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Kinetic characteristics of coal gas desorption based on the pulsating injection

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ABSTRACT

In order to understand the kinetic characteristics of coal gas desorption based on the pulsating injection (PI), the research experimentally studied the kinetic process of methane desorption in terms of the PI and hydrostatic injection (HI). The results show that the kinetic curves of methane desorption based on PI and HI are consistent with each other, and the diffusion model can best describe the characteristics of methane desorption. Initial velocity, diffusion capacity and ultimate desorption amount of methane desorption after PI are greater than those after HI, and the ultimate desorption amount increases by 16.7–39.7%. Methane decay rate over the time is less than that of the HI. The PI influences the diffusion model parameters, and it makes the mass transfer Biot number B_i' decrease and the mass transfer Fourier series F_0' increase. As a result, PI makes the methane diffusion resistance in the coal smaller, methane diffusion rate greater, mass transfer velocity faster and the disturbance range of methane concentration wider than HI. Therefore, the effect of methane desorption based on PI is better than that of HI.

1. Introduction

The methane is not only a kind of clean energy and valuable chemical material, but also a substantial root causing coal and gas outburst as well as explosion. In the natural coal, the fracture network is arranged by a large number of pores and cracks, from the defect in a molecular or atomic scale to visible cracks, with considerable specific surface area and strong methane adsorption capacity. The methane is adsorbed on the inner surface of the coal matrix physically. Methane adsorption and desorption characteristics are related to not only the pore structure of coal, metamorphism, ash, moisture and other intrinsic factors, but also gas pressure, temperature, stress, electric field, magnetic field and acoustic field [1,2]. Chen et al. determined the methane adsorption characteristics of the anthracite at different temperatures by the volumetric method [3]. Their results show that the equilibrium time of methane adsorption increased from 5 h at 50 °C to 25 h at −20 °C. The desorption process of adsorbed gas in coal from Nanshan Coal Mine was studied by He et al., using an experimental system with temperature–pressure coupling [4]. Their results show that a large amount of gas was expelled during the closure of fracture due to the confining pressure.

With the increase of coal mining depth and exploitation intensity, coal outburst and gas explosion seriously threaten miners' personal safety, and restrict the development of coal mines. Efficiently and safely relieving pressure of coal seam is an important guarantee to the safe production of coal mines. In recent years, all kinds of hydraulic measures have been taken in managing mine gas and prevention of coal and gas outburst by coal mining enterprises and scholars, including hydraulic fracturing, coal seam water injection, hydraulic slotting and so on [5–7]. Conventional hydrostatic injection (HI) can play a role in wetting the coal. However, due to blocking up the channel of the gas desorption and migration by the water, there is a blocking effect on the gas desorption, which has been confirmed by many scholars [8,9]. Pulsating injection (PI) is a new technology based on the original coal seam water injection and aimed at improving pressure relief of the coal seam gas. Many scholars have confirmed that it can effectively improve the seam permeability [10]. Zhai et al. took hydraulic fracturing experiments and mechanical analysis under the different pressures and frequencies, and analyzed the characteristics of coal fatigue damage [11]. Their results showed that alternating stress was formed at the end of coal fracture under the action of the pulsating water, and fatigue damage could occur in the coal due to the repeated

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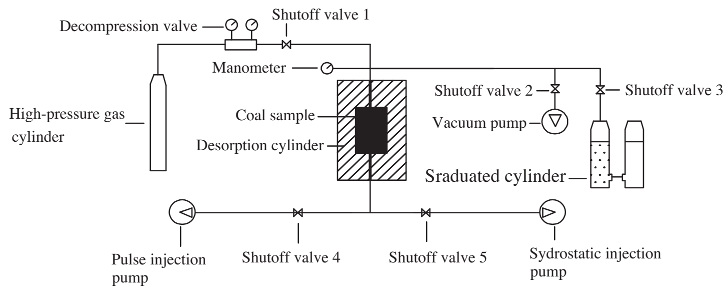

Fig. 1. Methane desorption system based on the PI and HI.

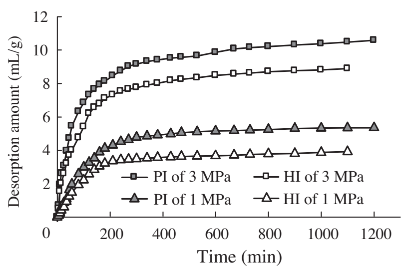

Fig. 2. Curves of gas desorption amount with time based on the PI and HI.

action of compression and expansion. Li et al. investigated the generation and propagation of pulsating stress wave and the mechanism of coal and rock breakage using theoretical review, laboratory experiment and field test [12]. Their study shows that reflection and superposition of pulsating stress wave could make stress increase in some areas, and make the stress decrease in other areas. Li et al. took the experiments in three aspects including different water injection mode and pulsating frequency and parameter combination by pulsating hydraulic fracturing system [13]. They concluded a result that the pulsating pressure should be controlled properly so that it could provide sufficient time for the pulsating water in the coal when the pulsating hydraulic fracturing was implemented. Ni et al. determined and analyzed the sealed parameters of pulsating hydraulic fracturing using the diameters of 95 and 108 mm rough inner wall seamless steel pipes as simulation drills [14]. They found that the reasonable sealed length was 13 m when the pulsating hydraulic pressure was 16 MPa. However, the impact of the PI on the kinetic characteristics of gas desorption is still not clear, and there is no relevant study to date. Therefore, this paper experimentally studies the gas desorption changes with time after PI and HI, and comparatively analyzes the kinetic characteristics of coal gas desorption based on PI.

2. Kinetic characteristics of methane desorption

In order to explore the kinetic characteristics of methane desorption, this research has made unremitting efforts to establish a variety of dynamic models, and put forward a number of equations to calculate the changes of methane desorption amount over the time in coal.

2.1. Empirical equations

Wang and Yang determined the velocity of the coal gas desorption using the gravimetric method, and put forward Eq. (1) to indicate the amount of desorption over the time [15].

$$Q(t) = \frac{\alpha\beta t}{1+\beta t} \tag{1}$$

where $Q(t)$ is the desorption amount; α the saturated desorption amount; β the desorption constant; and t the time.

2.2. Diffusion model

One, study makes the assumptions as follows: Firstly, this study makes the assumptions as follows: (1) coal particles were spherical; (2) coal particles were homogeneous and isotropic bodies; and (3) methane flow in coal particles followed the mass conservation law and the principle of continuity.

Under the above assumptions, the diffusion coefficient and the coordinate were independent. Ignoring the influences of concentration C and time t on diffusion coefficient and taking polar

Table 1
Kinetic parameters of methane desorption.

Dynamic model	Gas pressure (MPa)	Injection mode	α (mL/g)	β (min^{-1})	B (min^{-1})	Q_∞ (mL/g)	b (min^{-1})	Correlation coefficient R^2
(a) Empirical formula								
Empirical formula	3	PI	7.7149	1.1182				0.1693
		HI	6.4193	1.8843				0.1543
	1	PI	3.7445	1.6652				0.1021
		HI	2.7283	1.4590				0.1074
(b) Diffusion model								
Diffusion model	3	PI			0.0055	10.2868		0.9917
		HI			0.0050	8.5173		0.9899
	1	PI			0.0042	5.5457		0.9644
		HI			0.0036	3.9684		0.9524
(c) Penetration model								
Penetration model	3	PI				9.7969	0.0120	0.9754
		HI				8.3946	0.0125	0.9848
	1	PI				5.2423	0.0081	0.9538
		HI				3.7672	0.0093	0.9553