Study on the Law of Gas Desorption of Lump Coal Samples under Uniaxial Compression

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Abstract: Taking the mining influence on the gas desorption characteristics of coal body into consider, a new gas adsorption and desorption system of coal sample under compression was manufactured. Using this test system, the gas desorption characters of coal samples were experimented under different gas pressure with some uniaxial compress pressure and different uniaxial compress pressure with constant gas pressure. The experimental results show that: 1) under the same uniaxial compress load, the greater the initial gas pressure is in coal samples, the greater the cumulative desorption capacity is; 2) under the same initial gas pressure, the cumulative desorption capacity of coal not only relates to the load, but also has to do with internal pore structure and other factors of coal body; 3) fitting the experimental data with different empirical formula, the mathematical model of gas desorption of coal samples under uniaxial compression with different gas pressure was obtained. The results of this paper can provide some guidance for gas drainage in gas coal mine and those can improve the further understanding of gas adsorption and desorption in coal body under mining influence.

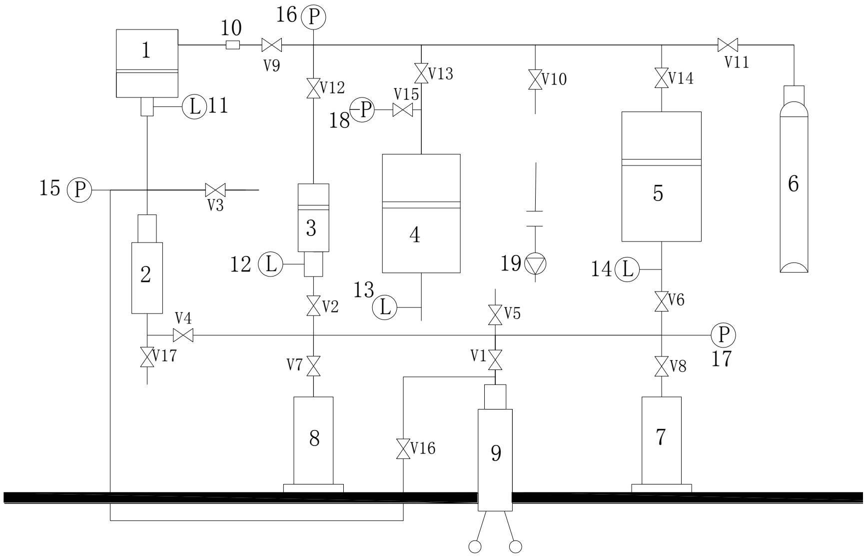
Introduction

Gas outburst and gas dynamic phenomena become more and more serious and frequent as the depth of coal mines in China are entering a relative deeper level than before mines[1]. Once the coal and gas outburst accidents happen, those often cause casualties and great economic losses. In addition, the gas emission from the working face or the coal and gas outburst are all accompanying with the gas desorption process, so studying the gas desorption laws has great significance for prevention of coal and gas outburst accidents and prediction of gas emission of coal body[2-4]. As to now, many scholars have carried out a lot of research on the laws of gas desorption of coal. R.M.Barrer[5] thought that the adsorption process and desorption process of gas were reversible and got the relational expression between the cumulative adsorption amount or the cumulative gas desorption quantity and time by studying the adsorption and desorption characteristics of gas in coal seam. Wang Youan[6] finally obtained the relationship of the cumulative gas desorption amount and time by means of experimental analysis of coal samples with different types of destruction. Qin Yueping[7-9] and his cooperators obtained that the reciprocal of cumulative gas desorption amount and the reciprocal of time square root had a good linear relation by combining experimental study and theoretical analysis. In addition, many scholars have studied the influence of gas pressure, temperature, water and grain size on the gas adsorption and desorption of coal. For example, Wang Cuixia, et al.[10] thought that for the same particle, the higher the initial pressure was, the more the maximum gas desorption was; the smaller the coal particle was, the more quickly the gas desorption rate was by gas adsorption and desorption experiment of coal particles with different particle sizes. Nie Baisheng, et al.[11] obtained that the capability of gas desorption in coal dramatically decreased, the limiting gas desorption amount, initial desorption rate decreased with the rise of moisture content by the desorption experiment of coal with different moisture content. However, these experiments are all taken the particle coal under mechanical disruption screening as the research object, so the results of these experiments have distinct difference with coal body in coal mine. Compared with real coal body, the primary porosity and fracture structure of particle coal is greatly damaged and its adsorption capacity and gas migration pathway which are important factors affecting the gas adsorption, desorption and migration of coal body are changed greatly, so the gas desorption laws between particle coal and coal body are different[12]. Moreover, previous studies have not considered the stress state of the coal sample and the mining influence. Thus, the results of the experiment are not consistent with the desorption law of coal under In-situ stress or mining influence. Therefore, in recent years, some scholars have improved the existing experimental devices, and began to study the characteristics of gas adsorption and desorption of coal samples under load. Tang Jupeng, et al.[13] got the relationship between desorption quantity or desorption time and gas pressure under the external load through applying different combination of axis pressure, gas pressure and confining pressure to coal samples. Wen Zhihui, et al.[14] studied the desorption laws of loaded gas-filled raw coal by using a self-made gas-filled coal heat - flow - solid - mechanical coupled adsorption - desorption experiment system under the combination of various confining pressure and pore pressure conditions. Zhang Peng[15] designed a new type of experiment system simulating gas migration law in three dimensional stope and researched the laws of gas adsorption and desorption of coal with large size under different water conditions. In summary, the studies on gas desorption laws of coal samples under load are still rare and the research work already done are focused in the gas desorption characteristics of coal in triaxial compression state. As a result, this paper design experiment to study desorption laws of coal sample under uniaxial compression, and under different gas pressure and uniaxial load.

Gas Desorption Experiment of Coal Samples under Uniaxial Compression

Experiment System

In order to study the gas adsorption and desorption characteristics of coal sample under complex physical and mechanical condition in coal seam, a new experimental system was designed and manufactured. With this experimental system, the gas adsorption and desorption experiments can carried out and the gas pressure and uniaxial load condition can changes as the operator want. The schematic and physical diagrams of this system are shown in Fig. 1 and Fig. 2, the experiment system mainly contains a sample tank, a pressure multiplier, desorption tanks, a gas tank with constant pressure, energy storage devices with constant load caused by gravity, a hand pump and a vacuum pump, high-pressure gas cylinders and so on, details are as follows:



1-sample tank; 2-pressure multiplier; 3-desorption tank under positive pressure; 4-desorption tank under negative pressure; 5-gas tank with constant pressure; 6-gas cylinder; 7,8-energy storage device with constant load caused by gravity; 9-hand pump; 10-filter; 11-14-displacement sensor; 15-17-pressure gauge; 18-vacuum meter; 19-vacuum pump; V1-V17-valve

Fig. 1 Schematic diagram of the experimental system of gas adsorption and desorption of coal (or rock) with compression load

(1)Sample tank: it is also called clamper and connected with pressure gauges. We can put the coal sample in a sample tank and set the axis pressure for coal sample by loading system. The displacement sensor located on the clamper can collect uniaxial displacement change of coal sample.

(2)Pressure multiplier: the section areas of piston ends located in the cylinder are different, pressure can be delivered from larger end of section area to the smaller one for achieving a greater load pressure.

(3)Desorption tank: it includes a tank under positive pressure and a negative one, which displacement sensors for calculating quantity of gas change locate on. Positive desorption achieves its function through energy storage devices caused by gravity while negative desorption realizes its function by adding small gravity block designed for balancing a part of the atmospheric pressure.

(4)Gas tank with constant pressure: it can store a large amount of high-pressure gas and can achieve constant pressure for the adsorption and desorption experiments. It is equipped with a displacement sensor to calculating gas change.

(5)Energy storage devices caused by gravity: they include two devices, which are equipped with gravity blocks with different weight and connected with other tanks to realize constant hydraulic pressure and constant gas pressure respectively.

(6)Hand pump: it contains emulsion mixed well and connects with Energy storage devices caused by gravity. We can hoist the Energy storage devices equipped with gravity blocks to achieve constant pressure through hand pump.

(7)Vacuum pump: the type of vacuum pump in this experiment is 2XZ type rotary vane, which is used for vacuum pumping for the experimental system.

(8)High-pressure cylinders: they include high-pressure methane cylinder and high-pressure helium cylinder (used to check air tightness of the system), the purity are all 99.99%.

Fig. 2 Physical diagram of the experimental system of gas adsorption and desorption of coal (or rock) with compression load

Coal Samples

Coal samples in this experiment come from some mining areas of the northeast and Xinjiang, in order to keeping the original state of the coal sample in the mining process as far as possible, the coal samples are exploited and sealed up in the sealing bag, brought them back to the laboratory and made into standard cylinder style with the diameter is 50mm and the height is 100mm according to experimental requirements, in which the smoothness of the upper and lower end surfaces should not be greater than 0.02% to ensure that the load is uniform. Coal samples made from different locations are labeled as 1#, 2# and 3# and are sealed and preserved. The experimental coal samples are shown in Fig. 3.

Fig. 3 Experimental coal samples

Experimental Procedures

The tests are done under room temperature. It takes axial pressure and gas pressure as variables to study the change trend of the cumulative amount of gas desorption over time under different axial pressure and different initial gas pressure. It designs the axial pressure of 0MPa and 2MPa and designs initial gas pressure of 0.5MPa, 1MPa, 2MPa and 4MPa for coal samples 1# and 2#. While it designs the axial pressure of 0MPa and 1.8MPa and designs initial gas pressure of 0.5MPa, 1MPa, 2MPa and 4MPa for coal samples 3#. The experimental steps of coal samples under different axial pressure and different gas pressure conditions are basically same, now taking the test under the axial pressure of 2MPa and the initial gas pressure of 0.5MPa as an example to describe operation steps. The steps are as follows:

1)Air tightness checking. Close valve 10 and valve 15, open the other valves of gas pipelines, and then import a certain pressure of helium to pipelines, in which the pressure of helium must exceed the maximum gas pressure required by the experiment. At last, close the inlet valve. After 24 hours, check whether the pressure value of the pressure gauge decrease or not. If obvious decline occurs, check the pipelines and all parts of the system until the pressure keeps constant, that is to say the system or pipelines can meet the experiment requirements.

2)Adsorption and desorption experiments of coal samples

① Dry the coal sample for 12 hours under constant temperature. After cooling, weigh it and place it in the sample tank. Use the vacuum pump to vacuumize the experimental pipelines, and after vacuumized, close other gas valves, open valve 11 and valve 14, use the gas cylinder import a certain amount of helium to gas tank with constant pressure, and then set the gas pressure of gas tank to 0.5MPa through energy storage devices caused by gravity. Then open valve 9 and let gas into the sample tank. At the same time, record the relevant data and calculate the free volume. At last, use the vacuum pump to vacuumize the gas pipelines again, and after 3 hours, close all valves.

② Open valve 11 and valve 14, use the gas cylinder import a certain amount of methane to gas tank with constant pressure, and then set the gas pressure of gas tank to 0.5MPa through energy storage devices caused by gravity. Then open valve 9 and let methane into the sample tank to begin the adsorption process until the piston of gas tank will not move for several hours. By then, the adsorption of coal sample has reached saturation, saves the experimental data and closes all gas valves.

③ Open valve 9 and valve 10, and discharge methane in sample tank. At the same time, observe the value change of gas pressure until the value reaches 0 MPa. Then conduct the desorption process and use drainage method to measure the amount of gas desorption in the test.

④ Repeat the above steps, complete the gas desorption experiments of 3 kinds of coal samples under different loading conditions and different gas pressure, and record the temperature and atmospheric pressure of each experiment.

Experimental Results and Analysis

Change laws of gas desorption cumulative amount under different gas pressure with the same axial pressure

By processing the experimental data, the change curves of cumulative desorption of three kinds of coal samples over time with different gas pressure under the same axis pressure are obtained and are shown in Fig. 4 to Fig. 9.

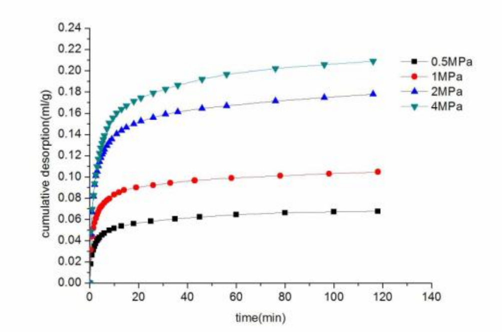


Fig. 4 The change curves of gas desorption of coal 1# under the axis pressure of 0MPa

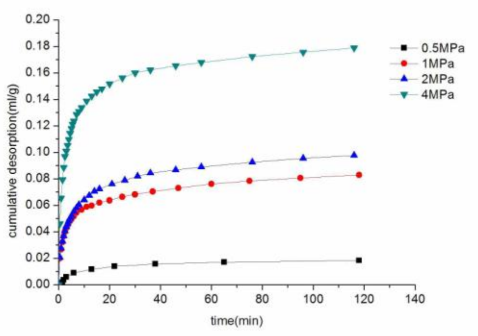


Fig. 5 The change curves of gas desorption of coal 1# under the axis pressure of 2MPa

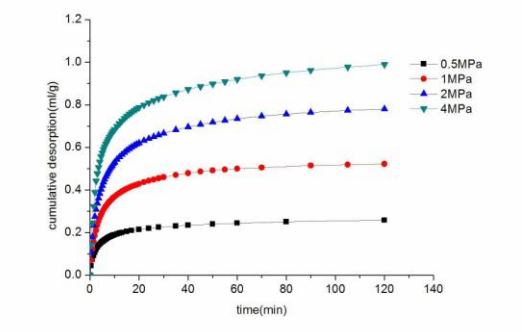


Fig. 6 The change curves of gas desorption of coal 2# under the axis pressure of 0MPa

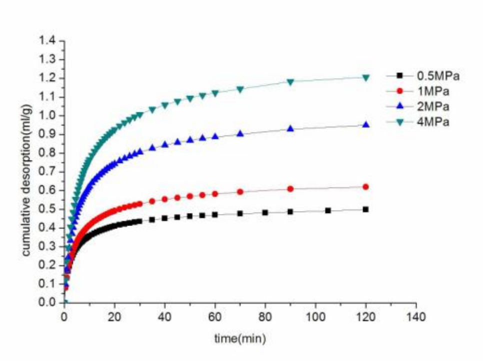


Fig. 7 The change curves of gas desorption of coal 2# under the axis pressure of 2MPa

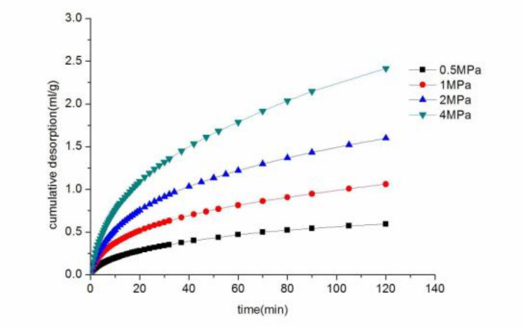


Fig. 8 The change curves of gas desorption of coal 3# under the axis pressure of 0MPa

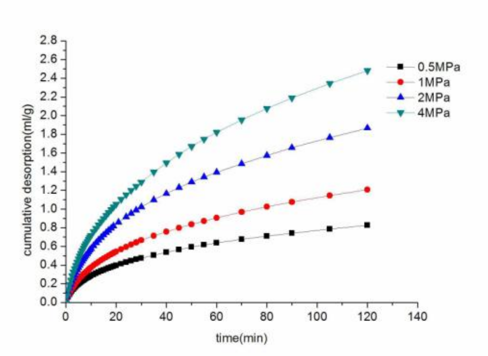


Fig. 9 The change curves of gas desorption of coal 3# under the axis pressure of 1.8MPa

From Fig. 4, Fig. 6 and Fig. 8, we can see that the cumulative desorption amount of coal sample 1#, 2#, 3# increases over time without axial compression, and finally keep stabilizes gradually. In addition, the cumulative gas desorption amount increases with the increase of the initial gas pressure, the initial rate of gas desorption also increases along with the increase of the initial gas pressure and decreases with time. This is the same as the laws of particle coal. From Fig. 5, Fig. 7 and Fig. 9, the change laws of cumulative gas desorption amount and gas desorption rate over time and initial gas pressure are the same as the laws without axial compression. While for different kinds of coal samples, the cumulative gas desorption amount and gas desorption rate are different even under same axial compression and same initial gas pressure, which is related to internal structure and other factors of coal sample itself.

Change laws of the cumulative amount of gas desorption under different axial compression pressure within the same initial gas pressure

By processing the experimental data, the change curves of cumulative desorption of three kinds of coal samples over time under different axial compression pressure within the same initial gas pressure are obtained and are shown in Fig. 10 to Fig. 13.

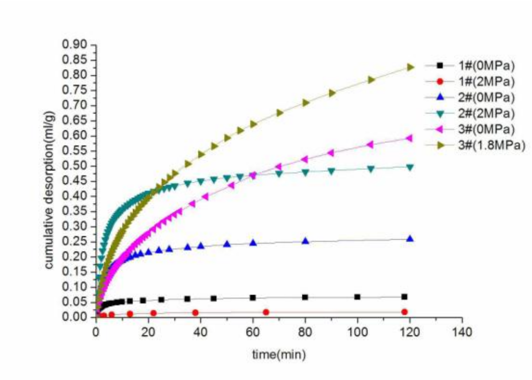


Fig. 10 The change curves of gas desorption of coal samples under the initial gas pressure of 0.5MPa

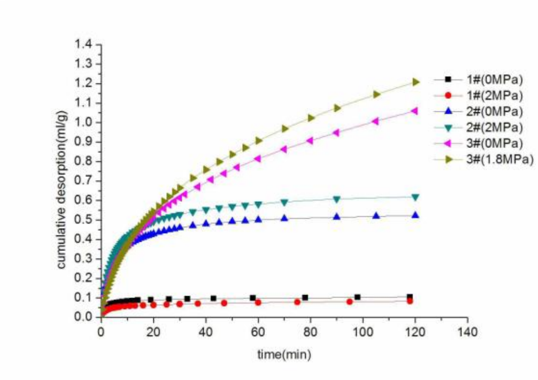


Fig. 11 The change curves of gas desorption of coal samples under the initial gas pressure of 1MPa

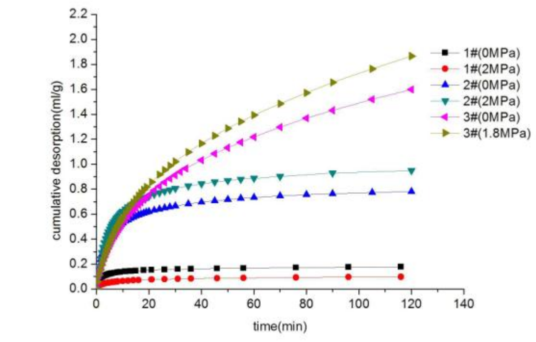


Fig. 12 The change curves of gas desorption of coal samples under the initial gas pressure of 2MPa

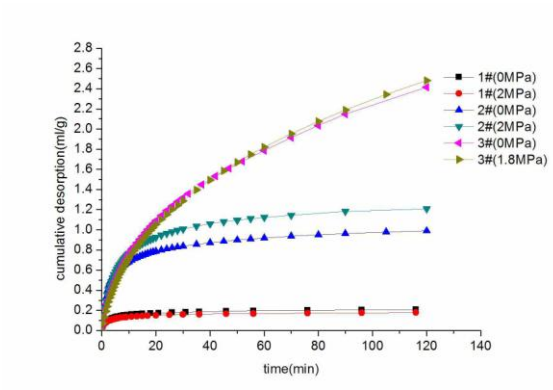


Fig. 13 The change curves of gas desorption of coal samples under the initial gas pressure of 4MPa

From Fig. 10 to Fig. 13, we can see that the desorption laws of different kinds of coal samples are not all the same. The cumulative gas desorption amount of coal sample 1# decreases with the axial pressure increasing, while the cumulative gas desorption amount of coal sample 2# and 3# increase with the axial pressure increasing. It means that under the same initial gas pressure, the cumulative desorption capacity of coal samples not only relates to axial pressure, but also has to do with internal pore structure and other factors of coal body. The cumulative gas desorption amount of coal sample 1# under the axial pressure of 2MPa is less than the one without axial pressure, and it means that under the axial pressure of 2MPa, the adsorption process of coal sample 1# should be in the closure stage of pores and fissures which blocks the channel of gas adsorption and makes the gas adsorption value under compression load less than the one without load. The processes of adsorption and desorption are reversible, so the cumulative gas desorption amount decreases over the axial pressure when in desorption process. However the cumulative gas desorption amount of coal sample 2# and sample 3# increases with the axial pressure, it means that the adsorption processes of coal sample 2# and sample 3# should be in the elastic or plastic stage. With the increase of the axial pressure, the damage increases, and the coal bodies have produce cracks, which greatly increases the adsorption capacity of the gas, so the cumulative gas desorption amount increases in the desorption process.

Desorption Model of Lump Coal under Uniaxial Compression

From the former analysis, the gas desorption laws of lump coal and particle one are similar. The cumulative amount of gas desorption has a monotonic increasing relation with time. Under the same axial pressure, the greater the initial gas pressure is, the greater the cumulative amount of gas desorption is at the same time. As a result, in order to find a function to depict the gas desorption law of lump coal, apply the experience formulas which describe the desorption laws of particle coal to fit the methane desorption laws of lump coal sample.

In recent years, the domestic and foreign scholars have carried on the intensive study on the gas desorption laws of particle coal and have proposed many empirical or semi-empirical formulas. These empirical or semi-empirical formulas can be divided into the types of power function and exponential function, in which the power function formulas mainly include R M Barrer, Wang Youan, Н .И. ВСТИНОВ, Sun Chongxu type, and the exponential function formulas mainly contain E.M.Airey, Bote, Vinterk and index type[16-17]. Are these formulas applicable to represent the gas desorption process of lump coal under compression load? Therefore, applying these formulas to fit the experimental data of gas desorption process under different axial pressure and different initial gas pressure, and through the fitting results find that the experience formulas of E.M.Airey and Wang Youan type can fit experimental data very well, and the fitting curve diagrams are shown in Fig. 14 to Fig. 21.

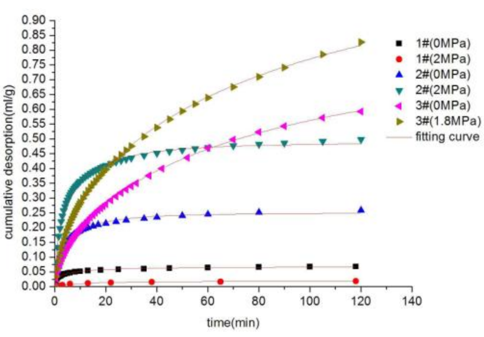


Fig. 14 the E.M.Airey-type fitting of various coal samples under the initial gas pressure of 0.5MPa

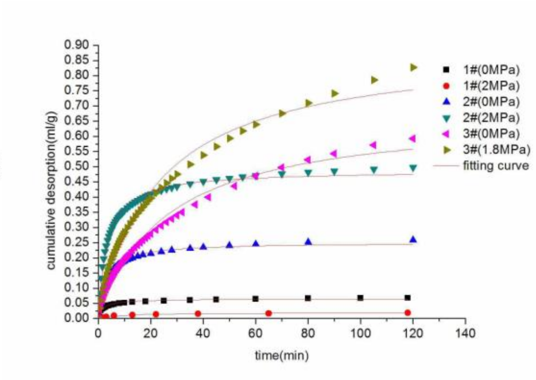


Fig.15 the Wang Youan-type fitting of various coal samples under the initial gas pressure of 0.5MPa

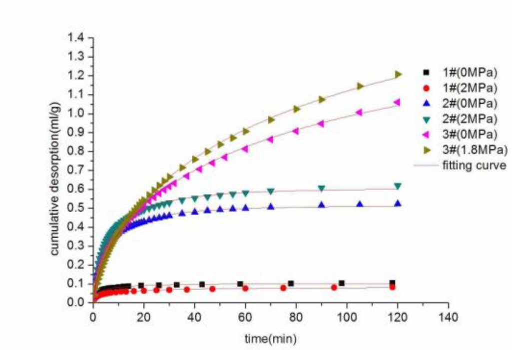


Fig. 16 the E.M.Airey-type fitting of various coal samples under the initial gas pressure of 1MPa

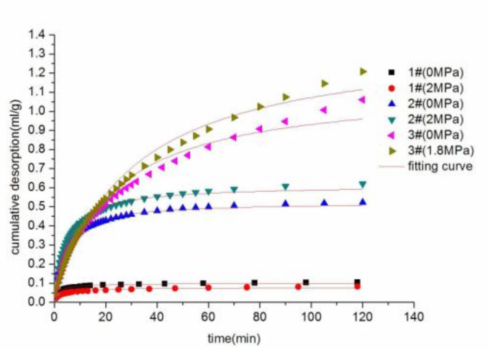


Fig. 17 the Wang Youan-type fitting of various coal samples under the initial gas pressure of 1MPa

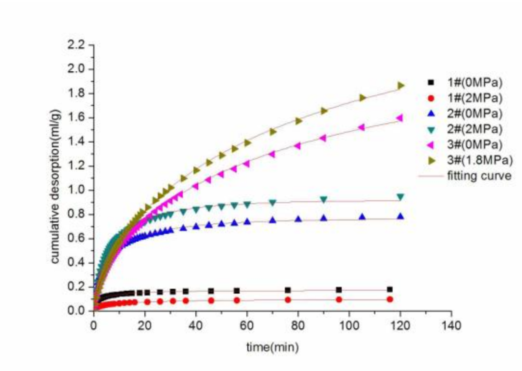


Fig. 18 the E.M.Airey-type fitting of various coal samples under the initial gas pressure of 2MPa

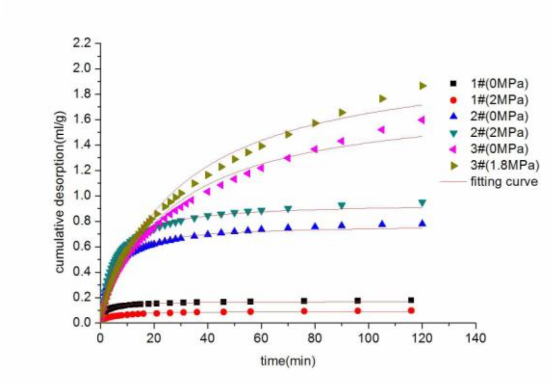


Fig. 19 the Wang Youan-type fitting of various coal samples under the initial gas pressure of 2MPa

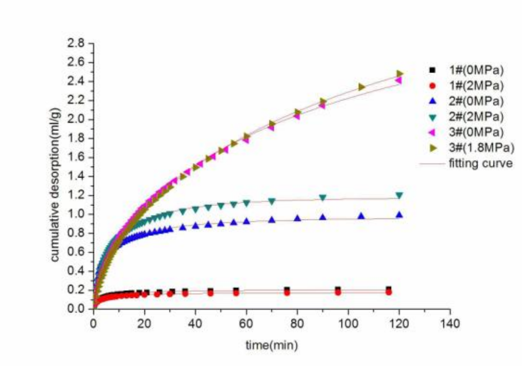


Fig. 20 the E.M.Airey-type fitting of various coal samples under the initial gas pressure of 4MPa

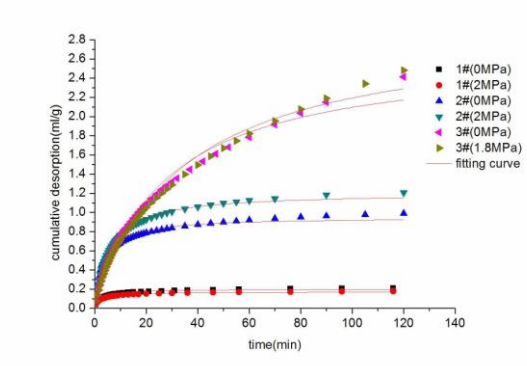


Fig. 21 the Wang Youan-type fitting of various coal samples under the initial gas pressure of 4MPa

From Fig. 14 to Fig. 21, we can find that when gas pressure is 0.5MPa, 1MPa, 2MPa or 4MPa respectively, the fitting degree of experimental formulas of E.M.Airey and Wang Youan type for lump coal sample 1# and 2# during the whole desorption process under different axial pressure is excellent and the difference is minimal. While for lump coal 3#, the fitting degree of E.M.Airey type is significantly higher than the one of Wang Youan type. In this experiment, the fitting degree of E.M.Airey type for various coals are excellent, so we assume the relation between the cumulative amount of gas desorption of lump coal and time under uniaxial compression just as the E.M.Airey type formula, but the physical meaning of the constant is not the same as the E.M.Airey type, and the formula is:

$$\frac{Q_t}{Q_\infty} = 1 - e^{-\beta t^m} \qquad (1)$$

In the formula:

Q_t —The cumulative amount of gas desorption at a certain moment t, ml/g;

Q_∞ —The maximum cumulative amount of gas desorption, ml/g;

β —A constant which depends on the size of coal sample;

m —A constant which depends on the fracture and pore structures of coal, considering the mining influence, it will change with mining stress and upside gravity compressed on the coal body, as to the experiment, it will change with the compression pressure;

t —The cumulative time of gas desorption, min.

By analyzing the constants through the experimental results, there are not obvious laws for β and m with Q_∞, and β and m of the fitting formula is not the same with different kinds of coal samples. So there needs a lot of lump coal samples to conduct the gas absorption and desorption experiment to obtain the truly law of different coal type. However Q_∞ and Q_t has the same changing trend, Q_∞ increases with the increase of the initial gas pressure under the same axial compression, Q_∞ is related to axial compression and internal pore or fissures structure and other factors of coal body itself.

Conclusions

Considering the real conditions in coal mines, a new gas adsorption and desorption experiment system of coal (or rock) was designed and manufactured, the system can carry out gas desorption characteristics experiments under different gas pressure and compress load. Using this experiment system, the gas desorption experiments of coal samples were conducted under different gas pressure with constant compress load and different compress load with constant gas pressure. Through analyzing the gas desorption data of coal samples, the following conclusions can obtained:

(1)For different kinds of coal samples, the cumulative amount of gas desorption increases with the increase of initial gas pressure under the same axial compression.

(2)For different kinds of coal samples, the cumulative amount of gas desorption not only relate to the axial compression, but also has to do with internal pore or fissures structure and other factors of coal body itself.

(3)The mathematical model of gas desorption of lump coal under uniaxial compression is $\frac{Q_t}{Q_\infty} = 1 - e^{-\beta t^m}$.

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