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Research Article

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Research on the Characteristics of Gas Adsorption by Coal Particles in a Low-Temperature Atmosphere

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Abstract: The law of coal gas adsorption provides a scientific basis for the prevention and control of mine gas disasters, the assessment of coal seam gas content, and the discrimination of outburst risks. To ensure the reliability and accuracy of the determination of coal seam gas content, a self-designed gas adsorption experimental device was used. Experiments on methane adsorption by coal were conducted at temperatures of 30°C, -10°C, and -20°C, with an initial adsorption pressure of 1.1 MPa, using a high-low temperature alternating thermostat. The amount of gas adsorbed under different temperature conditions was obtained. The study shows that under the same pressure conditions, as the gas pressure increases and the temperature decreases, the amount of gas adsorbed gradually increases.

Keywords: Low temperature; granular coal; gas; gas adsorption; adsorption model

1. Introduction

Coal and gas outburst is a complex dynamic phenomenon of mine gas, as well as a very serious and relatively common natural disaster that threatens the safety of coal mine production. As the mining depth increases, the gas content also increases [1].

The accurate determination of coal seam gas content is crucial for the safe mining of coal mines [2]. Currently, the direct method of gas content determination has several advantages over the indirect method. In the direct method, Wang Zhaofeng et al. [3] and Wang Long et al. [4] have proposed the frozen core technology.

In recent years, many scholars have achieved a series of results in the technology and related theories of frozen cording. Wang Zhaofeng [5] et al. and Yue Gaowei [6] et al. found that the adsorption constants a and b increase rapidly with the decrease in temperature (especially below 0°C), and that low temperature promotes gas adsorption and inhibits gas diffusion. Qin Lei [7] et al. found that the adsorption capacity a increases with the increase in liquid nitrogen freezing-thawing time and decreases with the increase in temperature. Xu Wenjie et al. [8] believe that increasing the gas injection pressure and lowering the adsorption temperature will increase the methane adsorption process, resulting in an increase in adsorption capacity. Ma Xingying et al. [9] found through research that low temperature affects the increase in the surface free energy of the coal body, and the thermal motion ability of gas molecules is reduced, showing that low temperature inhibits the desorption and diffusion of gas in coal. Wei Le [10] believes that the number of adsorption layers of gas on the coal surface increases linearly with the decrease in temperature, and the lower the temperature, the greater the adsorption capacity. Ma Shujun et al. [11] believed that during the process of lowering the test temperature, the gas adsorption capacity shows a characteristic of alternating increase and decrease (with the overall trend being an increase). However, there is currently a lack of systematic research on the characteristics of gas adsorption and diffusion under low-temperature conditions, and studying the characteristics of gas adsorption and diffusion under low-temperature conditions is crucial for the accurate determination of gas loss and coal seam gas content.

Based on this, this paper uses a high-low temperature intelligent constant temperature adsorption and desorption system to conduct experiments on coal adsorption of methane at different temperatures under different pressures. The characteristics of coal particle adsorption and desorption under a low-temperature atmosphere are analyzed, with the aim of providing a theoretical basis for the accurate calculation of gas content and loss.

2. Dynamic Adsorption Experiments and Adsorption Capacity Calculation of Low-Temperature Gas

COAL Sample Collection and Preparation

The coal samples required for the experiment were collected from the Guhanshan Coal Mine in Jiaozuo, Henan. Freshly exposed coal samples were collected and sealed in plastic bags, then sent to the laboratory. A portion of the coal samples was taken for adsorption constant and industrial analysis tests. Coal samples with a sieved particle size of 1-3 mm were used for the determination of pore characteristics by mercury intrusion porosimetry. Additionally, coal samples sieved to a particle size of 0.5~1.0 mm were used for dynamic adsorption experiments of low-temperature gas. The basic parameter measurement results of the coal samples are shown in Table 1.

Table 1: Measurement Results of Basic Parameters of Coal Samples

Adsorption Constants		M_{ad}/%	M_{ad}/%	V_{ad}/%	**TrueDensity /(g·cm^{-3})**	**Apparent Density /(g·cm^{-3})**
a/（m^3/m^3）	**b/（MPa^{-1}）**					
53.146	1.1	2.71	7.05	5.63	1.48	1.40

3. Low-Temperature Gas Dynamic Adsorption Experimental System

The low-temperature gas adsorption experimental system consists of a vacuum degassing system, an adsorption equilibrium system, a signal acquisition system, and a temperature control system. The vacuum degassing system is composed of a vacuum pump and related valves; the adsorption equilibrium system mainly includes a methane gas source, pressure sensors, a reference cylinder, a sample cylinder, valves, and the connecting pipelines; the temperature control system primarily consists of a high-low temperature alternating thermostat and related circuits; the signal acquisition system mainly includes pressure sensors, a computer, and related wiring. As shown in Figure 2-1. To reveal the dynamic characteristics of coal particle gas adsorption as the temperature decreases, the system was used to measure and calculate the dynamic change process of adsorption capacity over time under conditions where the temperature (30°C, -10°C, -20°C) was varied while maintaining the same adsorption equilibrium pressure.

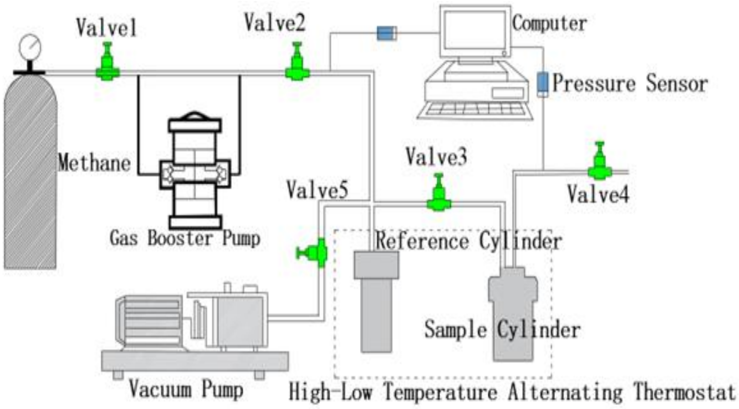

Figure 1: Schematic Diagram of the Experimental Setup

Experimental Procedure

1) Determination of the reference cylinder volume and the free volume of the coal sample tank: Calibrate the reference cylinder to calculate the volume of the reference chamber. Load the sieved coal samples into the sample cylinder, weigh the coal samples loaded into the sample cylinder, then connect the sample cylinder to the experimental system and calibrate the free volume of the sample cylinder. The free volume refers to

the sum of the pore-fracture volume of the coal body, the residual space of the sample cylinder, and the through-path volume in the sample cylinder, excluding the solid volume of the coal.

2) Vacuum degassing of coal samples: Start the vacuum pump and degas the coal samples under vacuum for 4 hours. Open the high-low temperature thermostat and adjust it to the temperature required for the experiment, then continue degassing for another 4 hours. Subsequently, turn off the vacuum pump and the valve between the reference cylinder and the sample cylinder to end the degassing procedure.
3) Methane filling and adsorption equilibrium: Turn on the computer signal acquisition device to monitor the filling pressure, the pressure in the reference cylinder and sample cylinder, and the temperature. Fill the reference cylinder with methane from the gas cylinder. When the pressure in the reference cylinder is about three times the set adsorption equilibrium pressure, close the high-pressure methane valve. After the pressure in the reference cylinder stabilizes, open the connecting valve between the reference cylinder and the sample cylinder to fill the sample cylinder with gas from the reference cylinder, initiating gas adsorption. The experimental data is automatically collected by the acquisition system and the computer.

Adsorption Capacity Calculation Method

The information acquisition system records the gas pressure data inside the sample tank at each moment. Based on the pressure difference between two consecutive time points inside the sample tank, the reduction in gas within the free space of the sample tank is calculated. This reduction in gas represents the amount of gas adsorbed during that time period. By summing up the adsorption amounts from each time period, the cumulative gas adsorption capacity can be obtained as follows:

$$Q_t = \sum_{\mathrm{i}=1}^{\mathrm{t}} \frac{\left(P_{\mathrm{i}} - P_{\mathrm{i-1}}\right)\left(V_1 + V_2\right)V_{\mathrm{m}}}{GZRT} \tag{1}$$

In the formula:

Q_t——Cumulative gas adsorption capacity of the coal sample at time t, (mL/g);
P_i——Gas pressure in the sample tank at time j, (MPa);
V_1——Volume of the reference cylinder, (mL);
V_2——Free volume of the sample cylinder, (mL);
V_m——Molar volume of the gas, (mL/mol);
Z——Compression factor of the gas under the pressure Pi, dimensionless;
R——Molar gas constant, (J·mol-1·K-1);
T——Experimental temperature, (K);
G——Weight of the coal sample, (g).

Dynamic Adsorption Capacity

Adsorption experiments on granular coal were conducted under an initial pressure of 1.1 MPa and varying temperature conditions (30°C, -10°C, -20°C), resulting in the pressure change curves shown in Figure 2. The adsorption capacity was calculated according to Equation (1), as illustrated in Figure 3.

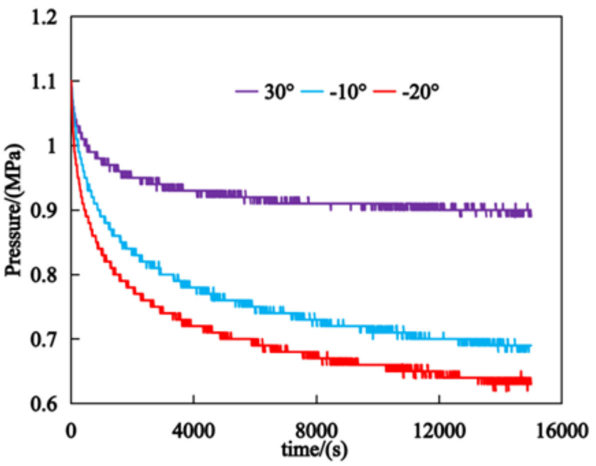

Figure 2: Pressure Change Diagram at Different Temperatures with an Initial Pressure of 1.1 MPa

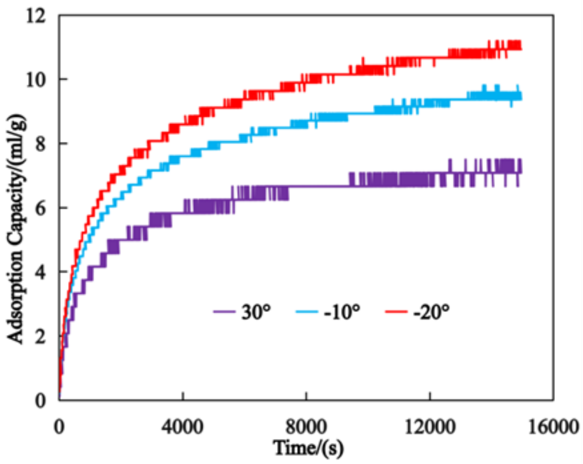

Figure 3: Gas Adsorption Capacity at Different Temperatures with an Initial Pressure of 1.1 MPa

Analysis of Figure 2 reveals that in the initial stage of adsorption, the pressure decreases rapidly, and as time progresses, the pressure tends to stabilize. At a constant initial pressure, the lower the temperature, the lower the equilibrium pressure, demonstrating that low temperatures can promote gas adsorption.

Analysis of Figure 3 shows that during the adsorption process of the coal samples, the adsorption capacity exhibits an increasing trend as time progresses. Under the same pressure conditions, the adsorption capacity increases as the temperature decreases over the same adsorption time, and the adsorption rate also accelerates accordingly. The trend can be divided into three stages: the initial adsorption stage, approximately within 0~2000s, where the steepness of the curve indicates a rapid increase in the gas adsorption rate; the intermediate adsorption stage, approximately within 2000~5000s, where the curve gradually flattens, indicating a slowing down of the gas adsorption rate; and the later adsorption stage, after approximately 5000s, where the curve gradually levels off, indicating that the gas adsorption rate proceeds slowly and the adsorption capacity gradually reaches saturation over time.

4. Conclusion

(1) The greater the initial pressure, the larger the amount of methane adsorbed by the coal, indicating that increasing pressure can promote gas adsorption.

(2) Under the same pressure conditions, the lower the temperature, the higher the gas adsorption capacity. This shows that low temperatures can promote gas adsorption.

(3) During the adsorption process of coal samples, the trend of adsorption rate changes can be divided into three stages: the initial rapid adsorption stage, the intermediate slow adsorption stage, and the later adsorption equilibrium stage.

References

[1]. Li Xijian, Lin Baiquan. Current Status and Analysis of Research on the Mechanism of Coal and Gas Outbursts[J]. Coal Geology & Exploration, 2010, 38(01): 7-13.

[2]. Wang Qiao, Wang Zhaofeng, Ma Shujun, et al. Study on Temperature Variation Characteristics of Coal Samples During Frozen Coring Process[J]. China Safety Science Journal, 2021, 31(02): 76-81.

[3]. WANG Zhaofeng, TANG Xu, YUE Gaowei, et al. Physical simulation of temperature infuence on methane sorption and kinetics in coal:Benefits of temperature under 273.15 KJ1. Fuel. 2015. 158.207-216.

[4]. WANG LOng, WANG Zhaofeng, Ql Chenjun, et al. Physical Simulation of Temperature and PressureEvolvement in Coal by Different Refri geration Modes for Freezing CoringJ,. AcS Omega, 2019, 4(23):20 178-20 187.

[5]. Wang Zhaofeng, Yue Gaowei, Kang Bo, et al. Experimental Study on the Inhibitory Effect of Low-Temperature Environment on Gas Desorption from Coal[J]. Journal of Chongqing University, 2014, 37(09): 106-112+143.

[6]. Yue Gaowei, Wang Zhaofeng, Kang Bo. Time-Varying Characteristics of Gas Diffusion Coefficient in Coal under Low-Temperature Environment[J]. China Safety Science Journal, 2014, 24(02): 107-112.

[7]. Qin Lei, Lin Haifei, Lan Shirui, et al. Experimental Study on Gas Adsorption Characteristics of Coal under the Action of Low-Temperature Liquid Nitrogen[J]. Coal Science and Technology, 2020, 48(10): 105-112.

[8]. Xu Wenjie, Yao Yanjun, Wang Yi, Wang Kai. Study on the Energy Change Law of Gas-Containing Coal during Low-Temperature Adsorption Process[J]. Safety in Coal Mines, 2023, 54(02): 40-45.

[9]. Ma Xingying, Wang Zhaofeng, Wei Rui, et al. Gas Diffusion Experiment in Low-Temperature Environment and Analysis of Different Model Fitting Degrees[J]. China Safety Science Journal, 2022, 32(03): 123-130.

[10]. Wei Le. The Kinetic Mechanism of Gas Adsorption in Coal and the Temperature Effect[J]. Safety in Coal Mines, 2020, 51(08): 7-11+16.

[11]. Ma Shujun, Wang Zhaofeng, et al. Study on the Process of Coal Adsorbing Gas under Low-Temperature Variable Conditions[J]. China Safety Science Journal, 2019, 29(10): 124-129.