Journal of Natural Gas Science and Engineering 28 (2016) 379–388

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Optimal coal discharge of hydraulic cutting inside coal seams for stimulating gas production: A case study in Pingmei coalfield

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A R T I C L E I N F O

Article history:
Received 9 July 2015
Received in revised form
29 November 2015
Accepted 5 December 2015
Available online 11 December 2015

Keywords:
Hydraulic cutting
Gas drainage
Stress-relaxed range
Gas outburst
Coal discharge

A B S T R A C T

The low permeability of coal seams is the primary difficulty for gas production. Hydraulic cutting is one of the most effective technologies for increasing permeability and stimulating gas production. This paper investigates the hydraulic cutting styles in boreholes and the optimal equivalent borehole diameter after discharging the pulverized coal particles. This paper introduces the hydraulic cutting equipment and cutting styles and determines that the cutting cylinder is the most suitable style for a soft coal seam that is prone to gas outburst. The numerical simulation suggests that the radius of the stress-relaxed range increases quickly when the equivalent borehole radius is small, and the rate slows when the borehole radius becomes large. Then the result was verified by a field experiment in Pingmei coalfield. The gas drainage flowrate and stress-relaxed range greatly increased after initially outputting 2 tons of coal from the borehole, whereas the second outputting 2 tons of coal did not appreciably increase the stress-relaxed range and the flowrate. Too much or too little coal discharge is not optimal, and the borehole radius is recommend to be between 0.3 m and 0.4 m after the hydraulic cutting considering the pros and cons in Pingmei coalfield. The results are helpful for the engineering application of the hydraulic cutting technology, for increasing coal seam permeability, and for stimulating gas production. The method for finding the optimal coal discharge in this paper is also helpful for other coal mines.

1. Introduction

Coal is the primary energy source in the world's economy, and the global coal production in 2014 was 7.9 billion tons, constituting 29.9% of the world's energy source. In some countries, some of the coal seams with high gas content and high ground stress are dangerous to mine, as gas outburst accidents occasionally occur. A gas outburst can erupt a large amount of coal and gas in a short time, the shock wave can cause casualties and widespread damage, and the gas may explode. Currently, many such coal seams are still being mined. For example, more than one thousand gas outburst coal mines occurred in China in 2014. Therefore, preventing gas outburst disasters is very important.

Boreholes are used for coal seam gas drainage to reduce the gas content, which can not only reduce the frequency of gas accidents but also reduce greenhouse gas emissions and make full use of the gas resources. Gas drainage technology is successfully used in high permeability coal seams (Guo, 2013; Rao and Hua, 2013). However, most of the gas outburst coal seams have low permeability, low borehole gas drainage flowrate and low influence range. To improve the gas drainage effect, many technologies for improving permeability have been studied. Loosening blasting technology is used to improve coal seam permeability. An explosive is filled in the borehole, and the coal is loosened by the high-pressure gas produced by the explosion (Suarez et al., 2001; Turcotte et al., 2002). Hydraulic fracturing is also used to generate new fractures to improve the gas flow ability (Koplos et al., 2014). Both loosening blasting and hydraulic fracturing can produce desirable effects when the coal seam is hard, and hydraulic fracturing is widely used

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http://dx.doi.org/10.1016/j.jngse.2015.12.004
1875-5100/

in many countries (Huang et al., 2011a,b; Jeffrey et al., 2013; Mohaghegh, 2013). However, the permeability improvement is not as good in soft coal seams, where the coal flows easily to close the new fractures caused by the loosening blasting and hydraulic fracturing technologies. Additionally, hydraulic fracturing may cause local stress concentrations to induce earthquakes (Ben et al., 2015; Li et al., 2013; McGarr, 2014; Ni et al., 2014). Hydraulic cutting, using a high pressure water jet to cut the coal in the borehole and discharge pulverized coal particles, is another technology for decreasing ground stress and improving coal seam permeability (Feng et al., 2004; Huang et al., 2011a,b; Lei and Wu, 2014; Liu et al., 2014; Yang et al., 2012; Karaman et al., 2015). Generally, the affected range of the hydraulic cutting is smaller than for hydraulic fracturing, but hydraulic cutting does not inject high pressure water into the coal seam. Therefore, no high stress concentration would exist in the coal seam, and thus hydraulic cutting should be much more suitable for soft coal seams. Hydraulic cutting is also used to decrease the stress and eliminate rock outbursts (Cheng et al., 2012).

Usually, the hydraulic cutting borehole and the common borehole are arranged alternately for gas drainage, and the borehole drainage range is one of the key factors for the borehole arrangement. The drainage range of cut boreholes is greatly affected by the coal discharge and the cutting styles, but few related studies have been published. Although the hydraulic cutting technology is successfully used in some coal mines, most borehole arrangements are simply based on operator experience. This paper, according to the condition of the Pingmei coal mine area, will first analyze the hydraulic cutting styles and the applicable conditions. Next, this paper will study the relationship between coal discharge and effect range by theoretical analysis and field experimentation. Finally, the optimal coal discharge for hydraulic cutting will be recommended, which will be useful for the scientific layout of boreholes.

2. Hydraulic cutting technology and the cutting styles

The equipment for the hydraulic cutting technology generally used in underground coal mines is shown in Fig. 1. The high pressure pump produces high pressure water, and the high pressure water is transported to the pressure regulator, which can regulate the water pressure between 0 MPa and 30 MPa. Then, the regulated water is transported to the water swivel connected to the drill pipes; finally, the water transports to the bit along the drill pipes and jets out from a nozzle located in the side of the bit. The pulverized coal particles discharge along the gap between the borehole wall and the drill pipes. The coal around the borehole will move towards the free space to decrease the ground stress and generate new fractures to improve the coal permeability and stimulate the gas drainage (Zou et al., 2014).

There are three cutting styles where the high pressure water cuts the coal around a borehole, as shown in Fig. 2. Fig. 2(a) illustrates the cutting disc style, where the water jet cuts the coal when the bit rotates in-situ. Fig. 2(b) illustrates the cutting plane style, where the water jet cuts the coal when the bit moves back and forth in the borehole, and the bit does not rotate. Fig. 2(c) illustrates the cutting cylinder style, where the water jet evenly cuts the surrounding coal to enlarge the borehole diameter when the bit moves back and forth in the borehole and rotates simultaneously.

The three cutting styles have different applicable conditions. The cutting disc and cutting plane styles are more suitable when the coal seam is hard, and a better stress-relaxed effect with less coal discharge can be obtained (Sarkisov et al., 2000). However, most of the gas outburst coal seams are soft. For example, in China, the coal firmness coefficient f of almost all of the gas outburst coal seams is lower than 0.5, and the coal would much more easily collapse during the high pressure water cutting process and block the discharge gap. Thus, slots of disc or plane cannot be formed in the soft coal seam by hydraulic cutting. The cutting cylinder style is much more suitable for soft coal seams because the moving and rotating of the bit and drill pipes will help to dredge the gap and discharge the pulverized coal particles.

Considering the better stress-relaxed effect of the cutting disc and cutting plane styles, we initially want to cut disc in the target soft coal seam in Pingmei coal minefield. However, the two phenomena of borehole block and spray appear alternately during the cutting process, and the sprayed gas will always cause the gas concentration overrun. When cutting disc in the soft coal seam, the drill pipes and the bit rotate in-situ, and the enlarged disc and the high pressure water jet will cause coal collapse irregularly and block the borehole. Thus, the coal, gas and the water can no longer flow out, and the gushing gas will gradually improve the gas pressure in the borehole. The blocked borehole will be opened once again when the borehole gas pressure is high enough, and a large amount of coal and gas erupts from the borehole in a short time, causing borehole spray, which is very dangerous for the coal mine. The borehole spray usually happens after the borehole block.

Although the stress-relaxed effect of cutting cylinder style is not as good as cutting disc, the borehole block time is obviously less than that of the cutting disc due to the moving and rotating of the bit and drill pipes. Therefore, in the Pingmei coal mine area, the cutting cylinder style is applied mostly in engineering, so the following theoretical and field experiments are carried out according to the style.

The equivalent radius of a borehole would be 0.5 m after 1 ton of

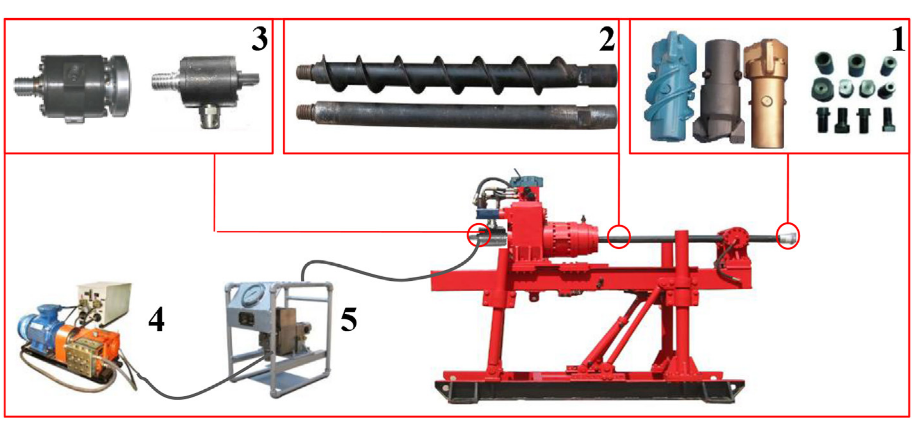

Fig. 1. Key equipment for hydraulic cutting of a borehole in a coal seam.