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Gas Adsorption-Desorption and Emission Law of Tectonic Coal under Different Degrees of Damage

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The purpose of this paper is to study the difference of tectonic coal with different degrees of damage (DoD) in terms of gas adsorption, desorption and emission. To this end, by taking the 3# coal seam coal sample in Gaohe Coalfield as an example, the isothermal adsorption-desorption test was carried out in this paper to study the gas adsorption-desorption and emission law of tectonic coal with different DoD. The results show that with the DoD deepening of tectonic coal, the adsorption capacity of coal seam gas (CSG) in the geological structure area is better, and the CSG adsorption limit (adsorption constant a) increases; the coal seam gas desorption capacity is also better in the geological structure area, and the gas adsorption constant b decreases. Besides, the gas emission curve of fitting results indicate that Sun Chongxu Formula can accurately describe the gas emission process of tectonic coal. By comparing the numerical analysis results with the experimental results, it is found that the variation trend of the two is in good agreement.

1. Introduction

Whether it is to take coal seam gas (CSG) as a resource for comprehensive mining, or as a disaster factor for control (Wang and Cheng, 2013), it is necessary to thoroughly study the process of coal gas adsorption and desorption and its emission law. Many studies at home and abroad have shown that at most of the outburst locations and outburst coal seams generally is there tectonic coal with certain thickness formed by tectonic action. Coal and gas outburst mainly occur in the development area of tectonic coal (Qiang et al., 2010; Han et al., 2007). High-energy gas and low-strength coal are the root causes for coal and gas outburst (Gang et al., 2010), so the characteristics of the tectonic coal such as low coal strength, high gas adsorption and rapid desorption and release make it necessary condition for coal and gas outburst. Gas exists in the coal seam mainly in the adsorption state. The adsorption characteristics of the tectonic coal affect its ability to store gas, and the desorption-emission characteristics reflect the gas migration capacity in the coal seam, which is an important basis for CSG drainage. The characteristics of gas adsorption, desorption and emission for tectonic coal are not only important contents of coal and gas outburst prevention research, but also of great significance for improving CSG drainage efficiency. Regarding the gas adsorption-desorption law, experts and scholars at home and abroad have proposed various empirical formulas for gas desorption of Winter J.H., Some researcher present some models to describe the desorption law (Li et al., 2013), but due to the different coal structure, the desorption rules often vary. Previous studies have focused on the relationship between coal adsorption, desorption, emission characteristics and the factors such as degree of metamorphism, moisture content (Nie et al., 2015), and pressure (Du et al., 2018), with special structure (Chen et al., 2018), coal particle size (Cheng et al., 2014) etc., but few research or reports about the relationship between the tectonic coal with different DoD and coal characteristics above. Therefore, in this paper, the tectonic coal samples (mylonitic coal, granulated coal, and cataclastic coal) at different distances from the fault were collected. Then, the experiments were conducted for the gas adsorption-desorption and emission law under different adsorption equilibrium pressures of different DoD tectonic coals at constant temperature, so as to deeply discuss the effect of tectonic coal at different DoD on gas adsorption-desorption and emission characteristics.

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Finally, the gas-emission characteristic function of tectonic coal with different DoD of No.3 coal seam in Gaohe Mine Field was fitted. The research results are of great significance for guiding coal and gas outburst disaster prevention and the development and utilization of CSG resources.

2. Coal sample collection

In this experiment, 3 groups of coal samples of 3# coal seam in Gaohe Coalfield were selected. Table 1 lists the sample details.

Table 1: Isothermal adsorption-desorption test and gas test coal sample information

No.	Coal seam	Sampling area	Damage type	a	b
G1	3#	Tectonic area	V (mylonitic coal)	26.175	0.7184
G2	3#	Tectonic area	IV (granulated coal)	23.388	0.7996
G3	3#	Non- tectonic area	III (cataclastic coal)	20.815	0.6031

3. Gas adsorption-desorption law

3.1 Experimental system

One set of experimental devices with gas adsorption and desorption law of gas coal was designed and processed. The whole experimental system consists of vacuum degassing unit, self-made gas adsorption-desorption unit, adsorber, desorber and high-pressure methane gas cylinder. Figure 1 shows its schematic diagram.

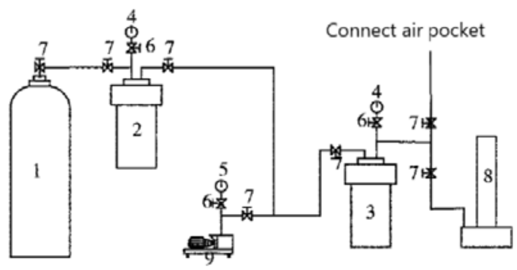


Figure 1: Schematic diagram of experimental system

1-high pressure methane gas cylinder; 2-gasing tank; 3- coal sample tank; 4-precision pressure gauge; 5-vacuum gauge; 6-pressure gauge switch; 7-high pressure shut-off valve; 8-adsorber (desorber); 9-vacuum pump

3.2 Analysis of experimental data

In this high-pressure adsorption-desorption experiment, G1, G2 and G3 coal samples were selected for analysis. These coal samples represent the V, IV and III damage types of tectonic coal, respectively. The adsorber and desorber at constant pressure loading and unloading (10 kPa/min) were used to conduct the adsorption-desorption experiment using the samples above (0.20-0.25 mm). The results are shown in Figure 2, in which the black curve is the adsorption curve and the red curve is the desorption curve.

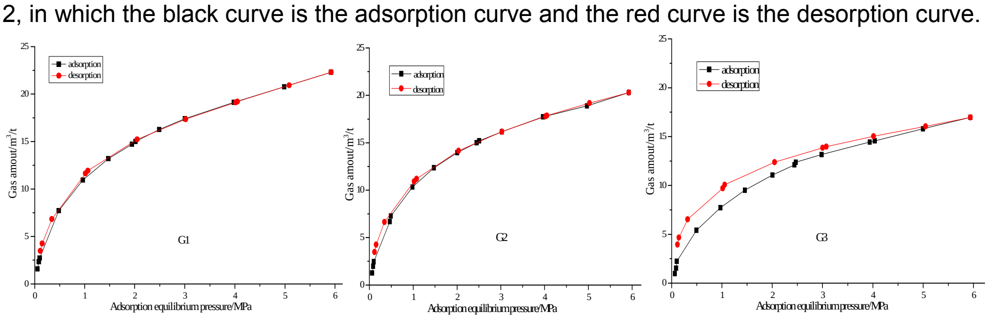


Figure 2: Isothermal adsorption desorption curve

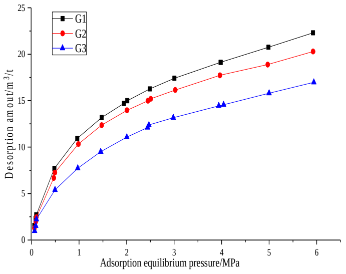


Figure 3: Isothermal adsorption curves of different coal samples

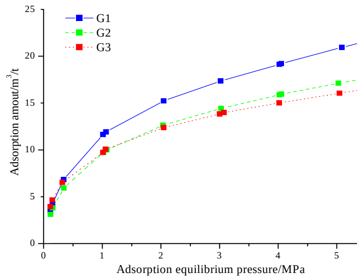


Figure 4: Isothermal desorption curves of different coal samples

Some scholars in China have shown in their studies that the isothermal adsorption-desorption processes of coal seam gas (Chen et al., 2018) in coal are not completely reversible processes as generally considered, and there exists certain difference between the isothermal adsorption curve and the isothermal desorption curve in the experiment, that is, the adsorption-desorption hysteresis [12]. According to the adsorption-desorption curve in Figure 2, with the loading-unloading of pressure, the adsorption-desorption curves of three coal samples such as G1, G2 and G3 showed some differences (but not obvious), i.e., adsorption-desorption hysteresis occurs. Among them, the isothermal adsorption curves and isothermal desorption curves of G1 and G2 coal samples are basically coincident, and only when the adsorption equilibrium pressure is below 1.5MPa, there is certain difference. But the difference of adsorption and desorption is small, and the hysteresis is not obvious. Whereas, for G3 coal sample, the difference between the isothermal adsorption curve and the isothermal desorption curve is very obvious; under the adsorption equilibrium pressure of 5 MPa, there is obvious difference between the two curves, and at the same adsorption equilibrium pressure, the desorption amount is obviously higher than the adsorption.

Figure 3 shows that there are some differences in the adsorption curves of three coal samples: G1, G2 and G3. Under the same adsorption equilibrium pressure conditions, the adsorption amount of G1 coal sample is larger than the other two coal samples, and the adsorption amount of G2 coal sample is slightly larger than that of G3 coal sample (the two are closer).

According to Figure 4, it can be seen that the isothermal desorption curve of the G1 coal sample is significantly higher than that of the G2 and G3, and the isothermal desorption curve of the G2 coal sample is slightly higher than that of G3 coal sample. Besides, under the same adsorption equilibrium pressure conditions, the gas desorption of G1 coal samples is generally larger than that of G2 and G3, and the isothermal desorption of G2 coal samples is generally larger than that of G3.

According to the isothermal adsorption experimental data, taking the adsorption equilibrium pressure as the X-axis and the adsorption gas as Y-axis, the scatter plot of isothermal adsorption data was drawn (Figure 5), and the data was also fitted by the Langmuir formula, in order to further analyse the adsorption characteristics of coal samples. The relationship between the amount of CSG gas adsorbed and pressure can be expressed by the isotherm adsorption equation proposed by Langmuir in 1918:

$$V_p = \frac{V_L P}{P_L + P} \tag{1}$$

where:

Vp-the amount of adsorbed gas under P pressure, m^3/t;

V_L-the Langmuir volume, m^3/t;

P-the adsorption equilibrium pressure, MPa;

P_L-the Langmuir pressure, MPa.

In the domestic gas field, when calculating the limit adsorption gas quantity of coal, the Langmuir equation is often changed as:

$$Q = \frac{abP}{1+bP} \tag{2}$$

where:

Q- Q=Vp, the amount of adsorbed gas under P pressure, m^3/t;

a- the limit gas adsorption amount, m^3/t;

b - the reciprocal of the adsorption equilibrium pressure corresponding to one-half of the limit gas adsorption amount;

The data points in Figure 5 were fitted using formula 2 to obtain adsorption constants. The limit gas adsorption capacity of different coal samples was calculated.

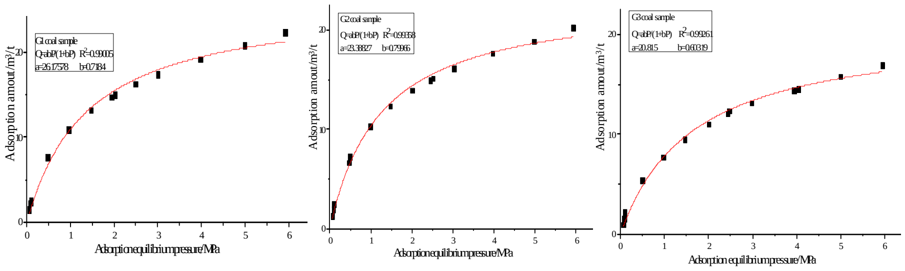


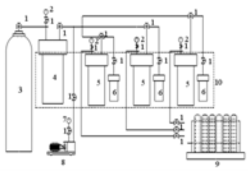
Figure 5: Calculation for limit gas adsorption capacity of different coal samples

The adsorption constant is an important characterization parameter for the adsorption desorption capacity. The adsorption constant a is the saturated adsorption amount when the pressure tends to the limit, and the b value is the rate at which the adsorption amount changes with the pressure. Based on the above analysis, it can be seen that the adsorption capacity of No. 3 coal seam in Gaohe Minefield has a tendency of G1>G2>G3, that is, as the degree of coal damage increases, the adsorption capacity also increases accordingly. Thus, the coal seam adsorption capacity in the geological structure area is stronger, and the CSG adsorption limit (adsorption constant a) increases with the DoD deepening; the CSG desorption capacity is stronger in the geological structure area, and the gas adsorption constant b decreases with the DoD deepened, making it easier to desorb a lot of gas under the same conditions. Based on the above analysis, it can be seen that the desorption capacity of No. 3 coal seam in Gaohe Coalfield has a tendency of G1>G2>G3, that is, as the DoD of coal increases, the desorption capacity increases accordingly, and more gas can be desorbed under the same adsorption equilibrium pressure.

4. Study on the law of gas emission

4.1 Experimental methods

The self-made experimental equipment of gas desorption and emission (Figure 6) was used to test the gas emission amount of the coal samples in 3# coal seam coal within 120 min under different adsorption equilibrium pressure conditions.



1-valve, 2-precision pressure gauge, 3-high pressure methane bottle, 4-gas tank, 5-large coal sample tank, 6-small coal sample tank, 7-vacuum gauge, 8-vacuum pump, 9-desorption cylinder, 10 - constant temperature water tank

Figure 6: Schematic diagram of the gas emission test equipment Analysis of experimental results

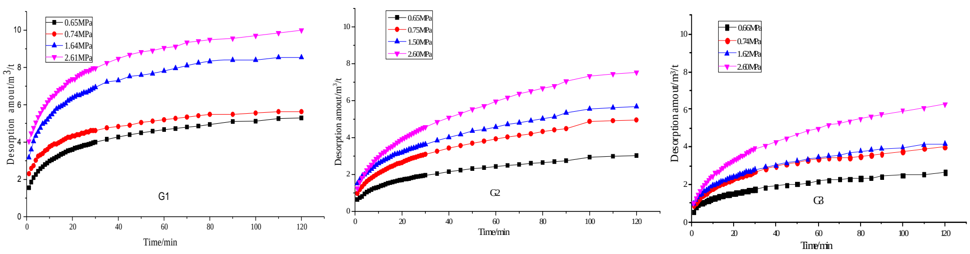


Figure 7: Gas emission curve under different adsorption equilibrium pressures

The typical coal samples G1, G2 and G3 from the No. 3 coal seam of Gaohe Coalfield were selected for the constant temperature gas emission test under different equilibrium pressures. Figure 7 shows the test results of gas desorption amount and time.

The gas desorption process of different coal samples in No. 3 coal seam of Gaohe Coalfield under different adsorption equilibrium pressures shows that the cumulative desorption of gas is positively correlated with the equilibrium gas pressure over time; the slope of the initial desorption curve is the largest and decreases over time, which size depends on the adsorption constant. This phenomenon indicates that the adsorption of coal on gas increases with the increase of pressure; the desorption rate and desorption rate of gas are proportional to the adsorption pressure; the desorption rate of gas decreases with time; there is a big difference in the emission curve of the coal gas among different DoD tectonic coals, and especially in the early stage of gas emission, the coal sample with larger DoD has a higher gas emission rate; for the time required to reach the ultimate desorption, the tectonic coal takes less time.

2) Study on the fitting formula of gas emission

In this study, in order to obtain a fitting formula suitable for the gas emission law of No.3 coal seam in Gaohe Coalfield, the commonly used formulas such as Barrer R.M, Sun Chongxu, Logarithmic formula, Н.и.БСТИНОВ were selected to conduct fitting analysis for the gas emission data under different adsorption equilibrium pressures. The data of three coal samples were used for comparison test to compare the fitting effects of different formulas. Through the data processing, the relevant parameters obtained by fitting with different formulas are calculated (Table 3).

Table 3: Correlation index statistical table of emission curve fitting formula (0.74MPa)

Formula	Barrer R.M formula $Q_t = k\sqrt{t}$		Н.и.БСТИНОВ formula $Q_t = v_0[\frac{(1+t)^{1-n}-1}{1-n}]$			Sun Chongxu formula $Q_t = at^i$			Logarithmic formula $Q_t = Aln(t-B)$		
No.	k	R^2	v_0	n	R^2	a	i	R^2	A	B	R^2
G1	0.82	0.62	1.74	1.27	0.97	1.56	0.28	0.99	1.15	-3.11	0.97
G2	0.60	0.91	0.91	1.03	0.97	0.90	0.36	0.99	0.87	-1.71	0.97
G3	0.52	0.89	0.81	1.04	0.96	0.80	0.35	0.99	0.75	-1.86	0.97

In statistics, the correlation index R^2 is an indicator reflecting the degree of correlation between variables. The closer R^2 is to 1, the higher the fitting degree of the regression equation, or the higher the reliability for expressing the variable changes using the equation. It can be seen from Table 4-5 that when the above formula is used to fit the emission data, the correlation index obtained by Sun Chongxu is as high as 99%, most approaching 1, that is, Sun Chongxu formula has the best fitting effect on the emission curve, with the highest degree of fitting. Thus, the use of Sun Chongxu $Q_t=at^i$ can accurately and reliably describe the gas emission characteristics of the 3# coal seam in Gaohe, and this function formula can be used as the gas emission function of the 3# coal seam.

Through analysis for the coal samples according to Sun Chongxu's $Q_t=at^i$ fitting results (Table 3), it's found that the fitting formulas of G2 and G3 coal samples are relatively closer, wherein there is difference by 0.1 for the coefficient a and by 0.01 for the coefficient i between the two, which is basically the same, indicating the emission law of the two are relatively similar. But, for G1 coal sample, its fitting formula differs greatly from that of the other two coal sample above. Among them, the G1 coal sample was taken near the fault, and the G2 and G3 were from the far side of the fault and the undeveloped fault. Therefore, using the fitting results in Table 3, the gas emission law in the coal seams of the geological structure areas and the non-geological structure areas in the 3# coal seam can be expressed.

1) Gas emission law in the geological structure area

The data of G1 coal samples were fitted according to Sun Chongxu's formula, and the obtained fitting formula was used to describe the gas emission law of tectonic coal in the 3# coal seam of Gaohe coalfield:

$$Q_t=1.56t^{0.28} \tag{3}$$

where:

Qt-the amount of gas released during the exposure time t of the coal sample, m^3/t;

T-the coal sample exposure time, min;

2) Gas emission law in non-geological structure areas

The data of G2 and G3 coal samples were fitted according to Sun Chongxu's formula. After the coefficients in the different formulas were averaged, t the gas emission law of the original structural coal can be expressed as:

$$Q_t=0.85t^{0.355} \quad (4)$$

where:
Q_t -the amount of gas released during the exposure time t of the coal sample, m^3/t;
t-the exposure time of the coal sample, min;

5. Conclusions

As the degree of damage (DoD) for coal increases, the gas adsorption capacity of the tectonic coal increases accordingly, and more gas can be adsorbed under the same adsorption equilibrium pressure conditions; the coal seam adsorption capacity in the geological structure area is stronger; the coal seam gas adsorption limit (adsorption constant a) increases with the degree of damage, and it can adsorb and store more gas under the same conditions.

As the DoD of coal increases, the desorption capacity increases accordingly, and more gas can be desorbed under the same adsorption equilibrium pressure. The coal seam gas desorption capacity is stronger in the geological structure area; the gas adsorption constant b decreases with the DoD deepening, and under the same conditions, a large amount of gas is more easily desorbed.

The adsorption of coal on gas increases with the increase of pressure; the desorption rate and desorption rate of gas are proportional to the adsorption pressure; the desorption rate of gas gradually decreases with time; the coal sample with larger DoD has a higher gas emission rate; for the time required to reach the ultimate desorption, the tectonic coal takes less time.

Numerical analysis and fitting were made for the gas emission process of coal sample. By comparing the numerical analysis results with the experimental results, it’s found that Sun Chongxu formula has the best fitting effect on the gas emission curve of the coal, so it can be used as the gas emission characteristics function.

Acknowledgement

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