



Improving the permeability of coal seam with pulsating hydraulic fracturing technique: A case study in Changping coal mine, China

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ARTICLE INFO

Article history:

Received 28 March 2018

Received in revised form 24 May 2018

Accepted 1 June 2018

Available online 5 June 2018

Keywords:

Pulsating hydraulic fracturing

Gas extraction concentration

Water content

Permeability

Mineral crystals

ABSTRACT

To improve the gas permeability of coal seams, industrial experiments of pulsating hydraulic fracturing (PHF) were carried out, and physical properties, including the reasonable fracture radius, gas extraction concentration, water content, permeability, pore and mineral composition of a coal seam, were investigated. The results show that the pulsating peak pressure is the main influencing factor of the fracturing radius, and the free surfaces of the fractured holes and guide holes can realize the directional penetration of the fractured area in the coal seam. The initial gas concentration of the fractured holes and the guide holes are 1.2–1.8 times and 1.5–2.2 times that of the ordinary hole, respectively. The gas concentration decreases with time, and the decay phase of the ordinary hole is approximately 14 days after fracturing, while the fractured holes and guide holes are 38 days and 34 days, and the gas concentrations are stable at 40% and 50%, respectively. The water content is approximately 2%, which is only 1.1 times that of the original coal seam. At the same time, the permeability coefficient of the coal seam increases by 48–217 times. Due to the erosion of pulsating water, the mineral crystals embedded in the coal are transported to the surface to form an erosion hole, which leads to improving the gas permeability of the coal seam by PHF.

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1. Introduction

China has the third largest known coalbed methane (CBM) deposits in the world, amounting to approximately 37 trillion cubic meters (Cai et al., 2013; Zhang et al., 2010; Cheng et al., 2018). However, due to the deposits' complex geological structures and deep burial depths, CBM reservoirs in China are marked by low permeability (Zou et al., 2014; Cheng et al., 2017a; Zhou et al., 2017a), low porosity and high in situ stress (Lu et al., 2017; Wang et al., 2017b), which result in low methane concentrations, reduced gas flow, and rapid concentration decay, thus bringing about coal and gas outburst hazards (Ni et al., 2016; Cheng et al., 2017b).

With the research of coal mine gas control, scholars have reached a certain consensus, that is, through hydraulic fracturing (Tang et al., 2016; Wang et al., 2017a), water injection (Mofazzal

and Rahman, 2008; Li et al., 2016), hydraulic cutting (Li et al., 2014a; Wang et al., 2016; Yan et al., 2016), hydraulic punching (Zhou et al., 2017b; Zhai et al., 2016) and other hydraulic technology (Rageh and Koraim, 2010; Fan et al., 2018; Klammler et al., 2014) to promote coal seam pressure relief, improve the gas permeability of coal seams, and strengthen the pre-pumping coal gas. Hydraulic fracturing technology in many mine applications has achieved very good results. However, in recent years, it is found that in engineering applications, due to the micro porosity, low permeability and high adsorption characteristics of coal seams in China, the fractures of hydraulic fracturing under large flow and high pressure are relatively simple (Zhou et al., 2018), prone to local stress concentration (Kang and Feng, 2012), and large fracturing fluid, which may have an inhibitory effect on gas desorption and migration in the coal seams (Liu et al., 2018; Wang et al., 2018). Therefore, new technologies need to be explored to improve the hydraulic fracturing technology and the efficiency of gas extraction.

Pulsating hydraulic fracturing (PHF) is a new technique based on the traditional hydraulic fracturing to improve the effect of coal seam pressure relief and gas permeability (Li et al., 2013b).

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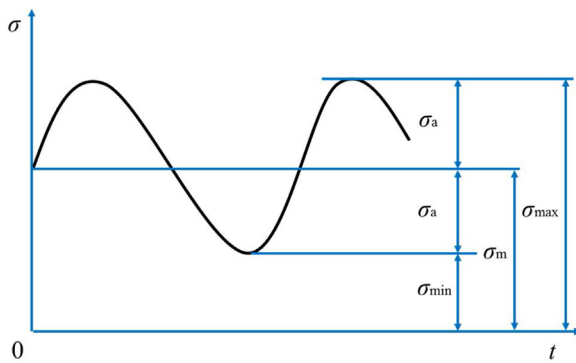


Fig. 1. Wave shape of the pulsating water pressure ($\sigma_{\min}$ and $\sigma_{\max}$ is the minimal and maximum pressure of pulsating load, σ_a is the pressure amplitude and σ_m is the average pressure value).

This technique continuously pulsates water at a certain frequency while it is injected into the coal seams by the peak pressure and the bottom pressure (Fig. 1). The alternating load of “compression-expansion-compression” on the original pore-fracture of coal gradually makes the coal body undergo fatigue damage and promotes the formation of small pore-fractures. In addition, the internal cracks and new fractures in the coal are expanded and extended, forming a fractured network that penetrates each other to provide new flow channels for gas and greatly improves the permeability of coal seams (Zhai et al., 2015). Engineering practice has proven that the technology has a greater advantage in improving the effect of coal fissure expansion; the pulsating pressure is safe and reliable, with a broad application prospect (Xu et al., 2017; Ni et al., 2015).

The pulsating load is applied earlier in water injection technologies of coal seams and petroleum reservoirs. Zhao (2008) proposed a variable frequency method for coal seam water injection, with a pulsating pressure of 0–15 MPa, to achieve pulsating water fracturing with a high pressure and form a new interrelated pore-fracture network within the coal seam. Lin et al. (2011) studied the propagation law of pulsating pressure in fractures and the effect of coal seam pressure relief; they found that pulsating hydraulic fracturing can cause some of the physical quantities of coal to alternately change, clearing the pores and improving coal seam permeability. Zhai et al. (2011) analyzed the characteristics of coal fatigue damage by the high pulsating water pressure, which indicated that the crack of the coal body is operated by the repeated “expansion-compression” role in the formation of the crack network. Li et al. (2013a) thought that a pulsating water pump provides a good pulsation, which has a reflection-superposition phenomenon, resulting in the local expansion of pulsating pressure and thus breaking the coal. Li et al. (2014b) found that low frequency and low pressure can fully develop the fractures and that high frequency and high pressure can promote the rapid expansion of the main cracks and thus proposed a “double frequency and double pressure” fracturing process.

The above research reveals the mechanism of coal seam fissure expansion and the extension and control law of the PHF from the macro point, promoting the development of the technology. However, during the application of the project, the fracturing radius and the influence range of the PHF is not clear, leading to blind fracturing drilling construction and an unobvious coal seam penetration effect. Numerical simulations and laboratory experiments often present the errors of boundary conditions, material parameters, and other aspects. Therefore, in order to improve the efficiency of PHF in engineering applications, we carried out an industrial experiment of PHF in the coal seam 3 work face 4306 of the Shanxi Changping coal mining company. In this paper, the reasonable

Table 1

Design parameters of the fractured and guide holes.

Holes	Inclination (°)	Azimuth (°)	Aperture (mm)	Depth of hole (m)
Fractured	2	270	125	150
Guide	2	270	125	150

fracture radius, gas extraction concentration, water content and permeability of the coal seam were investigated, and the mechanism of PHF was discussed from the perspectives of pore and mineral compositions. The fracturing radius refers to the distance between the fracturing hole and the guide hole, and the guide hole plays the role of investigating the influence range of pulsating hydraulic fracturing.

2. Industrial experiments of the PHF

2.1. General engineering situation

The Changping coal mine is located in the middle of the Qinshui Coalfield in Shanxi Province, China, as shown in Fig. 2. The mining area is 160.24 km² and is divided into six panels, with two in the north and the rest in the south.

The Changping Mine field contains 4 layers of the coal seam that the region or local area can mine, which from top to bottom are the Shanxi group No. 2 and 3 coal seams and the Taiyuan group No. 8 and 15 coal seams. PHF was carried out in the coal seam 3 working face 4306, the gas content of which is 3.92–23.62 m³/t, with an average of 13.77 m³/t; the original gas pressure is 0.55 MPa; the permeability coefficient of the coal seam is 0.01–0.05 m²/(MPa² d); and the initial velocity of gas dispersion is 14.3–20.6.

2.2. PHF equipment

The PHF equipment mainly includes three parts: a fracturing system, pipeline system and monitoring system, as shown in Fig. 3.

The fracturing system includes a pulsating injection pump, automatic control tank, and inverter. The pulsating pressure is 0–25 MPa; the pulsating frequency is 0–1460 times/min; the output flow is 0–120 L/min; the motor voltage is 660 V, the power is 55 Kw; the motor speed control range is 140–1200 rpm; and the water tank capacity is 1.5 m³.

The pipeline system includes a seamless steel pipe in the borehole and a high-pressure hose outside the borehole with a diameter of 25 mm.

The monitoring system ensures the reading of important parameters such as pressure, water injection flow and time during PHF. The system mainly includes a pressure gauge, flow meter, relief valve group and stopwatch. To control the pulsating pressure, the relief valve is used to control the pressure change of the fracturing system.

2.3. Industrial experiment

2.3.1. Drilling arrangement

The boring arrangement of the PHF is arranged in an alternating form between fractured holes and guide holes. As shown in Fig. 4, the guide holes can play the roles of guiding the crack expansion and investigating the fracturing effect.

According to the actual situation of the roadway, six groups of a fractured hole and guide hole are designed. The design spacing of the first group is 2 m; the design spacing of the second to sixth groups are 3 m, 4 m, 5 m, 6 m and 8 m.

The design parameters of the fractured and guide holes are shown in Table 1, and the process overview of the PHF are shown in Table 2.

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