An experimental study on coal gas desorption laws with different particle size

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Abstract

Based on the self-designed coal containing methane gas desorption law experimental system and coal gas desorption kinetics law, the gas desorption law for different particle size coal under isothermal-isobaric condition are measured by combining combined simulation measurement with the theoretical analysis. The effect of particle size on coal gas desorption laws are obtained through fitting analysis on experimental data: 1.Under the same sorption and desorption conditions, coal particle size was inversely related to total desorption gas amount in the same period. 2. For coal with any particle size, the gas desorption amount firstly increased as time, and finally reached the maximum value, which was equal to the gas sorption amount unit per mass. 3. For coal with higher gas and coal outburst risk trend, the effect of particle size on initial desorption velocity and total desorption amount with time was less. 4. Within the limit particle size, the gas initial desorption velocity had a negative relationship with particle size. Finally we theoretically analysed the effect of particle size on coal gas desorption laws.

Keywords: Particle size, Gas desorption, Gas adsorption, Pore

1 Introduction

Gas desorption law in coal can reflect the gas and coal outburst risk and be applied to determine the loss during the gas content measurement. Many empirical formulas based on the relationship between desorption amount and time has been presented by worldwide researchers through many experiments. These formulas can be classified into two types, one was power functions, represented by R.M. Barrer formula [1]. The other was exponential functions, with E.M. Eirey formula as the representative one.

However, to some degree, these results have their limitation and range ability because they were obtained based on some certain conditions and coal samples. In fact, there are many factors which can affect gas desorption law, for example, gas absorption ability of coal, gas absorption pressure, coal failure type, particle size, moisture in coal sample, temperature and so on [5]. In particle size study, Yang Qiluan, Cao Yaolin, Wang Zhao Feng [1-6] pointed out that there existed a limit particle size. When sample particle size was less than limit particle size, gas desorption intensity and attenuation quotient would decrease with sample particle size increasing. While when the sample particle size is bigger than limit particle size, attenuate trend became little. However, predecessors research results are widely accepted and applied to engineering nowadays, the validity and systematises of these results also need to be verified and adjusted through experiments and theories. At the same time, reports about mechanism of particle size affecting gas desorption are rare. Therefore, it is necessary to carry out gas desorption law study of different particle size under isothermal-isobaric condition and analyse the mechanism.

2 Gas desorption kinetics law

In gas desorption kinetics law study, researchers presented many empirical formulas, diffusion models, permeability models. For less uncertainty constants in these formulas or models, they are taken as predictive index for coal and gas outburst. However, they have the same deficiency, when $t=0$, the testing data fitting results are bad. In some cases, when $t<1h$, the fitting results agree with testing data. While in some cases, an available result can be obtained when $t\to\infty$. So far, the only verified model is three-constant diffusion control model presented by Chen Chang Guo [7].

In this model, gas desorption includes two parts, one is the desorption amount of coal seam/particle and open macro pore surface, $Q_0(t)$. For the surface is directly contacted with surrounding environment, gas can release freely. The other part is the desorption amount of coal seam/particle of internal pore surface, $Q_d(t)$. A diffusion process is necessary for gas to exchange with surrounding environment. So the total gas desorption amount $Q(t)$ is equal to $Q_0(t)$ surplus $Q_d(t)$, i.e. $Q(t)=Q_0(t)+Q_d(t)$.

The gas desorption in the first part belongs to a physical process, which can finish instantaneously. So

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$Q_0(t)$ is a constant Q_0. In the second part, gas diffusion in coal/particle is the main factors affecting coal desorption/sorption velocity. In three-constant diffusion control model, gas desorption kinetics formula can be described as following:

$$Q(t) = Q_0 + Q_d(\infty)\sqrt{1 - \exp(\frac{4\pi^2 D}{d^2})}\,, \tag{1}$$

where, $Q(t)$ is gas desorption at t time, Q_0 is a constant reference to gas surface desorption, $Q_d(\infty)$ is gas desorption when time tend to infinity, D is diffusion coefficient, d is particle equivalent diameter.

3 Different particle size coal samples gas desorption experiment

3.1 EXPERIMENT SYSTEM

A gas-containing desorption experiment system with desorption apparatus and volume adjusting apparatus were developed. The system was established based on the measurement method of coal methane adsorption (MT/T752-1997). The whole system includes vacuum degassing element, gas absorption-desorption element, desorption apparatus element and high-pressure gas element.

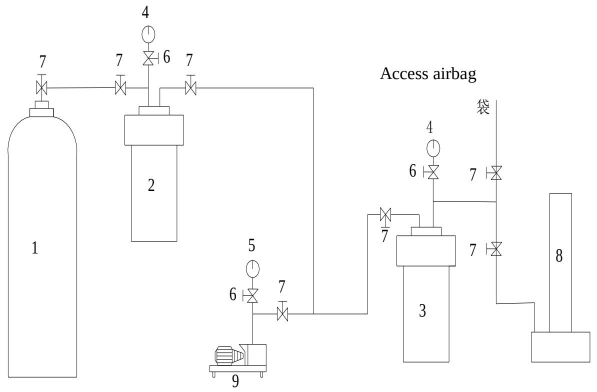


FIGURE 1 Schematic drawing of experiment system
1. high-pressure gas bottle; 2. gasing tank; 3. coal sample tank;
4. precision pressure gauge; 5. vacuum gauge; 6. pressure gauge switch;
7. high-pressure disconnecting valve; 8. desorption apparatus;
9. vacuum pump

3.2 EXPERIMENT PRINCIPLE

Making constant mass dry vacuum degassed coal sample in coal sample tank is connected with high-pressure gas bottle under a selected gas sorption balance pressure. When it reaches to the balance point, testing the gas desorption process of coal sample disposed in air and releasing the pressure at a constant desorption temperature.

3.3 EXPERIMENT METHOD

Two kinds of coal samples were collected from Yian coal mine of Xin'an coalfield and Zhaogu No.1 coal mine of Jiaozuo coalfield respectively. The former were soft coal seam, which had been heavily destroyed with high gas and coal outburst risk. The latter was protogenesis structure coal without gas and coal outburst risk. These coal samples were powdered and classified into small particle sizes: 0.2~0.5 mm, 0.5~1 mm, 1~3 mm, respectively, and then enclosed into six ground glass containers labelled with different label. The testing procedure includes five steps: coal sample pre-treatment, vacuum degassing, gas adsorption equilibrium, determination of the coal sample desorption process, and determination on data processing.

1) Coal sample pre-treatment. Prepared coal is dried with temperature (105±1) ℃ for about 1.5 h, and keep these coal samples in air-dried state; then we take amount of coal into coal tank. Then the tank is fully compacted as much as possible to reduce the dead space volume in the tank. Cover the sample with cotton and 80 mesh copper net, and seal coal tank.

2) Coal vacuum degassing. Open water bath and vacuum pump. Set the water bath temperature be (60±1) ℃. Open the coal tank valve, vacuum degas the coal until the vacuum table to 2 h-0.1 MPa.

3) Gas adsorption equilibrium. After degassing, adjust the water bath temperature be (30±1)℃; unscrew the high pressure gas cylinder valve and inflatable tank valve, and connect high pressure gas cylinders with the inflatable tank. Buffer the pressure of the coal gas into tank. When the pressure of the Inflatable tank comes to 1.2 times of the ideal equilibrium pressure, we close the high pressure gas cylinder valve, and wait to inflate the samples tank, then open the valve connected the samples tank and the inflatable tank, the inflatable tank inflate the samples tank. Depending on the size of the coal, samples tank will get equilibrium after adsorb gas for more than 12 h.

4) Determination of the coal sample desorption process. Firstly read stopwatch, air bags, desorption apparatus, measure, and record the temperature and air pressure. then connect air bags with desorption apparatus, and close the valve between the coal sample tank and inflated tank; open the valve connecting vacuum airbag, so that the free gas in the coal sample tank can go into the vacuum airbag. When the pressure of the tank go to 0, open the valve connected the vacuum airbag, and the valve connected the desorption apparatus, and press the stopwatch and record the start time, read and record the amount of desorption gas.

5) Determination on data processing. For comparative analysis of different coal gas desorption, gas desorption volume will be measured under standard conditions, conversion formula is as follows:

$$Q_t^{'} = \frac{273.2}{101325(273.2 + t_w)}(P_{atm} - 9.81h_w - P_s)Q_t^{''},\qquad(2)$$

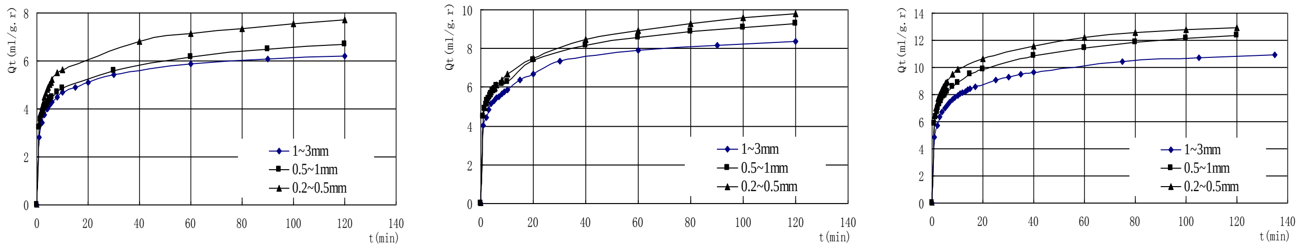
where Q_t' - Standard state of the total gas desorption, cm^3;
$Q_{t''}$ - Experimental conditions the total measured gas desorption, cm^3;
T_w - The amount of water pipe, ℃;
P_{atm} - Atmospheric pressure, Pa;
h_w - Read the amount of data within the water column tube, mm;
P_s - saturated water vapour pressure, Pa.

During the test, as desorption environment temperature was maintained at 30±1℃, gas outlet pressure is approximate 0.1 MPa (ignore the water column influence in the desorption apparatus). Therefore, we took this test as an isothermal-isobaric desorption procedure condition of all these particle coal samples.

4 Results and analysis

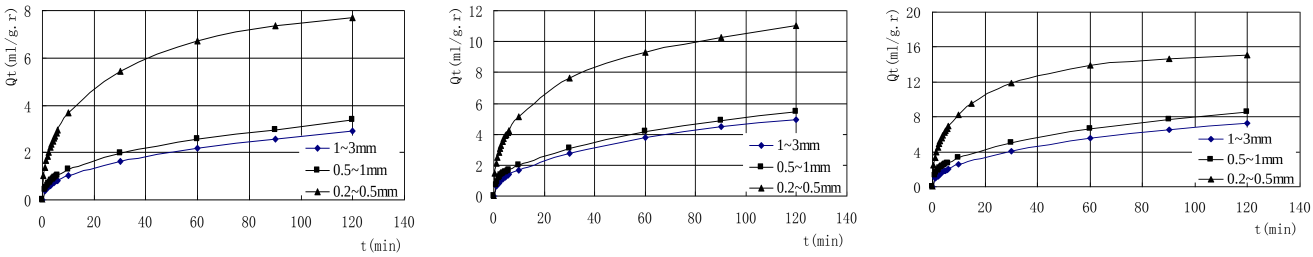
4.1 PARTICLE SIZE EFFECTS ON GAS DESORPTION LAW

The particle size of coal sample was less than limit particle size, which was accordance with the sampling in the field. In order to study effects of particle size on gas desorption law, the above 6 samples were tested under the same sorption and desorption conditions. The fitting results were showed as following figures.



(a) Adsorption equilibrium pressure, 0.5 MPa (b) Adsorption equilibrium pressure, 1.0 MPa (c) Adsorption equilibrium pressure, 2.5 MPa

FIGURE 2 The desorption change curve of different particle size of soft coal seam from Yian coal mine



(a) Adsorption equilibrium pressure, 0.5 MPa (b) Adsorption equilibrium pressure, 1.0 MPa (c) Adsorption equilibrium pressure, 2.5 MPa

FIGURE 3 The desorption change curve of different particle size of protogenesis structure coal from Zhaogu No.1 coal mine

From above Fig. 2 and Fig. 3, we learnt that when the particle size was less than limit particle size, the heavily destroyed coal was analogous to the effects of protogenesis structure coal on gas desorption process. Under the same gas pressure, gas content was not affected by particle size. When the particle size was big, coal desorption velocity was low. When the particle size was small, velocity was fast. The reason was that the gas flow resistance increases with particle size increasing, thus the gas desorption velocity decreases. So particle size can affect the gas desorption of gas-containing coal, this effect was mainly reflected in the following aspects:

1) Under the same sampling place and absorption and desorption conditions, the desorption total amount had a negative relationship with particle size in the same period.

2) Particle size would not affect the total desorption amount, and the total desorption amount change curve was always a monotone increasing with top limit, which was the gas sorption amount unit per mass.

3) We learnt that the higher gas and coal outburst risk trend is, the less effect of particle size on initial desorption velocity and total desorption amount with time changing will be.

4) The displacements of desorption gas and hindrance force acting on the gas were influenced by coal particle size. Smaller particle size leads to shorter gas displacement and higher gas desorption rate [9]. The initial rate of gas desorption decreases with an increase in particle size. Extreme particle size was proposed by Yang [10]. Extreme particle size is related to physical-chemical properties of coal, but is irrelevant to damage extent. When coal particle size is larger than extreme particle size, the coal is divided into lots of fine particles by the cracks and large pores. It is regarded that the hindrance force of pores within the coal having extreme particle size are constant. Moreover, the hindrance of the cracks and large pores is far lower than that of all of the coals with extreme particle size. Hence, when the coal size was up to a certain value (extreme particle size), the initial rate of gas desorption did not decrease anymore.

5) The gas initial desorption velocity decreased with particle size increasing. According to the limit particle size theory, coal sample initial desorption velocity would reach to be constant, which was verified by the testing data with particle size 0.5~1 mm, 1~3 mm. Furthermore, it also showed the validity of this conclusion.

4.2 THEORY ANALYSIS ON THE PARTICLE SIZE EFFECTS ON THE GAS DESORPTION LAW

According to the gas desorption kinetics law, coal seam or particle desorption is affected by coal seam/particle surface, open macro pore surface and coal internal pore space. The particle size firstly affected the coal total surface area, secondly the pore space gas molecule in or out the coal particle.

Total specific surface area: Coal is a complex porous medium and nature sorbent. The surface area proportion with microspore diameter less than 10-4 mm, up to 97.3%, specific area to 200 m^2/g determined the adsorption volume to some degree. Through analysing the coal sample with particle size (0.5~1, 5~10 mm) pore structure testing data, Zhang Xiaodong [8] pointed out that particle size had little influence on the pore specific area, especially for microspore. In addition, particle size had little effect on the dry coal desorption amount. So, from the specific area point, particle size hardly affected the gas desorption.

Particle coal internal pore space: The particle size can reflect the gas desorption transportation distance and resistance. For the same coal sample, the bigger the particle size, the longer desorption transportation distance and the bigger the resistance. So in the per unit time, the desorption amount was small. At the same time, during the sorption process, the coal sample body would swell, leading the coal microstructure to irreversible deformation. Under the same condition, for the coal sample with small particle size, this deformation process might enhance the micro connectivity and enlarge the surface area, causing the adsorption amount increasing. Of course, the gas desorption intensity in per unit time and given time gas desorption would increase meanwhile.

5 Conclusions

The gas desorption of coal is influenced by many factors. These factors can be categorized into two types. One is the physical-chemical properties of deformed coal, such as metamorphic grade, adsorption capacity, damage type, internal moisture, and particle size, etc. The other is external factors, which include gas adsorption equilibrium pressure and environmental temperature, etc. [11].

Through studying, the effects of particle size on gas desorption law, we can obtain the following conclusions:

1) Under the same absorption and desorption conditions, coal particle size is inversely related to total desorption gas amount in the same period.

2) For coal with any particle size, the gas desorption amount firstly increased with time, and finally reached the maximum value, which was equal to the gas sorption amount unit per mass.

3) For coal with higher gas and coal outburst risk trend, particle size on initial desorption velocity and total desorption amount show less effect with time.

4) Within the limit particle size, the gas initial desorption velocity had a negative relationship with particle size.

The sample particle size can affect the total specific surface area. However, the results showed that it had little influences on the gas absorption or desorption. Particle size can affect the pore space that gas molecular transport, which can directly influence the desorption pathway and resistance. Meanwhile, the swelling deformation induced by gas sorption can affect gas desorption of different particle size. This result can explain the reason why gas desorption law of different particle size were obviously different under the same conditions.

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