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Effect of an electrostatic field on gas adsorption and diffusion in tectonic coal

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ABSTRACT

The characteristics of adsorption, desorption, and diffusion of gas in tectonic coal are important for the prediction of coal and gas outbursts. Three types of coal samples, of which both metamorphic grade and degree of damage is different, were selected from Tongchun, Qilin, and Pingdingshan mines. Using a series of experiments in an electrostatic field, we analyzed the characteristics of gas adsorption and diffusion in tectonic coal. We found that gas adsorption in coal conforms to the Langmuir equation in an electrostatic field. Both the depth of the adsorption potential well and the coal molecular electronegativity increases under the action of an electrostatic field. A Joule heating effect was caused by changing the coal–gas system conductivity in an electrostatic field. The quantity of gas adsorbed and ΔP result from competition between the depth of the adsorption potential well, the coal molecular electronegativity, and the Joule heating effect. ΔP peaks when the three factors control behavior equally. Compared with anthracite, the impact of the electrostatic field on the gas diffusion capacity of middle and high rank coals is greater. Compared with the original coal, the gas adsorption quantity, ΔP, and the gas diffusion capacity of tectonic coal are greater in an electrostatic field. In addition, the smaller the particle size of tectonic coal, the larger the ΔP.

1. Introduction

Tectonic stress causes tectonic coal, which is a product of strong ductile and rheological deformation, to be squeezed, sheared, and damaged in a coalbed [1,2], and results in a record of the ground stress field. Coal and gas outburst is a process in which high energy gas is released abruptly and desorbed [3,4]. Tectonic coal, which contains high energy gas, is a predictor for coal and gas outburst. The fundamental causes of coal and gas outburst are features relevant to tectonic coal, and include high adsorbability, fast diffusion, low strength, and low permeability. Electromagnetic fields affect gas adsorption and desorption, and play an important role in the correct understanding of coal and gas outburst. Numerous investigations have been conducted on this topic. Research on gas preserved in tectonic coal has seldom covered the complete process of gas adsorption, desorption, and diffusion by the action of an electrostatic field. Furthermore, research results differ. Du has shown that an electrostatic field has little effect on the adsorption constant *a*, while *b* increases with an increase in electric field strength, where *a* and *b* are from the Langmuir equation [5]. Xu has shown that *b* decreases regardless of whether a coal outburst occurs or not [6]. Li believes that the initial gas diffusion velocity depends on competition between the depth of the adsorption potential well and coal molecular electronegativity [7]. Liu has shown that the impact of Joule heating on gas adsorption and desorption from the coal surface in an electrostatic field cannot be disregarded [8]. In this paper, we study the constants *a* and *b* in the adsorption isotherm of tectonic coal, and the characteristics of gas adsorption, desorption, and diffusion. Results from these studies should help explain or predict coal and gas outburst.

2. Experimental

2.1. System

The apparatus used to assess the effect of an external electrostatic field on gas adsorption and diffusion consists of three parts, the EST-802 ESD generator, the WY-98b gas adsorption constants analyzer, and the WT-1 initial gas diffusion velocity analyzer (see Figs. 1 and 2).

The EST-802 ESD generator has a contact and air discharge mode. The constant voltage output is adjustable between 0 ± 20 kV. In this paper, we adopt the contact discharge mode

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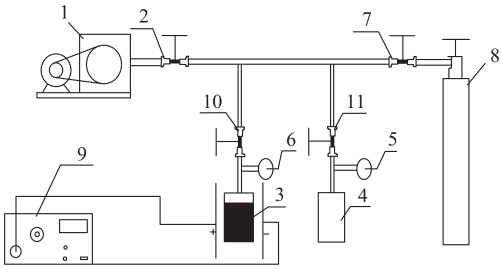

Fig. 1. Device for evaluating effect of electrostatic field on gas adsorption (1-vacuum pump; 2,7,10,11-electromagnetic valves; 3-coal sample canisters; 4-inflatable canisters; 5,6-pressure sensors; 8-methane; 9-EST-802 ESD generator).

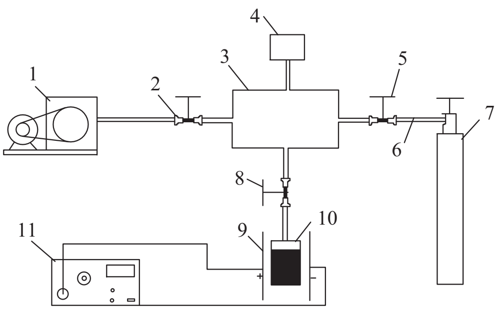

Fig. 2. Device for evaluating effect of electrostatic field on gas desorption (1-vacuum pump; 2,5,8-electromagnetic valves; 3-diffusion space; 4-pressure sensors; 6-pipeline; 7-methane; 9-electrode plate; 10-coal sample canisters; 11-EST-802 ESD generator).

because the discharge energy loss is small, the discharge path is certain, and the measured results are more accurate than for air discharge. The WY-98b gas adsorption constant analyzer tests the quantity of gas adsorbed by a coal sample at different pressures by thermostatic adsorption and then produces an adsorption isotherm. The least squares method can be used to calculate the maximum amount of adsorption (the *a*-value) and the initial slope of the isotherm (the *b*-value). The WT-1 initial gas diffusion velocity analyzer is an isometric pressure-swing analyzer. It monitors degassing, adsorption, and diffusion progress at a constant temperature and then tests for changes in diffusion capability between the additive and subtractive voltages.

The electrostatic field generated by an electrostatic generator and that in a coal mine are essentially the identical. The electrostatic field in a coal mine is an external field that cannot represent the electromagnetic field intensity of coal. Coal is a typical dielectric and exhibits dielectric polarization and a dielectric heating effect under an external electric field. From this information, it can be stated that the experimental system used is scientific.

2.2. Samples and methods

According to the experimental requirements, we collected three groups of coal samples with different metamorphic grade and different degrees of damage, including Pingdingshan fat coal, Qilin meager coal, and Tongchun anthracite. Basic information on the coal samples is provided in Table 1.

Table 2
Basic characteristics of coal samples.

Number	Industry analysis			Fixed carbon (%)	True density (g/cm^3)	Apparent density (g/cm^3)
	M_{ad} (%)	A_{ad} (%)	V_{ad} (%)			
tN	0.94	17.31	9.59	71.26	1.47	1.28
tD	1.01	16.32	9.08	72.59	1.45	1.22
qN	0.95	16.27	15.11	67.67	1.39	1.34
qD	1.02	16.38	14.96	67.79	1.38	1.33
pN	1.07	6.60	20.77	71.56	1.35	1.21
pD	0.82	8.91	20.08	70.19	1.36	1.17

Coal sample preparation may differ according to the experimental purpose for which the sample is required, and should be conducted meticulously to minimize errors. We measured the sample volatility, moisture content, ash content, true density, and apparent density using the national industrial analysis (GB/T212-2001) and density (GB/T217-1996) standards (Table 2).

Coal samples of particle size 0.20–0.25 mm were selected for the isothermal gas adsorption experiments. The samples (30 g) were kept for 2 h at 0, 4, 8, 12, and 16 kV before being placed into canisters and sealed. The coal samples were degassed when the vacuum pump was started and the electromagnetic valve opened. When the vacuum gauge pressure was 4 Pa, the electromagnetic valve was closed and the air tightness checked. Adsorption experiments were carried out as soon as air tightness was achieved. The bath temperature was set to 30 ± 1 °C, and methane (purity 99.99%) was pumped into the coal sample canisters. The valve was shut off immediately once the coal sample canister pressure reached a set value. The data were recorded when adsorption equilibrium was achieved (when the change on the pressure gauge was less than 0.05 MPa over 4 h). The above steps were repeated, and the change in gas adsorption quantity was compared for different voltages.

Coal samples (3.5 g) of particle size 0.25–0.5 mm were selected from the Tongchun, Qilin, and Pingdingshan mines for the initial gas diffusion velocity experiments. To compare the gas diffusion characteristics of coal samples of different particle size, other coal samples (3.5 g) with particle sizes of 0.1–0.25 mm, 0.5–1 mm, and 1–1.5 mm were used. These coal samples were kept for 2 h at 0, 4, 8, 12, and 16 kV before being placed in coal sample canisters. The vacuum pump was started, the electromagnetic valve was opened to degas the coal samples, and the electromagnetic valve closed and then checked for air tightness. High purity methane was pumped into the sample at 0.1 MPa once air tightness had been achieved and coal sample adsorption proceeded for 90 min. By opening the electromagnetic valves in turn, gas then diffused freely into the vacuum. The pressure from the transformation of adsorbed gas into free gas was termed p_1 at 10 s and p_2 at 60 s. The ΔP of all coal samples was determined from p_2 minus p_1 ($\Delta P = p_2 - p_1$).

Table 1
Summary of experimental coal samples used.

Coal type	Number	Coalbed	Metamorphic grade	Damage type	Firmness coefficient
Original coal from Tongchun mine	tN	B_4#	Anthracite	I–II	0.85
Tectonic coal from Tongchun mine	tD	B_4#	Anthracite	IV–V	0.53
Original coal from Qilin mine	qN	17#	Meager coal	II	0.62
Tectonic coal from Qilin mine	qD	17#	Meager coal	IV–V	0.48
Original coal from Pingdingshan 10 mine	pN	$Amyl_{9-10}$	Fat coal	I–II	1.02
Tectonic coal from Pingdingshan 10 mine	pD	$Amyl_{9-10}$	Fat coal	IV–V	0.45