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Temperature Variation of Coal during the Gas Adsorption Process

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ABSTRACT
Using a self-made coal gas adsorption-desorption instrument, laboratory research on temperature variations of the adsorption process under different conditions was completed to study the adsorption law of coal gas and to reveal coal gas adsorption mechanisms. Under the same conditions, the order of unit mass of coal's gas adsorption and the temperature variation is: Zhenxing 2# Coal > Runhong 3# coal > Malan 8# coal. The results show that gas adsorption gets lower as the temperature increases. For the same coal sample under the same conditions, the smaller the particle size, the greater the pressure variations of the methane adsorption process and the larger the gas adsorption in the same period. The results of this paper reveal the mechanism of coal and gas outburst.
KEYWORDS: coal particles; gas adsorption; thermal effect; temperature variation; experimental study

1. INTRODUCTION

China is the largest coal producer in the world and it also has the most serious coal mine disasters. According to the statistics, there are nearly a thousand coal mines in China, including more than 110 key state-owned mines that at a risk for coal and gas outburst. Hundreds of coal and gas outburst events occur each year, often causing serious casualties and economic losses (State Administration of Work Safety, 2007). With the continuing exploitation of coal resources, the depth of Chinese coal mines increases about 100 meters every year, causing serious (Xie et al., 2006). Face coal temperature is closely related to ground stress, gas content, and coal's physical and mechanical properties. The three factors above are related to coal and gas outburst (Zhang, Z Z et al., 2010. Liu, Z et al., 2012. Chen, G et al., 2014). Gas in the coal body is mainly in the adsorption state hosted in coal matrix when undisturbed.

At present, the real mechanism of gas adsorption, desorption, and the diffusion process in coal and the influence factors are not clear. Because of the limits of current prediction methods and technological level, gas accident prevention theory and technology are not valid.

Energy conversion is associated with the process of gas adsorption and desorption (Nie et al., 2013a; Chaback et al., 1996; Nodzeński, 1998; An, ZX., 1983; Rike & Yuan, 1989; Zhao, 1994; Niu, GQ., 2003). Temperature variation exists along with the process of coal and gas outburst (Nie et al., 2013b; Guo et al., 2000a; Guo & Jiang, 2000; Zhang et al., 2011; Wang et al., 1999). Some scholars try to predict gas accidents according to temperature variation (Wang, 2001; Guo et al., 2000b; и.а.Renke & и.я.Lieming, 1985; Lun and Tang, 1992). The predictive indexes that have been developed are mainly empirical values. There is a gap between the practical application and theory, because there is currently no systematic study of temperature change in the process of gas desorption and diffusion, especially the relationship between the equilibrium pressure, adsorption volume, adsorption rate, and temperature variation.

This paper aims to systematically study the laws of temperature variation in the process of gas adsorption under laboratory conditions to reveal the energy conversion and transmission process.

2. TESTS OF THE BASIC PARAMETERS OF COAL BODY

2.1 Basic information of coal samples

Three kinds of coal samples were taken from high gas coal mines in different areas of China, including coal 8# from Malan coal mine, coal 2# from Zhenxing second coal mine, and coal 3# from Runhong coal mine. The industrial analysis and density test results of three kinds of coal samples are shown in Tables 1 and 2.

Table 1: True density and apparent density of coal.

Coal sample ID	Name of coal sample	True density, g/cm^3	Apparent density, g/cm^3
1	Malan coal 8#	1.28	1.12
2	Zhenxing coal 2#	1.42	1.24
3	Runhong coal 3#	1.303	1.18

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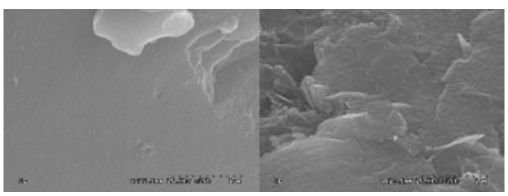
Table 2: Industry analysis of coal.

Coal sample ID	Name of coal sample	M_{ad} (%)	A_d (%)	V_{daf} (%)	F_c (%)
1	Malan coal 8#	0.44	2.66	51.18	45.72
2	Zhenxing coal 2#	2.22	11.96	9.45	76.37
3	Runhong coal 3#	2.02	16.05	12.25	69.68

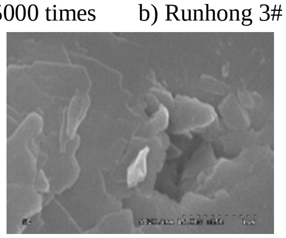
Among them, M_{ad} is the moisture content of coal, V_{daf} is the volatile content of coal, A_d is the ash content of coal, and F_c is the fixed carbon content of coal.

2.2 Test of pore structure in coal samples

After being collected and processed, coal samples were scanned with electron microscopy in different magnification. Scanning results reflect the coal samples' pore structure conditions. The micro-pore's development situation is one of the most important factors affecting the adsorption of methane. Using a Hitachi S-4800 scanning electron microscope, morphology of the coal samples was scanned. The scanning magnification was 35,000 times, as shown in Figure 1.



a) Malan 8#,35000 times   b) Runhong 3#，35000 times



c) Zhenxing 2#，35000 times

Figure 1: SEM images of Coal Samples.

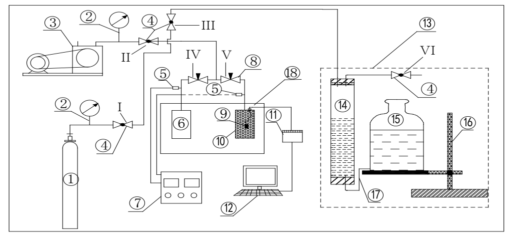
Experimental results showed the presence of a large fissure structure and an obvious loose layered structure in the coal sample from Zhenxing coal mine. Degree of pore developments were roughly: Malan 8 # coal < Runhong coal < Zhenxing second mine coal.

3. TEMPERATURE TEST DURING GAS ADSORPTION PROCESS

According to certain experimental standards, the coal samples were crushed and those particles measuring 60-80 mesh, namely between 0.178 mm-0.25 mm in diameter, were collected with a sorting sieve.

3.1Experimental system

To study the temperature response characteristics during gas adsorption process, temperature change tests were carried out. The structure diagram of the adsorption-desorption instrument is shown in Figure 2.



①high pressure gas cylinder ②pressure gauge ③vacuum pump ④ball valve ⑤pressure sensor ⑥reference tank ⑦industrial computer ⑧needle valve ⑨temperature sensor ⑩sample tank ⑪temperature signal acquisition card ⑫sample tank ⑬desorption test system ⑭measuring cylinder ⑮leading bottle ⑯lifting platform ⑰rubber hose

Figure 2: The system schematic diagram of gas adsorption and desorption experiment.

3.2Experimental procedure of adsorption process

The system should first be debugged. The main steps are as follows:

1) Connect the high-pressure gas tank to the experimental system.

2) Turn on the vacuum pump, open valves II, IV and V and make sure other valves stay closed. After vacating the sample tank for 4 hours, close valves II, IV and V.

3) Open the temperature acquisition system and pressure collection system. Adjust the high-pressure gas tank outlet valve to the desired pressure value. Open valve I and then slowly open valve IV until the reference tank pressure reaches the predetermined value. Close valve I, open valve V slowly, and continuously inflate for 12 hours. Record and save the temperature and pressure values.

4. TEMPERATURE VARIATION RESULTS OF THE COAL GAS ADSORPTION EXPERIMENTS

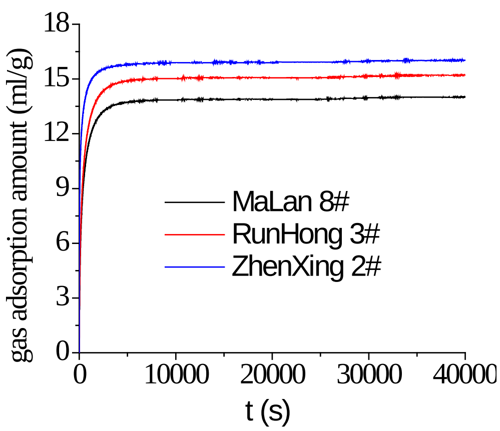
The three coal samples were sealed from different coal mines and were transported to the laboratory. They were processed into four different mesh sizes such as 10 to 20 meshes, 20 to 40 meshes, 40 to 60 meshes and 60 to 80 meshes. The information about coal samples are presented in Table 3.

Table 3: The parameters of coal sample in coal gas adsorption experiment.

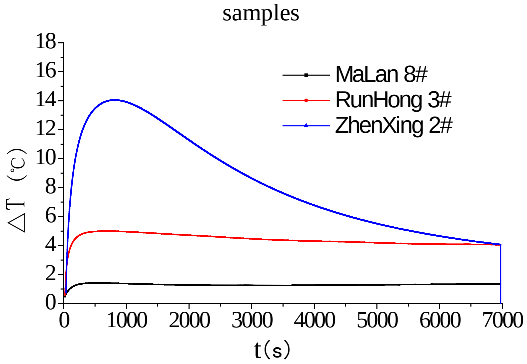
Coal sample name	Coal sample size	Free volume of sample canister	Coal sample quality
		ml	g
Zhenxing second mining	10-20 mesh	551.8266	769
	20-40 mesh	603.1798	701.4
	40-60 mesh	621.5689	657.6
	60-80 mesh	556.6884	695.82
Malan8#	10-20 mesh	489.9777	784.9
	20-40 mesh	541.13	600
	40-60 mesh	530.4417	618.3
	60-80 mesh	431.8605	467.4
Runhong	60-80 mesh	493.9033	562

4.1 Temperature variations during gas adsorption for different coal samples

Figure 3 shows the adsorption process results for the three coal samples in 60 to 80 meshes under a gas pressure of 3.1 MPa.



a) Relationship of adsorption volume and time of the 3 coal samples



b) Temperature variation of the 3 coal samples during the adsorption process

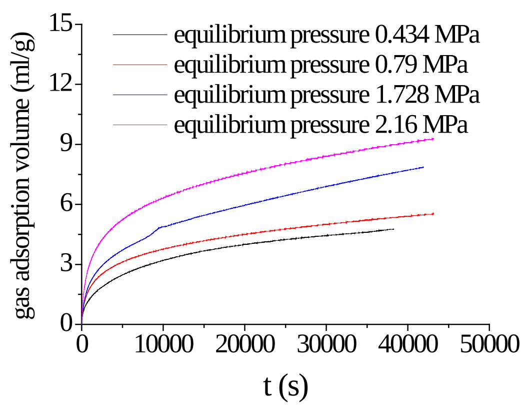
c) Temperature change rate of the 3 coal samples during the adsorption process

Figure 3: the adsorption experimental results of three coal samples in 60 to 80 meshes under gas pressure of 3.1 MPa.

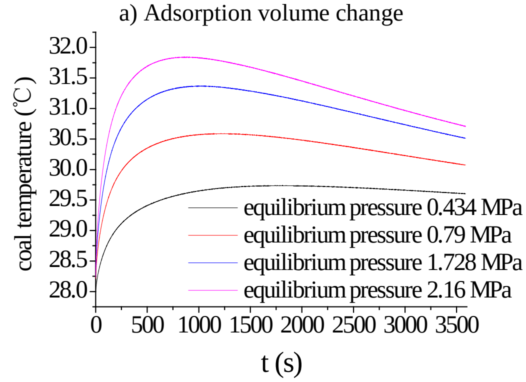
The results showed that under the same conditions, the order of gas adsorption reaching equilibrium was: Zhenxing second mining 2# coal > Runhong 3# coal > Malan 8# coal. Equilibrium adsorption capacity values were 15.06 ml/g, 15.2 ml/g and 16.1 ml/g, respectively. Similarly, temperature variations during the adsorption process were different, and the order of temperature variation for a unit mass of coal sample was: Zhenxing second mining 2# coal> Runhong 3# coal > Malan 8# coal. The variations were 14.056℃, 5.0℃ and 2.304℃, respectively. The methane adsorption was an exothermic physical process, where the higher the adsorption the more heat was released.

4.2 Temperature variations of gas adsorption under different adsorption equilibrium pressures

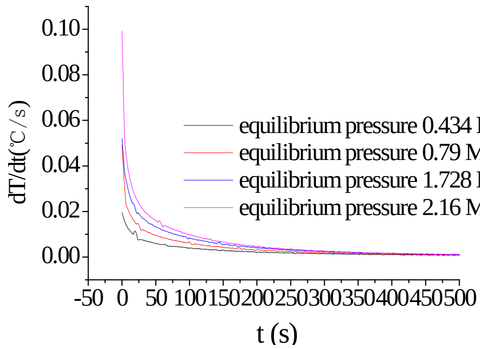
The current study examined the gas adsorption law of coal under different adsorption equilibrium pressures. The adsorption experiment results of 40 to 60 mesh coal samples from Malan 8# mine and Zhenxing 2# mine were analyzed. Figure 4 shows the adsorption experiment result for the Malan 8# coal sample while Figure 5 shows the adsorption experiment result for Zhenxing 2# coal sample.



a) Adsorption volume change



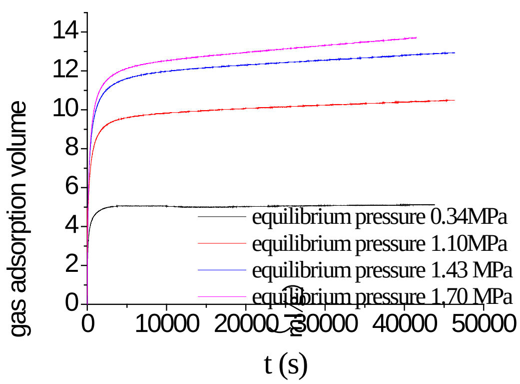
b) Temperature variation during adsorption process



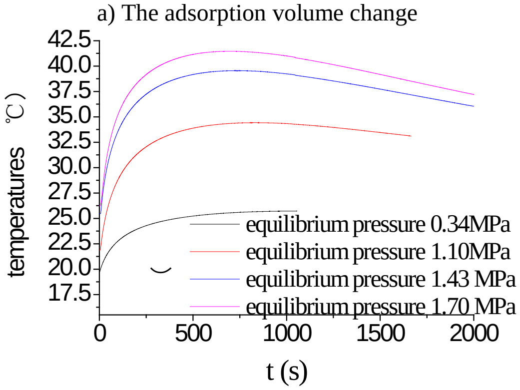
c) Temperature change rate during adsorption

Figure 4: adsorption experimental results of Manlan 8# coal sample(40-60 mesh) under different equilibrium pressure.

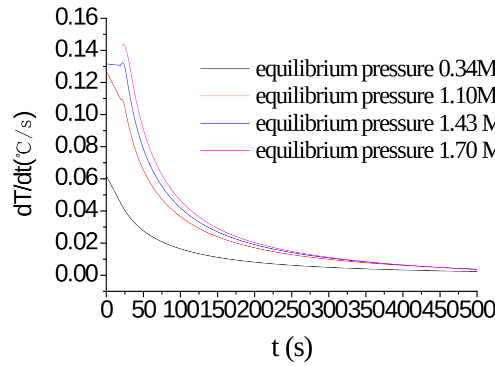
The initial aeration pressures were 1.0 MPa, 2.7 MPa, 3.4 MPa, and 4.1 MPa, respectively in the reference tank. After equilibrium, the pressures were 0.434 MPa, 0.79 MPa, 1.782 MPa, and 2.16 MPa, respectively. The pressure variations △P were 0.206 MPa, 0.24 MPa, 0.2712 MPa, and 0.411 MPa, respectively while the adsorptions were 4.756 ml/g, 5.536 ml/g, 6.345 ml/g, and 9.254 ml/g, respectively. The maximum amounts of temperature variations were 1.66 ℃, 1.856 ℃, 2.845 ℃, and 3.108 ℃ respectively.



a) The adsorption volume change



b) The temperature variation during adsorption



c) The change rate of adsorption temperature

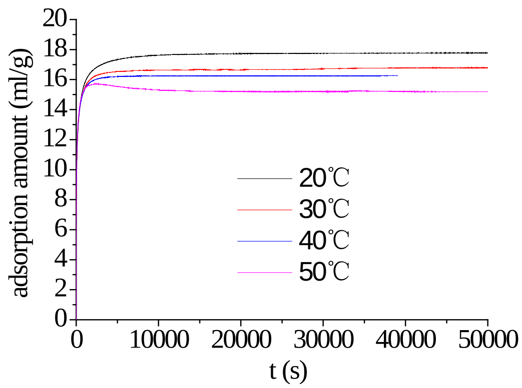
Figure 5: the adsorption experiment result of Zhenxing mine coal samples in 60 to 80 mesh.

As shown in Figure 5, the initial aeration pressures were 1.0 MPa, 2.7 MPa, 3.4 MPa, and 4.1 MPa, respectively in the reference tank when the sample can was filled with coal samples in 40 to 60 mesh. The coal sample was selected from Zhenxing coal mine. After equilibrium, the pressure values were 0.34 MPa, 1.1 MPa, 1.43 MPa, and 1.7 MPa, respectively. The pressure variations △P were 0.218 MPa, 0.44 MPa, 0.557 MPa, and 0.589 MPa, respectively. The adsorptions were 5.118 ml/g, 10.488 ml/g, 12.96 ml/g and 13.702 ml/g, respectively. The maximum amounts of temperature variations were 6.307℃, 11.81℃, 13.23℃, and 14.28℃, respectively.

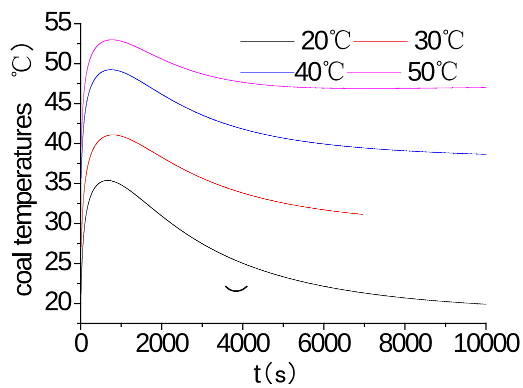
The experiment results showed that the coal's adsorption for gas increased with the rising of gas pressure for a specific temperature. In the initial adsorption stage, the smaller the particle size, the larger the gas adsorption volume and the greater the temperature rise gradient. Adsorption is an exothermic process. Theoretically, coal temperature will always rise. However, the experimental system is not an adiabatic system. There is heat exchange with the external environment in the adsorption process, thus the adsorption temperature will reach a maximum at about 700 s in the adsorption temperature change chart. After that, as the adsorption gets weaker, heat exchange will occur between the coal and the external environment because of the temperature gradient. Thereby, the coal temperature decreases until it reaches the same temperature as the external environment.

4.3 The temperature variation of gas adsorption at different temperatures

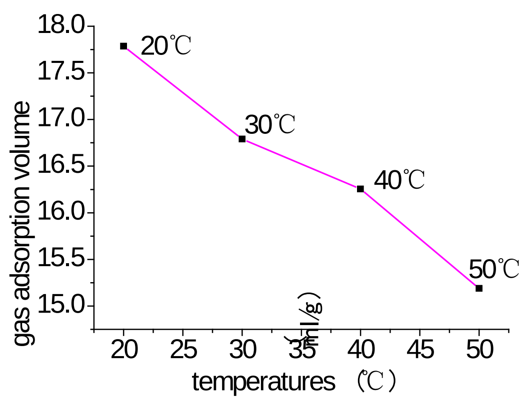
Figure 6 shows the results of the adsorption process for the Zhenxing 2# coal sample in 60 to 80 meshes at 20℃, 30℃, 40℃, and 50℃ when the charging pressures were all 3.1 MPa.



a) The adsorptions at different temperatures



b) The adsorption temperature



c) The equilibrium adsorption volume

Figure 6: The experiment results of adsorption processes of Zhenxing second mining coal samples in 60 to 80 mesh at different temperatures

The gas adsorption capacity for coal was easily influenced by the temperature change. For the coal samples in 60 to 80 meshes from Zhenxing coal mine, the final equilibrium pressure was very different under the same charging pressure. The coal sample's adsorption equilibrium pressures at 20℃, 30℃, 40℃, and 50℃ were 1.269 MPa, 1.2455 MPa, 1.303 MPa, and 1.33 MPa, respectively. The pressure drops were 0.214 MPa, 0.188 MPa, 0.1816 MPa, and 0.179 MPa, respectively. The unit mass coal's adsorptions were 17.787 ml/g, 16.79 ml/g, 16.255 ml/g, and 15.19 ml/g, respectively after equilibrium, which showed that the gas adsorption dropped as the temperature was getting higher.

The coal adsorption of methane was an exothermic physical process. The larger the adsorption, the more heat released. This law can also be reflected by the temperature variation in adsorption experiments. The △Tmax at 20℃, 30℃, 40℃, and 50℃ were 15.93℃, 14.06℃, 13.57℃, and 13.43℃, respectively. △Tmax represents the absolute difference between the initial temperature and the maximum temperature of the adsorption process. Because the adsorption-desorption experiment system was not an adiabatic system, with the decrease of the adsorption rate, the external environment had more and more impact on the temperature inside the sample tank. When temperature reached the peak, the environmental temperature played a dominant role. Therefore, the temperature variations from beginning to the temperature peak were studied in this experiment.

4.4 Temperature variations during gas adsorption in different particle size

Figure 7 shows the adsorption equilibrium curves of coal samples in 10 to 20 mesh, 20 to 40 mesh, and 40 to 60 mesh from Malan 8# coal mine when the charging pressure were 1 MPa, 2 MPa, 3 MPa, and 4MPa, respectively. Under the same charging pressure, the smaller particle size was, the larger gas adsorption was after adsorption equilibrium.

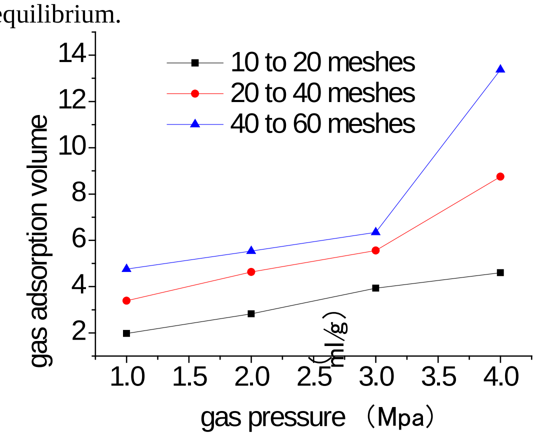


Figure 7: The Malan 8# coal samples adsorption in different particle sizes and pressures.

The charging pressure of the 10-20 mesh, 20-40 mesh, and 40-60 mesh coal samples tank were 1.06 MPa, 1.07 MPa, and 1.0 MPa, respectively. The initial pressures were 0.6835 MPa, 0.65875 MPa, and

0.643 MPa, respectively after opening the valve between the reference and sample tanks. The final equilibrium pressures were 0.60 MPa, 0.539 MPa, and 0.434MPa, respectively. The pressure variations △P were 0.0835 MPa, 0.145 MPa, and 0.206 MPa, respectively from the beginning of the adsorption to the end.

The adsorption of Malan 8# coal samples in 10-20 mesh, 20-40 mesh and 40-60 mesh after adsorption equilibrium were 1.971 ml/g, 3.388 ml/g, and 4.756 ml/g, respectively when the charging pressure of the reference tanks were 1 MPa.

The results showed that for the same coal sample under the same condition, the smaller particle size is, the greater the pressure variations for the methane adsorption process and the larger the gas adsorption volume. In addition, the influence of particle size on adsorption was also reflected on the temperature variations of the coal adsorption process. Namely, the smaller the particle size, the greater the temperature variation of the adsorption process was when other conditions remain unchanged. The reasons were that the smaller the coal particle size is, the greater the specific surface area. The greater the adsorbed area of methane molecules, the larger the methane adsorption volume under the same gas pressure and temperature conditions.

According to adsorption potential theory (Dubinin M M, 1960; Clarkson C R et al., 1997; Mosher K et al., 2013), methane molecule adsorption would release a part of the potential energy in an exothermic physical process. Thus, the higher the gas adsorption volume, the more heat was generated, and the greater the temperature variation.

5. CONCLUSIONS

Adsorption laws of coal gas were tested with different coal samples at different temperatures, in different sizes and under different adsorption equilibrium pressures. Specific conclusions are as follows:

(1) The difference of temperature variations in adsorption process was large. The order of unit mass of coal samples' temperature variation was: Zhenxing 2# coal > Runhong 3# coal > Malan 8# coal. Their variable quantities were 14.056℃, 5.0℃, and 2.304 ℃, respectively. The rate of temperature variations followed the same order: Zhenxing 2# coal > Runhong 3# coal > Malan 8# coal, indicating that Zhenxing 2# coal has a stronger adsorption capacity.

(2) At a specific temperature, with the increasing gas pressure, coal's gas adsorption capacity increased. At the initial adsorption stage, the smaller the particle size, the higher the gas adsorption volume, as well as the temperature rise gradient.

(3) For Zhenxing 2# coal samples in 60 to 80 mesh at 20℃, 30℃, 40℃, and 50℃, the adsorption and desorption process were studied when the charging pressure was 3.1 MPa. The results showed that gas adsorption decreased as the temperature increased.

(4) For the same coal sample under the same conditions, the smaller the particle size, the greater the pressure variations of the methane adsorption process and the larger the gas adsorption volume in the same period.

6. ACKNOWLEDGEMENT

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