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Laboratory measurements of methane desorption on coal during acoustic stimulation

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A B S T R A C T

An apparatus considering the impacts of acoustic waves (mechanical vibration effect, thermal effect, and the cavitation effect) was designed to study the characteristics of gas adsorption and desorption on coals. Experiments of methane desorption on coals were performed under the effects of different acoustic frequencies and different acoustic intensities. The results showed that acoustic wave has promoted desorption of methane on coals. It was found that the initial desorption rate is relatively high, and then desorption rate decreases slowly with time, and finally achieves equilibrium. The desorption amount of methane on coals under the effect of acoustic waves is higher than that obtained without acoustic waves, and we found that desorption amount of methane on coals increases as acoustic intensities increase. It was also found that desorption rate of methane on coals is promoted under the effect of acoustic waves. Since the existing desorption models cannot describe the desorption characteristics of methane on coals under the effect of the acoustic intensity, a correction term was introduced into the existing models in this study, and thus a new model that is able to describe methane desorption under the effect of acoustic waves was established. The promotion mechanism of methane desorption on coals by the acoustic waves was also studied, it was found that the thermal effect of acoustic waves on methane desorption can be clearly seen.

1. Introduction

Coalbed methane is a kind of unconventional natural gas that can be used as a kind of clean energy. However, coalbed methane can also result in great disasters in coal mines [1–5], so the coal seam gas exploitation is imperative. China has a large reserve of coalbed methane, but it is difficult to exploit because the permeability of coal reservoir is very low [6]. Therefore, increasing the desorption rate and permeability of coals are important to improve the extraction rate of coalbed methane. The factors that influence the desorption rate and the permeability of methane on coals include the composition of coals (the moisture [7,8], ash content, and coal pores [9]), and the physical factors such as gas pressure [10], gas component [11,12], temperature [13–15], the electric field, stress field [16], and acoustic field etc. Currently, many methods such as hydraulic cutting seam [17], hydraulic fracturing [18,19], gas injection [20–23], blasting vibration [24,25] and physical field excitation have been put forward to increase the extraction rate of coal bed methane. Among these methods, it was found that the physical field excitation (electric filed, magnetic field, and acoustic field etc.) is able to promote the extraction rate of coalbed methane significantly.

Many researchers have researched the characteristics of methane adsorption and desorption on coals. Liu [26] studied the adsorption and desorption characteristics of methane on coals in the electric field, and found that the adsorption amount of methane on coals both decreased in electrostatic field and alternating electric field. This was caused by the temperature increment of the coal–gas system due to the joule heating effect of the electric field. In recent years, the technique of acoustic wave has been successfully used to promote oil recovery and increase the efficiency of gas extraction [27–29]. Therefore, using the effect of acoustic waves to reduce methane adsorption ability and to promote the gas desorption rate was put forward based on the successful acoustic flooding in Enhanced Oil Recovery (EOR) engineering [30,31]. However there are a few studies focused on the coalbed methane adsorption–desorption characteristics, models and mechanisms under the effect of acoustic wave.

The purpose of the present work is to study the characteristics of methane desorption on coals under the effect of acoustic waves. The experiments of methane desorption on coals were performed under the impacts of acoustic wave frequencies and intensities. A new model that is able to describe methane desorption under the effect of acoustic waves was established through introducing a

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correction term into the existing models. Finally, the mechanism in the promotion of methane desorption on coals by the acoustic waves was discussed. The results reported in this work are of great significance to the improvement of the extraction rate of coal bed methane with acoustic technology.

2. Experimental work

2.1. Preparation of coal samples

There are three coal samples in the research of this paper. Anthracite coal sample (SAM1) from Nantong Coal Mine, Meager coal sample (SAM2) from Sanhui no. 1 Coal Mine and Anthracite coal sample (SAM3) from K3 coal seam of Songzao Coal Mine were selected as coal samples for the experiments performed in this work. The constituents of these coal samples were tested by the coal industrial analyzer. The results are as shown in Table 1.

Sanhui no. 1 coal mine is located in Sanhui town of Hechuan city that is in the distance of 85 km north from Chongqing downtown. It is in parallel chine of Sichuan eastern. Severe coal and gas outburst has occurred for many times in Sanhui coal mine, and the coal seam in exploitation is also in danger of outburst. Nantong coal mine is located in Wansheng District of Chongqing, and the place is at the juncture of Qijiang County, Nanchuan County of Chongqing and Tongzi County of the Guizhou Province in China. The average depth of the coal seam is about 500 m, and the maximum gas pressure of sampling points in this test is 3.1 MPa. Songzao coalmine is located in Qijiang County of Chongqing. The characteristics of this coal seam is loose and broken structure, and the coal seam is also in danger of gas outburst.

2.2. Experimental apparatus

The apparatus used for testing methane desorption under the effect of acoustic waves is mainly composed of an acoustic generator, a gas distribution cylinder, a desorption cylinder, the gas supply system, the pressure measurement system, testing system, and the temperature controlling system. The schematic of the experimental device is shown in Fig. 1. The acoustic generator is a ZJS-2000 acoustic generator designed by Hangzhou Chenggong Ultrasonic Equipment Co. Ltd., Zhejiang Province, China, and the output power is adjustable. Coal samples should put into the desorption cylinder, and the maximal operation pressure of the gas distribution cylinder is 8 MPa. Methane was depressurized through a pressure regulator and charged into the dispensing container from a high-pressure gas bottle. The pressure gage has a precision of 0.01 MPa. The temperature cabinet is an XH001 constant with a precision of 0.1 C. In this experiment, the gas distribution cylinder and the desorption cylinder were both placed in the constant temperature cabinet to maintain a uniform temperature. Then desorption volume was measured using the drainage method. Fig. 2 shows the apparatus with the thermal effect of acoustic waves, which is composed of a loading system, a gas supply system, an acoustic wave generator, a temperature controlling system, and a vacuuming system.

Table 1
Industrial analysis results of coal samples.

Sample no.	Property	Moisture (%)	Ash content (%)	Volatiles (%)
SAM1	Anthracite coal	0.99	13.77	15.93
SAM2	Meager coal	1.22	11.09	20.91
SAM3	Anthracite coal	2.73	31.9	10.54

2.3. Experimental methods and techniques

The conditions of desorption experiments of the coal samples are as follows: in the first part, the desorption characteristics of SAM1 under different acoustic frequencies of 27.7 kHz, 34.1 kHz and 40.0 kHz was studied. And the output power was 80 W, the gas pressure was 1.5 MPa. In the second part, the desorption characteristics of SAM2 and SAM3 under different acoustic intensities were studied, while the gas pressure was 1 MPa and the temperature was 30 °C.

The experimental methods of desorption are as follows: (1) The coal samples for testing were sieved to 40–60 mesh, and then the industrial parameters of the coal samples were analyzed, which include true-density, moisture, ash content, volatile matter and so on. Coal samples were weighed with a precise electronic balance and loaded into the desorption cylinder, and the weight of SAM1 is 131.6 g, the weight of SAM2 is 136.5 g, while the weight of SAM3 is 132.6 g. (2) Turn on the temperature control system and heat the constant temperature cabinet to the setting temperature, after that, start vacuuming for six hours to make the desorption cylinder reach a vacuum condition. Then inject methane into the desorption cylinder to a set pressure, and the coal samples are kept to adsorb methane for 8 h before the equilibrium states are reached. (3) After the equilibrium is reached, desorption cylinder is vented to atmosphere for 30 s. Then the rubber tube is connected to the valve. The volume of water discharged to the cylinder from the bottle will be measured at different time, and the curves between desorption quantity and time are obtained as well. If it is needed to add sound field in the experiment, just open the acoustic generator when methane starts to desorb.

The procedures used for the testing of thermal effect are as follows: (1) prepare the coal samples; (2) fill coal samples into sample container and tamped, then tighten the screw bolt and seal the container up; (3) turn on the vacuum pump to vacuum the coal sample for about 24 h; (4) execute certain load onto coal samples to compress it; (5) fill methane into coal sample through opening release valve for about 48 h, until the samples reach absorption equilibrium; (6) start acoustic wave generator and record the container temperature and the room temperature at different time. Then we can observe the variation of temperature of coal samples under the effect of acoustic waves.

3. Results and discussion

3.1. Models of methane desorption on coals

Methane desorption on coals can be described by many desorption models, such as the empirical formula, diffusion model and percolation model. The relationship between desorption amount and time can be obtained in these models. The models are expressed as follows:

(1) Empirical formula. The curve of desorption kinetics is similar to the isothermal curve, so the empirical formula can be used to describe the relationships between desorption amount and time as well.

$$Q_d = \frac{\alpha\beta t}{1+\beta t} \tag{1}$$

where Q_d is the desorption quantity of methane on coals, ml/g; α is the total desorption amount, ml/g; β is the desorption constant, min^{-1}; t is time, min.

(2) Diffusion model. Based on the cinder methane diffusion equation, an approximate solution such as the root mean