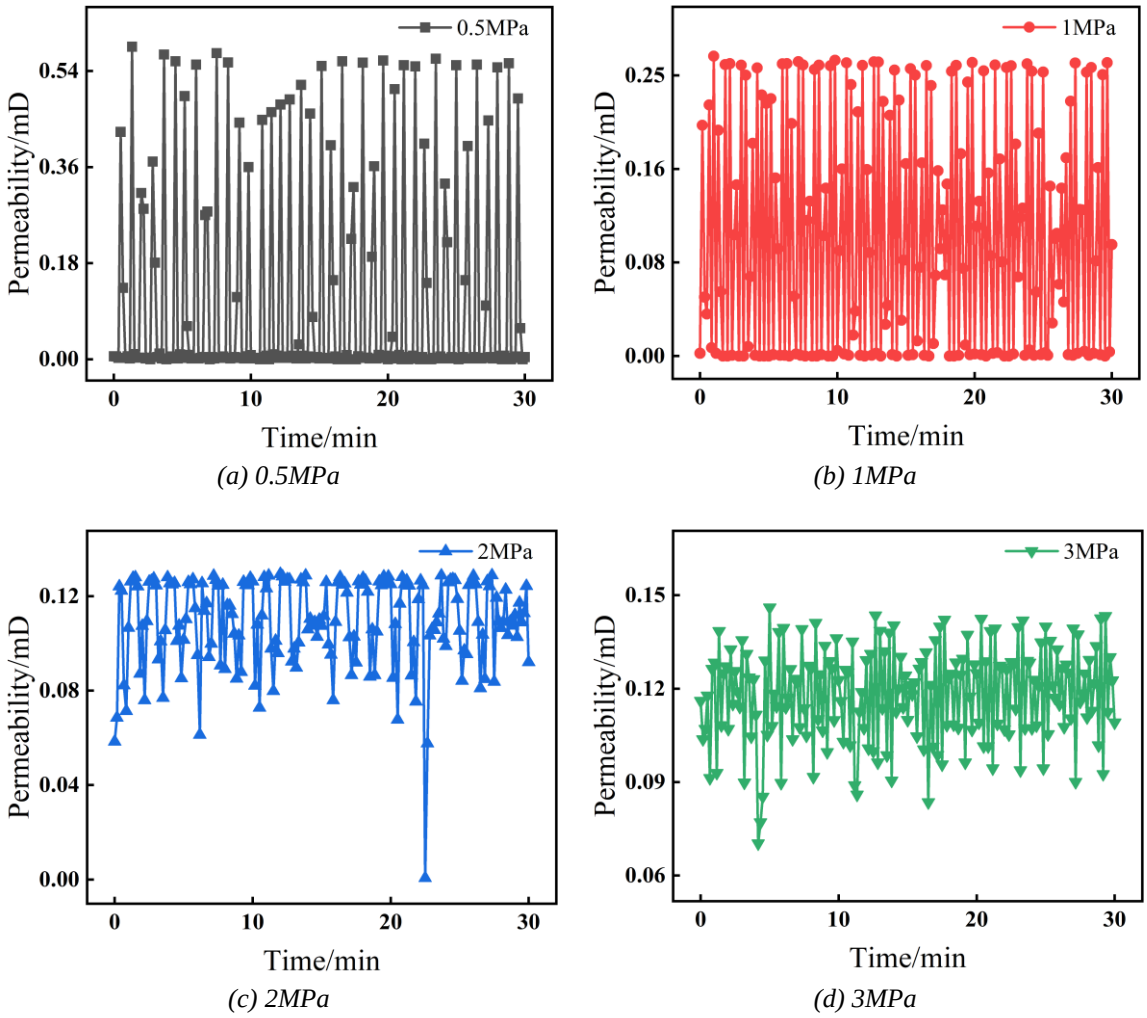
Experimental program

In order to study the effect of high-temperature hot water on the permeability of coal sample under different injection pressures, the experimental temperature of hot water was set at 130℃, and high-temperature hot water with pressures of 0.5MPa, 1MPa, 2MPa and 3MPa was injected into the coal in sequence, and the time of each injection was 30min. the axial pressure of 8MPa and radial pressure of 6MPa were maintained during the experimental period, and the data were monitored and recorded by computer in real time.

3. Experimental Results

Analysis of Experimental Results

After injecting hot water into the coal body at different pressures, the electromagnetic scale in the experimental system records the quality of the liquid at the downstream end in real time, the computer receives the data and calculates the liquid flow rate and then substitutes it into the liquid permeability formula to get the liquid permeability. The trend of liquid permeability change with time under different pressure conditions is shown in the figures as below.



(a) 0.5MPa *(b) 1MPa*

(c) 2MPa *(d) 3MPa*

Figure 2: Comparison of liquid measured permeability at different injection pressures

From Figure 2, it can be seen that under different injection pressures, the liquid measured permeability undergoes irregular pulsation changes with the increase of time.

1. As shown in Figure 2(a), when the injection pressure is 0.5MPa, the measured permeability basically varies between 0 and 0.54mD. In the 2nd min, the liquid-measured permeability reaches the maximum value of 0.58mD.
2. As shown in Figure 2(b), when the injection pressure is 1MPa, the pulsation range of the liquid-measured permeability is between 0 and 0.25mD. The liquid-measured permeability reaches the maximum value of 0.26mD at the 3rdmin.
3. As shown in Figure 2(c), when the injection pressure is 2MPa, the pulsation range of liquid permeability is reduced to 0.08~0.12mD, and the maximum value of liquid permeability is 0.145mD.
4. As shown in Figure 2(d), when the water injection pressure is 3MPa, the liquid-measured permeability concentrates the pulsation between 0.1~0.12mD, and the maximum value of liquid-measured permeability is 0.141mD.

5. The average liquid-measured extreme permeability under each water injection pressure condition was calculated and plotted as shown in Figure 3.

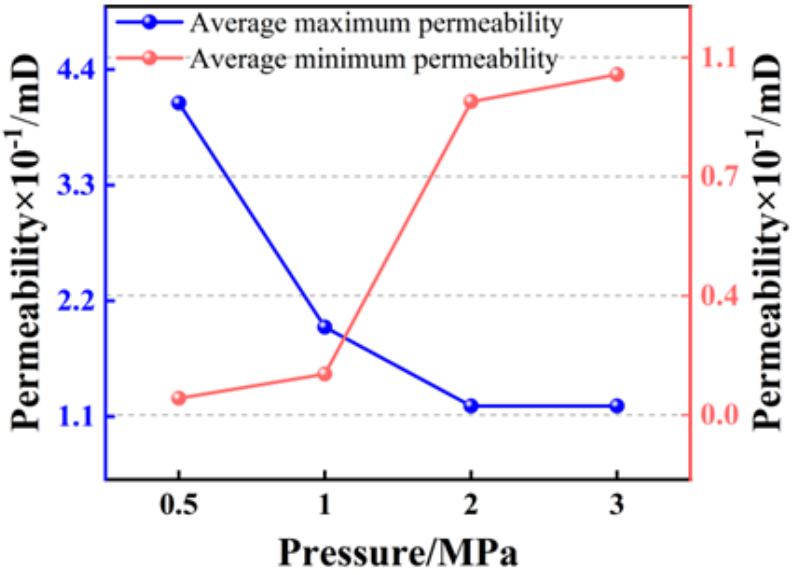


Figure 3: Average extreme penetration rate

As can be seen from Fig. 3, under the same temperature condition, the average very large value liquid-measured permeability gradually decreases with the increase of water injection pressure. And the average small value permeability gradually increases.

In summary, comparing the trend of liquid permeability with time under different injection pressures, it can be found that the seepage of hot water in the coal mainly has the following pattern:

The liquid-measured permeability shows irregular pulsation changes with time, with both a large range of pulsation and a small range of fluctuation.

With the increase of water injection pressure, the maximum value of the liquid-measured permeability, the amplitude of pulsation and the average large value permeability gradually decrease, the liquid-measured permeability value becomes more and more concentrated, while the average small value permeability gradually increases.

4. Mechanism Analysis of Experimental Results

The internal structure of the coal body is complex, and it is very easy to produce the hydrolock effect in the process of injecting hot water into the coal. When the hot water flows through the pores in the coal, affected by the driving force and pore structure, the water is very easy to accumulate in the smaller pores, forming liquid segment plugs. The formation of liquid segment plugs will block the hot water flow channel, resulting in a decrease in the permeability of the coal body. At the same time, the hydrolock effect makes the liquid pressure in the blocked pore space rise. When the pressure in the pore space reaches the peak, the liquid segment plug is excluded, the hydrolock effect is lifted, and the permeability of the coal body increases. The formation and release of the liquid segment plug cause the pulsation change of the coal body liquid permeability with time.

There are various types of pores of different scales in the coal, and the flow of hot water in the pores of different scales will form liquid segment plugs of different sizes. The larger the liquid segment plug is, the less likely to be broken through, the higher the pressure required to break through the liquid segment plug. When the liquid segment plug is broken through, the permeability will also undergo a large-scale pulsation change. On the contrary, the liquid-measured permeability fluctuates within a small range.

With the increasing of water injection pressure, the driving force of hot water flow inside the coal body is stronger, on the one hand, it is not easy to form a larger liquid plug, on the other hand, the liquid plug is easier to break through, resulting in the reduction of the range of pulsation of the liquid-measured permeability and the concentration of the value of the permeability.

5. Conclusion

This paper carried out the seepage experiment of high-temperature hot water injection into coal body under different pressure conditions, analyzed the change rule of permeability with time and mechanism in the process of injecting hot water into coal, and obtained the following main conclusions:

1. The liquid-measured permeability is pulsating with time. As the pressure of injected hot water rises, the amplitude of liquid permeability pulsation decreases, and the peak value decreases. This pulsation change is related to the formation of liquid segment plugs in the coal pores, and the formation and breakthrough of liquid segment plugs cause the periodic pulsation change of the liquid-measured permeability. The small value of permeability occurs when the liquid plug is generated, and the large value occurs when the liquid plug breaks through.
2. The average large value permeability and the average small value permeability show opposite patterns of change with the increase of water injection pressure. This is related to the driving force of hot water flow inside the coal body, and the increase of water injection pressure leads to the increase of fluid driving force, the average large value permeability decreases, and the average small value permeability increases.

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