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Full Length Article

# Gas desorption characteristics effected by the pulsating hydraulic fracturing in coal

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ABSTRACT

In order to clarify the effect of pulsating fracturing on gas comprehensive desorption, experimental study of gas desorption characteristics effected by the pulsating hydraulic fracturing (PHF) and static hydraulic fracturing (SHF) were carried out, the gas displacement amount (GDA) and natural desorption amount (NDA) under different hydraulic fracturing methods are investigated. The results show that the GDA generated by the SHF is significantly less than the PHF. At the same time, the GDA increases linearly first, and then logarithmically with the fracturing frequency; with the increase of pulsating peak pressure, it showed a logarithmic increase. The water has an inhibitory effect on the natural desorption of gas. With the increase of pulsating pressure and frequency, the effect of pulsation fracturing suppressing the natural desorption of gas is weakened. According to the effect of different fracturing methods on gas desorption, the PHF is divided into four types: low pressure-low frequency, low pressure-high frequency, high pressure-low frequency and high pressure-high frequency. Because the gas displacement rate ($\eta_d$) determines the changes of gas comprehensive desorption effect, the low pressure-low frequency inhibits gas desorption, while the low pressure-high frequency, high pressure-low frequency and high pressure-high frequency can promote gas desorption. The results provide theoretical guidance for optimizing pulsating parameters, increasing gas desorption and promoting coal seam gas drainage.

## 1. Introduction

About 70% of China's coal-bed methane deposits have the characteristics of micro porosity, low permeability, and high adsorption, and the permeability of coal seam is poor, which leads to the difficulty of gas extraction in most coal seam, and seriously affects the utilization rate of gas extraction [1–3]. With the deepening of research work on coal-bed methane control, scholars reached a certain consensus that hydraulic technologies, such as hydraulic fracturing [4–6], coal seam infusion [7–10], hydraulic cutting seam [11–13], hydraulic punching [14–16], etc. can be used to promote pressure relief of coal seams, improve permeability and strengthen pre-extraction of coal seam gas. Among many hydraulic technologies, hydraulic fracturing has achieved good effects in many mine applications. However, engineering applications in recent years have found that because of the micro-porosity, low permeability and high adsorption characteristics of coal seams in China, traditional hydraulic fracturing under large flow and high pressure is relatively simple to form cracks [17], and local stress concentrations are easily generated [18]. Moreover, the large flow fracturing fluids may have an inhibitory effect on desorption and other migration of gas in coal seams [19,20]. Therefore, new technologies need to be explored to improve hydraulic fracturing technology and gas extraction efficiency.

The pulsating hydraulic fracturing (PHF) is a new technology aimed at improving the pressure relief and anti-reflection of coal seams based on traditional hydraulic fracturing [21]. The technique is to continuously inject the pulsating water with certain frequency into the coal seam, and the peak pressure and the bottom pressure constitute a periodic pulsation wave, which produces a 'compression-expansion-compression' alternating or repeated load action on the pore-fracture of the coal body. Gradually cause fatigue damage of coal body, prompt formation and opening of tiny pores and fissures in the coal seam, and the weak surface of the internal fractures of the coal body begins to expands and extends, and creates new fissures to form interpenetrating fissure networks, providing a new flow channel for gas, greatly improve the coal seam permeability [22]. The engineering practice has proved that this technology has great advantages, can greatly improve the effect of crack expansion of coal. And the pulsating pressure is secure and

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reliable, which has broad application prospects [23,24].

Moreover, The PHF not only promotes the development of the pore-fracture structure, but also affects the gas migration characteristics in the coal seam [25,26]. The research on the characteristics of gas desorption and diffusion in the damaged coal body is insufficient, which leads to the unclear distribution of gas in the coal seam of pulsating fracturing process, and the gas extraction technology is blind. At the same time, the law of gas desorption and diffusion can reflect the changes of gas pressure and outburst risk of coal seam to a certain extent, which is of great significance to determine the gas pressure and outburst risk of coal seam [27–29].

While the traditional hydraulic technology was applied, the migration characteristics of gas have also attracted the attention of scholars. For example, Cheng et al. [30] found that the hydraulic fracturing could drive the gas flow in the coal body, moreover, the increase of moisture has the time effect on gas migration and desorption in coal. By testing the gas emission data during the hydraulic fracturing, Qin et al. [31] found that the gas emission amount from adjacent free extraction holes increases during the hydraulic fracturing, and believed that the increase is mainly due to the high pressure displacement of water and displacing desorption of gas. Meanwhile, Zhao et al. [32] carried out the experiment of high pressure water injection under different pressures, which indicated that the water has a great influence on the desorption characteristics of gas. The gas desorption rate after water injection is only 50%~70% of the natural desorption of raw coal. Zhang et al. [33] carried out a comparative experiment on the effects between the water intrusion and the anhydrous on gas desorption. The results show that water intrusion not only greatly reduces the gas desorption amount, but also terminate the time of gas desorption in advance. Xiao and Wang [34] found that the adsorption amount and residual gas content in the isothermal desorption process of water-injected coal samples are larger than those in raw coal samples. As the moisture increases, the initial desorption rate decreases, and the decay rate slows. Chen et al. [35] selected four kinds of coal samples to study the effect of external moisture on the kinetics characteristics of gas desorption. It is concluded that the external moisture promotes the gas desorption of the Yonghong, Gaojiazhuang and Qinan coal mines, and inhibits the gas desorption of Dalong coal.

Obviously, the impact of hydraulic technology on gas desorption and diffusion characteristics has now formed two perspectives. Some scholars believe that hydraulic technology promotes gas desorption. Another part of scholars believe that hydraulic technology reduces the desorption rate of gas in the coal, has a plugging effect on gas desorption, and avoids the rapid desorption of large amounts. During the PHF process, the pulsating wave uses the water medium as a carrier to affect the microscopic pore-fracture damage of the coal, thereby influences the gas desorption characteristics. In order to clarify whether the process of promoting gas desorption or suppressing the gas desorption exist unilaterally or simultaneously during the pulsating fracturing, it is necessary to study the law of gas desorption in damaged coal. In this paper, a self-designed gas desorption device under the PHF and static hydraulic fracturing (SHF) was used to experimentally study the effects of different hydraulic fracturing on the gas desorption, and the characteristics of gas displacement and gas natural desorption were analyzed, then comprehensive analysis of promoting or inhibiting gas desorption were carried out, optimizing the pulsating parameters and promoting the gas drainage of coal seam.

## 2. Experiment

### 2.1. Experiment system

Fig. 1 shows the diagram of gas desorption experiment under the PHF and SHF. The experimental system consists of two subsystems: the PHF subsystem and the gas adsorption-desorption subsystem.

The PHF subsystem consists of four parts: pulsating pump, damper, control cabinet and tank. The damper can eliminate the effect of pulsating frequency to achieve the SHF. The gas adsorption-desorption subsystem is mainly composed of the pressure relief value, adsorption tube, water bath, gas tank and vacuum pump. The ultimate of vacuum pump is 2 Pa. The internal pressure and gas purity of gas tank are 15 MPa and 99.99%, respectively. The changes of gas pressure was controlled through the pressure relief valve, the experimental range of output pressure is 0–15 MPa. The temperature range of water bath is 5–99 °C.

### 2.2. Experiment design

#### 2.2.1. Selection and preparation of coal samples

The experimental coal samples were selected from the Guhanshan Mine of Jiaozuo Mining Group, Yangliu Mine of Huaibei Mining Group and Songshu Mine of Tonghua Mining Group, all of which were from the low permeability coal seams.

Petrographic and proximate analysis results of coal samples are shown in Tables 1 and 2. It is concluded that the Guhanshan coal, Yangliu coal and Songshu coal belong to the high metamorphic anthracite, middle-grade metamorphic coal and low-metamorphism long flame coal, respectively. This article uses ø100 × 100 mm cylindrical raw coal, drilled a hole with a diameter of 10 mm and a depth of 80 mm in the center position of the raw coal bottom. The bottom fracturing tube of the coal sample tank is inserted into the drill hole of the coal sample to perform the PHF and SHF.

#### 2.2.2. Experimental procedures

In the experiment, coal samples were firstly adsorbed and then subjected to hydraulic fracturing. The equilibrium pressure of gas adsorption is 1.0 MPa; the pulsating pressure are 2 MPa, 4 MPa, 6 MPa and 8 MPa, respectively; the fracturing frequency are 0 Hz, 4 Hz, 8 Hz, 12 Hz, 16 Hz and 20 Hz, respectively; the pulsating fracturing time is 30 min. The experimental steps are as follows:

First, the coal samples were placed in a vacuum drying oven, vacuumed and heated at 105 °C for 4 h to dry. After cooling, the dried coal samples were loaded into a tank, then put the tank into the water bath, setting the temperature to 60 °C, and using a vacuum pump to degas the coal samples for 8 h.

Secondly, quickly inject gas with a concentration of 99.99% into the tank. Adjust the gas pressure of tank to make the gas pressure of adsorption equilibrium reach to 1.0 MPa. After the dried coal samples had been adsorbed with the gas, open the tank and measure the amount of the free gas.

Finally, start the pulsating fracturing system, adjust the pulsating pressure and fracturing frequency to each predetermined value and use the different fracturing ways to PHF with the time of 30 min in tank. After the fracturing is completed, test the amount of gas in displacement.

## 3. Results and discussion

### 3.1. Displacement gas component analysis

The displacement gas component of the pulsating hydraulic fracturing is measured by a direct test method. First, the free gas volume ($V_0$) of the dry coal sample is tested, and then the free gas volume (V1) of the coal sample after fracturing is tested, and the Displacement gas component is $V = V_1 - V_0$.

To verify the reliability of the experimental system and measurement method of gas displacement, the displacement gas component was measured using an A5000 gas chromatograph. The content of each gas component was detected, as shown in Fig. 2.

According to the principle of gas chromatograph, the chromatogram of the gas mainly has three peaks, which are $O_2$, $N_2$, and $CH_4$, and their peak area sizes are different. Among them, the peak area of $CH_4$ is the