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Variation of methane adsorption property of coal after the treatment of hydraulic slotting and methane pre-drainage: A case study

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ABSTRACT

The variation of methane adsorption property of coal after the treatment of hydraulic slotting and methane pre-drainage was investigated by testing the seven coal samples obtained from the coal seam #10 of Yangliu Mine. The methane isothermal adsorption experiments were conducted to measure the adsorption constants and the Mercury Injection Capillary Pressure (MICP) and Nitrogen Gas Adsorption (N_2GA) were organically combined to depict the pore size distribution (PSD). It is revealed that non-significant variation occurs in the various indexes of proximate analysis. With the increase of borehole distance, adsorption constant *a* presents a tendency toward enlargement and adsorption constant *b* has an opposite variation tendency, which is consistent with the change tendency of the curvatures of the curves. Remarkable variation occurs in pore size distribution of coal samples and adsorption pore proportion decreases from 55.38% to 33.27% with the decrease in borehole distance. The curves of coal parameters (a, b, X_{abs}) present a characteristic of boundness and nonlinearity and the variation amplitude is "gentle-drastic-gentle", which obeys the Boltzmann equation. There exists a significant sectionalized feature after the treatment of hydraulic slotting and methane pre-drainage. That is, region of significant influencing, region of transition and region of non-significant influencing. The gas pressure decreases and the effective stress increases after the treatment, which controls the adsorption property of coal. Hydraulic slotting and methane pre-drainage are sequential processes and each is a dominate factor that changes the methane adsorption property in relevant process. The results can provide reliable theoretical support for the application of hydraulic slotting.

1. Introduction

The simultaneous exploitation of gas and coal, essential components of Chinese current energy structure, is a great demand for safe, efficient and clean utilization of the coal resource (Liu, 2009; Wang, 2010, Wang and Cheng 2012). Nevertheless, gas disaster, a major restriction on achieving full potential of the two resources, tends to be increasingly prominent in process of deep single high-gassy coal seam mining(Wu et al., 2011; Wang et al., 2014). In recent years, hydraulic technology, characterized by desirable artificial permeability enhancement and typically represented by hydraulic slotting and hydraulic fracturing, gradually becomes one of the principle measures to realize coal seam modification and efficient mining (Lu et al., 2009, 2010; Shen et al., 2012; Lin et al., 2012; Zhao et al., 2012; Zhai et al., 2013; Li et al., 2013a). Hydraulic fracturing, widely applied in improving production of oil-gas well, is a measure that plenty of water mingled with fracturing fluids is pressed into rock stratum to release the natural gas. Nevertheless, there exists substantial difference between coal and rock and the fractures generated by hydraulic fracturing are readily closed, which affects the effect of gas drainage. By contrast, hydraulic slotting is a method of pressure relief, which is relatively advantageous for generation and expansion of fractures. A considerable amount of research has been conducted during the last few decades seeking to better understand the details of mechanism and effect of hydraulic slotting. A combination of simulation experiment and field test was applied to investigate the variation of coal mass subjected to the influence of hydraulic slotting. The findings revealed that hydraulic slotting could substantially enlarge porosity and fracture connectivity rate, which improved the coal seam permeability and gas drainage efficiency significantly (Lin et al., 2012; Lu et al., 2010). Li

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et al. (2009) established a dynamic damage model to describe the coal mass dynamic damage property under transient dynamic load and flexible impact from high-pressure pulsed water jet. Lin et al. (2011) developed a gas flow capillary model within depressurized range of hydraulic slotting and obtained an outburst-eliminated criterion at any point in the affected zone of hydraulic slotting and the total outburst-eliminated period in pressure relief zone. From the aforementioned analysis, it is obvious that the research to date has tended to focus on the effect of hydraulic slotting on mechanical and seepage behaviors of the coal mass around the slots from a perspective of effect of gas drainage, water jet impact property and flow characteristics of depressurized gas. However, far too little attention has been paid to variation of methane adsorption property of coal after the treatment of hydraulic slotting and methane pre-drainage.

Numerous studies have focused on the description of characterization of coal mass pore structure. Jiang et al. (2011a) have elucidated the pore structure characterization of outburst-prone coal specimens and its influence on gas outburst. An et al. (2013) have selected eleven coal samples for petrographic analysis, methane adsorption test and CO_2 adsorption test from Northern China to expound the effect of small micropore on methane adsorption. It is demonstrated that the volume and surface area of micropore have stronger effect on Langmuir volume (V_L) than Langmuir pressure (V_p). The effects of igneous sills on the physical properties of coal and gas occurrence were investigated by Xu et al. (2014) and the experimental methods are scanning electron microscopy (SEM), mercury porosimetry and gas adsorption. Research conducted by Xue et al. (2012) and Song et al. (2013) revealed the pore structure characterization of tectonic coal in various regions and its effect on adsorption capacity. Besides, X-ray micro CT, low-field nuclear magnetic resonance (NMR) and small-angle/ultra-small-angle neutron scattering (USANS/SANS) were employed to determine coal pore size distribution and its crucial role in interpretation of coal/rock permeability and connectivity (Yao et al., 2010; Clarkson et al., 2012; Tiwari et al., 2013; Li et al., 2013b). From the previous research achievements analyzed above, much more concentration has been placed on coal mass pore structure characterization of various regions and coal ranks via multifarious test methods instead of organic combination of those methods.

In this paper, given the sensitivity and accuracy of experimental methods, N_2GA and MICP are organically combined to depict pore size distribution features and variation of adsorption property of coal mass subjected to hydraulic slotting and methane drainage, which could provide reliable theoretical support for field application of hydraulic slotting.

2. Fundamentals of hydraulic slotting

High pressure water jet, a novel technique, is rapidly developed since the 1970s and has achieved a wide application in various fields from automotive and aerospace to medical and food industries (Etchells, 1997; Summers, 1995; Folkes, 2009).The mining industry is one of the earliest users of the technology due to its extreme simplicity and flexibility but the significant commercial application is hardly ever realized at the working face (Yao, 1991). Generally, high pressure water jet is mainly employed in three mining processes, namely roadway excavation, hydraulic mining and gas pre-drainage. In the respect of exploring the availability of using this technique as a rapid, highly efficient and economical method in coal and rock excavation, Liu et al. (2014) established a damage model of rock breaking with a conical cutter under the assistance of front and rear water jet via the SPH and Lagrange algorithm and underlined the rear water jet (RWJ) was better than the front water jet (FWJ), contributing to lowering cutting forces, prolonging the life of cutter and improving the efficiency of roadway excavation. Besides, a new drilling method combing with abrasive water jet was proposed for increasing the drilling depth and reducing the thrust force and torque (Li et al., 2000; Li et al., 2013c; Tang et al., 2014). As for hydraulic mining, the Borehole Hydraulic Coal Mining System (BHCMS) is a feasible method characterized by fragmentation of coal seams and removal of coal slump through a drilled hole by hydraulic or air-lifting method (Xia et al., 2008).

Recently, the hydraulic slotting plays an important role in solving the safety problems associated with gas drainage and outburst elimination (Shen et al., 2012; Lu et al., 2010, 2011). The developed high pressure water jet slotting is shown in Fig. 1.The composition of the system and the function description of the major components is listed in Table 1.

The procedures of hydraulic slotting can be simply summarized as two parts: high pressure water jet formation and slotting. As is depicted in Fig. 1, water pressurized by emulsification pump flows into the dual-power drill bit through the control valve, sealing rotator and drill pipe. The pressurized water is compressed by the nozzles embedded in the dual-power drill bit and then ejects out, forming high pressure water jet (see Fig. 2). The pressure of the water is 20~35 MPa and the rock with firmness coefficient of 6 is easily cut through (see Fig. 3).

The second part can be illustrated in Fig. 4. In general, the procedures are as follows: (1) a borehole is drilled. (2) the drill pipe is rotated and the high pressure water impacts the coal mass. The crushed coal is discharged. (3) pull the drill pipe towards the orifice of the borehole and slot the coal seam. The distance of the adjacent slots is 1~1.5 m.

It can be deduced from Fig. 4 that the stress state of the coal mass around the slots changes during the formation of the slots (Lu et al., 2011). The change of stress is well consistent with the variation of the permeability of the coal mass (Wang et al., 2013; Ye et al., 2014). The gas drainage efficiency can be improved if the permeability is enhanced (Wu et al., 2010; Wang et al., 2012a). Nevertheless, it has not been fully understood that the microscopic mechanism of variation of adsorption property after the treatment of hydraulic slotting and methane pre-drainage. Thus, the following section aims to disclose the variation characteristics via a combination of field tests and relevant laboratory experiments.

3. Experimental

3.1. Experimental background

Yangliu Colliery, located in Suixi County of Anhui Province, China and affiliated with Huaibei Mining (Group) Co.,Ltd, is outburst-prone with a production of 1.8 Mt/a (see Fig. 5). Yangliu Colliery contains nine coal seams, of which coal seams #8_2 and #10 are the most mineable. Coal seam #10 has an average thickness of 3.19 m. The absolute gas pressure of coal seam #10 is 2.0 MPa, above the critical value of 0.74 MPa, and its minimum of firmness coefficient f is 0.36, below the critical value of 0.5, which indicates that the coal seam possesses the fatality of outburst (State Regulation of Coal and Gas Outburst Prevention and Control of China (2009)). The floor elevation of working face in mining area #106, located in northeastern, ranges from −588 m to −750 m. Overall, the mining area #106 is a uniclinal structure inclining eastward and the magmation is weak. The ventilation pattern is U-shaped and the mining is fully mechanized. The free falling is applied to manage the roof of coal seam. The gas control pattern is “pre-drainage by the layout of boreholes cross the coal seam in floor roadway (designed for shielding roadway tunneling) + pre-drainage by the layout of boreholes down the coal seam (designed