

EFFECT OF CYCLIC TEMPERATURE IMPACT ON COAL SEAM PERMEABILITY

by

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The gas permeability of the coal samples, subjected to cyclic temperature impact under different conditions, was considered in the article. Meanwhile, the change of the coal sample permeability and fractures were analyzed through scanning electron microscopy. The obtained results show that the cyclic temperature impact has largely positive effect on the increase of the coal sample permeability and that new fractures and permeability growth increase with the higher temperature difference.

Key words: thermal stress, cyclic temperature impact, fracture, coal permeability

Introduction

Coalbed methane (CBM) extraction can not only prevent coal mine gas disaster, but also be used as a clean energy. However, the low permeable characteristics of CBM reservoirs restricted the rapid development of CBM industry in China. An effective way to improve the CBM drainage rate is the hydraulic fracturing method which is the most common measure to increase the production of reservoirs [1]. But this measure faces a series of technical problems, such as poor permeability increase effect and serious water pollution. With the development of technologies, the methods including heat injection and low-temperature fluid fracturing reservoirs have been applied to CBM production [2], and the investigation of coal seam permeability improvement through thermal stress generated by the temperature change has attracted more and more attentions in recent years.

The effect of heating on coal and rock properties, such as the coal and rock thermal cracking, coal pore structure, mechanical property as well as permeability changes after thermal treatment, was reported in [3-6]. The studies of low temperature treatment on coal and rock mainly focus on low temperature damage to materials and the influence on physical and

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mechanical properties. The micro-pores and meso-pores in dark coal were proposed in [7]. The mechanism of liquid nitrogen was considered in [8]. The freezing cracking effect of rock by using low temperature fracturing test apparatus and acoustic emission test, and the analysis displayed that the degree of freezing and cracking of rock were related to lithology (see, for example, [9]). The damage effect of liquid nitrogen freezing on sandstone and coal was investigated in [10].

The studies mentioned above mainly focus on impact of high temperature or low temperature on CBM desorption seepage, internal pore structure as well as physic-mechanical properties. However, there are few experimental studies on the effect of temperature cyclic impact on the fracture and permeability of coal. The main aim of this paper is to carry out the temperature cyclic test of coal samples, and to analyze the change law of coal seam permeability under the influence of the temperature cyclic impact.

Test equipment and research scheme

The SLX-80 high and low temperature treatment system, fig. 1, was adopted to carry out the hot-cold cyclic impact test for coal samples. In order to realize the hot-cold cyclic impact test on the coal sample, two boxes are required.

The permeability test equipment is the three-axis gas seepage experimental system. As shown in fig. 2, the system consists of the coal sample holder, manual pressurized pump, vacuum system, gas seepage system, flow monitoring system, displacement monitoring system, and the temperature monitoring system. The device can achieve gas seepage experiment under different temperatures, different axial pressures and different confining conditions.



Figure 1. The SLX-80 high and low temperature treatment system



Figure 2. Triaxial gas seepage testing system

The anthracite coal samples used in the experiment were taken from the No. 3 coal seam in the Weiding Coal Mine, Shanxi Province, China. The big fresh coal blocks were taken back to the laboratory, then were drilled into a diameter of 50 mm columnar along the vertical bedding direction by using a core drilling machine, and finally were produced to the coal sample into a 50 mm \pm 1 mm length by using the core cutter. To maintain the integrity of the drilling of coal samples, it is necessary to drill coal pillars slowly in the process of drilling.

The test of coal sample permeability is carried out by using the three-axis gas seepage test system, and the test gas is nitrogen with a purity of 99.99%. The specific test conditions for the coal sample permeability are shown in tab. 1, and the specific method can be found in papers [11, 12].

The temperature impact time is the most important factor in this test process. If the temperature impact time is too short, the internal temperature of coal samples would not reach the ambient temperature, and the test results would be affected. Assuming that the time required for the coal sample center to set the surrounding temperature is t , the total amount of heat that is required to be absorbed or released by the whole coal sample is Q :

$$Q = 1000cv\rho\Delta T = K_T L\Delta T t \quad (1)$$

where, c is the specific heat of the coal sample, v – the coal sample volume, ρ – the coal sample density, K_T – the thermal conductivity of the coal sample, L – the heat conduction distance, ΔT – the temperature change, and t – the impact time.

In this paper, there are two plans, the first plan is used to investigate the effect of the temperature impact time on the permeability of coal samples, and the second plan is used to study the impact of different environmental conditions on the impact of coal permeability. The details are as follows: The first plan is shown in tab. 2.

Table 1. Testing conditions of the coal permeability

Confining pressure	Axial pressure	Test gas	Gas pressure	Temperature
2	2	N ₂	0.6	25

Table 2. The test plan for different temperature impact times

High temperature	Low temperature	Impact time	Number of impacts
100 °C	-100 °C	3 h	1, 2, 3, 4, 5

The specific operations are as follows.

The dry columnar coal samples were marked. The electronic balance was used to weigh coal samples. The gas permeability of the coal sample was measured by the three-axis gas seepage test system. Each coal sample was measured three times, and take the average as the permeability under the initial state of the coal sample. Starting two SLX-80 type high and low temperature test chamber, the temperature of the high temperature box was set to 100 °C, and the temperature of the low temperature box was set to -100 °C. The coal sample was placed in the high temperature box, when the temperature of the high temperature box reached 100 °C and stabilized after 3 hours, the temperature of the coal in the high temperature box has reached 100 °C. Opening the high temperature box, the sample was quickly transferred from the high temperature box to the low temperature box with the temperature of -100 °C for the temperature impact treatment, the treatment time was 3 hours. Opening the low temperature box, the use of special fixture transferred from the coal sample into the drying tank cooling to room temperature (25 °C), then weighing coal samples and testing the permeability of coal samples, and recording the test data, and a temperature impact test is completed.

The second test plan of the temperature impact test under different conditions is shown in tab. 3.

Experimental results and analysis

Influence of the temperature impact time on the coal seam permeability

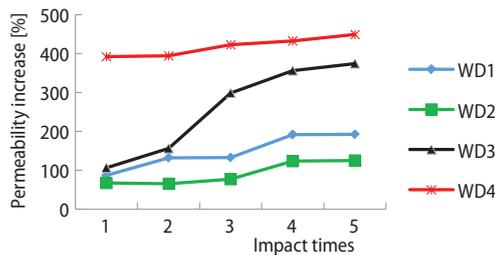
The test samples used in this paper are fully dried to avoid the frost heave effect of water on the coal seam. It can be seen from fig. 3 and tab. 4 that the permeability of coal sample shows the variation law of fluctuation under the action of temperature cyclic impact. The average permeability increase rate of coal samples after the temperature impact treatment was shown in fig. 4.

Table 3. Testing conditions of the cyclic temperature impact under different conditions

Serial number	High temperature	Low temperature	Temperature difference	Impact time	Impact times
1 [#]	100 °C	-100 °C	200 °C	3 h	5
2 [#]	140 °C	-140 °C	280 °C	3 h	5
3 [#]	180 °C	-180 °C	360 °C	3 h	5

Table 4. The permeability of coal samples after cyclic temperature impact

Coal sample number	Initial permeability [mD]	After 1 st impact [mD]	After 2 nd impact [mD]	After 3 rd impact [mD]	After 4 th impact [mD]	After 5 th impact [mD]
WD1	0.189	0.351	0.437	0.439	0.549	0.551
WD2	0.075	0.126	0.124	0.133	0.168	0.169
WD3	0.089	0.184	0.229	0.356	0.408	0.424
WD4	0.005	0.026	0.026	0.028	0.028	0.029

**Figure 3. Increase of the permeability of coal samples before and after temperature impact****Figure 4. Mean of the permeability of coal samples after the temperature impact treatment**

Effect of temperature environment on coal seam permeability

The influence of the impact temperature environment on the permeability of the coal seam can be obtained by comparing the coal sample permeability after 5 times of temperature impact.

The change in permeability of each coal sample under the different temperature environment is listed in tab. 5. The individual differences in coal samples result in a different increase in coal sample permeability under the same temperature environment. The temperature difference for 1[#] to 3[#] are 200 °C, 280 °C, and 360 °C, respectively.

As shown in fig. 5, the average permeability increases with the temperature difference growth. The coal damage degree increases with the growth of the temperature difference, leading to the fracture generation and expansion and the increase of the permeability.

The coal is one of the typical porous heterogeneous materials, and obeys the law of thermal expansion and contraction under variable temperature conditions. When the coal is subjected to external temperature impact, there is a large temperature gradient in the surface

Table 5. Coal permeability after the cyclic temperature impact under different conditions

Serial number	Coal sample number	Initial permeability	After 5 times temperature cycling impact		
			Permeability	Increase of permeability	Average increase rate
1 [#]	WD1	0.189	0.551	192.41	285.00
	WD2	0.075	0.169	124.47	
	WD3	0.090	0.424	374.05	
	WD4	0.005	0.029	449.06	
2 [#]	WD5	0.014	0.086	507.04	370.96
	WD6	0.069	0.255	269.61	
	WD7	0.013	0.045	248.44	
	WD8	0.051	0.287	458.75	
3 [#]	WD9	0.062	0.412	567.31	573.26
	WD10	0.032	0.224	603.76	
	WD11	0.136	0.724	431.35	
	WD12	0.045	0.354	690.63	

of the coal wall, the crack surface and the coal body. Since the thermal conductivity of the coal seam is low and has strong anisotropy (see, e. g., [13]), the contraction stress (temperature impact stress) in the coal rock generate with the temperature change [8]. The thermal stress generated in the coal sample can be calculated by:

$$\sigma_{ij} = \alpha_{ij} E_{ij} \Delta T \delta_{ij} \quad (2)$$

where σ_{ij} is the thermal expansion, α_{ij} – the coefficient of linear expansion of the coal sample, E_{ij} – the elastic modulus of the coal sample, and δ_{ij} – the Kronecker symbol.

The elastic modulus of the coal sample used in the experiment was 2692 MPa and the uniaxial tensile strength was 2.25 MPa. From eq. (2), the thermal stress values 15.40 MPa, 21.56 MPa and 27.72 MPa can be calculated under the temperature difference of 200 °C, 280 °C and 360 °C, respectively. It is shown that the thermal stress produced by the temperature impact conditions exceeds the strength of the coal sample, leading to the structural failure and fractures generation, thus an increase in the average permeability of coal samples.

With the aid of the electron microscopy, the development of fractures under the cyclic temperature impact in the temperature gradient environment can be clearly seen from the fig. 6. If the thermal stress exceeds the strength of the coal, new fractures will generate or make the primary fractures further expand. Under the cyclic temperature impact, more microbursts and fractures will generate, develop and connect, so the permeability of the coal seam can be improved.

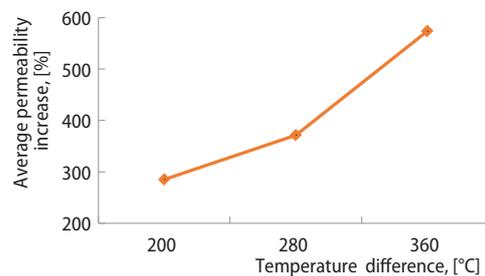


Figure 5. The change of coal samples permeability with the temperature difference

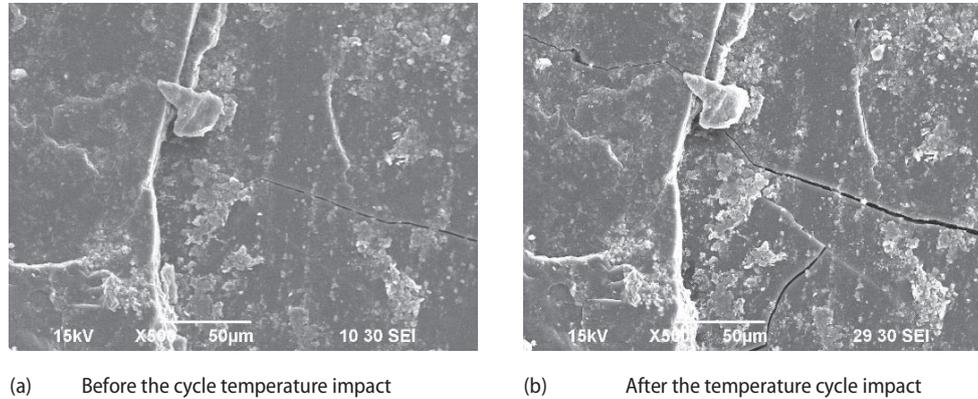


Figure 6. Fractures growth of coal samples before and after cycle temperature impact

Conclusion

The cyclic temperature impact is one of effective means to improve the permeability of the coal seam. The heterogeneity and anisotropy of the coal seam directly lead to the unbalance and increase in permeability after temperature cyclic impact. After the cyclic temperature impact, the increase of the coal seam permeability can be affected by the temperature impact times, temperature gradient and thermal stress. The thermal stress, caused by the temperature gradient, is the key role of the coal permeability growth.

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Nomenclature

c – specific heat of the coal sample, [$\text{kJkg}^{-1}\text{K}^{-1}$]
 E_{ij} – elastic modulus of the coal, [MPa]
 K_T – thermal conductivity of the coal sample, [$\text{Jm}^{-1}\text{K}^{-1}\text{s}^{-1}$]
 L – heat conduction distance, [m]

Q – total amount of heat by the coal sample, [J]
 t – impact time, [h]
 v – coal sample volume, [m^3]

Greek symbols

ρ – coal sample density, [kgm^{-3}]

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