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A case study of gas drainage to low permeability coal seam

Zhang Li [a], Zhang Hui [b,*], Guo Hao [c]

[a] China Coal Strategies Research Center & China Center for Occupational Safety and Health, Beijing 100713, China
[b] Institute of Public Safety Research/Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[c] College of Resource and Safety Engineering, China University of Mining & Technology, Beijing 100083, China

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ABSTRACT

Gas drainage at low gas permeability coal seam is a main barrier affecting safety and efficient production in coal mines. Therefore, the research and application of drainage technology at low permeability coal seam is a key factor for gas control of coal mine. In order to improve the drainage effect, this paper establishes a three-dimensional solid-gas-liquid coupling numerical model, and the gas drainage amounts of different schemes are examined inside the overburden material around the goaf. The Yangquan mine area is selected for the case study, and the gas movement regularity and emission characteristics are analyzed in detail, as well as the stress and fissure variation regularity. Also examinations are the released gas movement, enrichment range and movement regularity during coal extraction. Moreover, the gas drainage technology and drainage parameters for the current coal seam are studied. After measuring the gas drainage flow in-situ, it is concluded that the technology can achieve notable drainage results, with gas drainage rate increase by 30%–40% in a low permeability coal seam.

1. Introduction

Mine gas accidents are some of the most serious disasters in coal mines [1,2]. Mine gas extraction in China is difficult due to the characteristics such as micro-porosity, low-permeability and high adsorption of coal seams [3]. Hence, coal seams in most Chinese coal mines are difficult to drain in coal seams with low permeability. This makes it difficult to conduct pre-drainage, and the drainage efficiency is quite low [4,5]. Gas drainage in low permeability coal seam is a main barrier affecting safety and efficient production in coal mines. Therefore, the research and application of drainage technology in low gas permeability coal seam is a key technical problem in coal mine gas control.

Wang et al. studied the Klinkenberg effect of the coal seam and raised an improved model [4]. Alam et al. studied the change of permeability induced by the change of confining pressure [6]. Wang et al. studied and utilized the drainage technology for high gas and low permeability [7]. Guo et al. also studied the method to predict the permeability of the coal seam [8]. Through experiments, Chen et al. discussed the development of damage and permeability in coal [3]. There are also other scholars who studied the coal seam permeability [5,9–18].

Since the gas drainage is dramatically influenced by gas permeability, many scholars have thought about the coupling effect of different physical phases, such as solid and gas [14,16–22]. What's more, the temperature is also discussed and studied [23–25]. All studies indicate that numerical modelling is an efficient and effective way to study the gas-related problems such as gas drainage technology in low permeability coal seams.

Many in-situ engineering applications of gas drainage have also been conducted. Zhang et al. studied the mine ventilation network and gas drainage zone by simulation and laboratory modelling [26]. Clarkson reviewed and analyzed the unconventional gas wells production, and compared different practices [27]. Wang et al. studied the possibility of directional drilling technology used for gas drainage in Australia [28,29]. Gas drainage is also proven to be an ideal way to reduce the chance of coal and gas outburst in coal mines [30]. Though there are some basic principles for gas drainage in coal mines, different schemes and procedures are still necessary due to the difference of geological conditions.

In this paper, the solid-gas-liquid coupling model will be employed to study the permeability of the coal seam in a coal mine in Yangquan coal area, and the gas drainage procedures will be addressed based on that. At the same time, the measurements in-situ will help to test the coupling model and the drainage technology utilized in the coal mine.

* Corresponding author.
E-mail address: hndfzhanghui@gmail.com (H. Zhang).

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2. Solid-gas-liquid coupling model

2.1. Measuring method for properties of low permeability coal seam

The initial speed of methane emission ($\triangle p$) is one of the predictions of risk indicators in coal and gas outburst. It can reflect the speed of coal body containing gas radiation and use WT-1 gas diffusion velocity test system to measure. In addition, the competent coefficient of coal showed soundness of coal. The methane adsorption constants on coal were measured by the isothermal adsorption instrument, to obtain adsorption constants *a* and *b*.

2.2. Analysis of gas distribution patterns by using the coupling model

Surface borehole well drawing gas is mainly gas extraction of mining face goaf. However, gas reservoir and flow patterns depend on the motion features and the movement rule of overlying strata. Also known are the moving cracks in overburden, which can be divided into three vertical zones and three cross areas caused by mining. The three vertical zones are, from bottom to top, caving zone, fault zone, and bending zone along the roof of goaf in the vertical direction. The three cross areas are divided into solid, separation area and recompaction zone along the direction of the advancing work face. With the failure of floor caused by mining, there are "the next three-zones", the goaf floor from top to bottom respectively including direct damage, effect and small changes zone. The cracks in rock strata on the working face goaf provide channel space for gas reservoir and transportation, and make it possible to reach the surface borehole well for gas extraction. The changes of goaf gas flow field and its likes were analyzed by 3D model that COSFLOW simulation of working face to the vertical stress distribution.

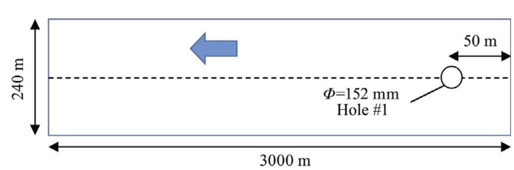

Fig. 1. Plan view of the working face.

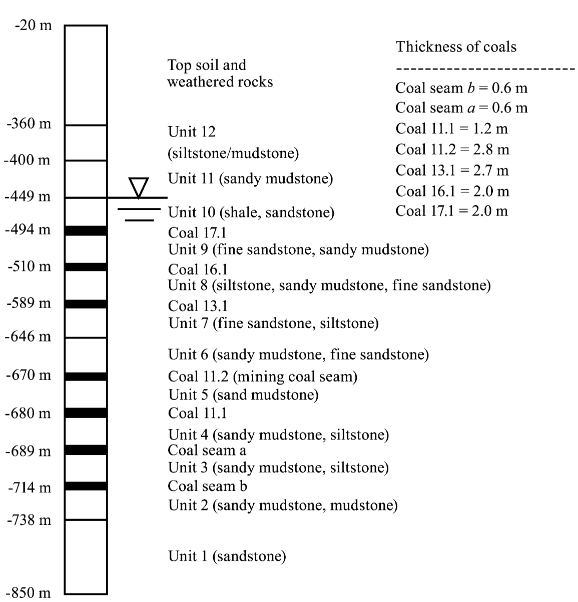

Fig. 2. Geologic log of the model.

The working face simulated is 240 m wide, 3000 m long. The mining #11.2 coal seam is on average 2.8 m thickness, with a dip of about 13–16° on the working face. Fig. 1 shows a plan view of the panel. Fig. 2 presents the geological log of the model. And Table 1 displays the different schemes for the modelling.

The simulation results of panel methane emission are shown in Fig. 3, in which the value of face methane emission is between 9.2 and 10.5 m^3/min, which approximately corresponds to the average value of methane emission that is 9.6 m^3/min measured in the working face.

For the specific circumstances of the measured face, the basic distribution pattern of goaf was established from a CFD model. The data which was used in the model was collected from the coal mine field. The result of COSFLOW and the experience of the previous CFD modelling of methane flow are reported. The basic model of the working face, which was 500 m away from the open-off cut, was used to study methane flow in goaf. The width of the basic model is the 240 m, and the height of goaf in fracture development zone is 100 m. The height of seam and roadways is 3.0 m, and the width of all roadways is 4.0 m. The elevation of return roadways is 60 m, higher than the machine roadways, and face elevation is the same with the open-off cut. Those geometric characteristics of the basic model are shown in Fig. 4, which corresponds with the actual situation.

There are two groups of ground well drilling to the goaf in the model. One group is running along the center line of the working face, and the other is 75 m from the return roadways. Those drilling wells can be opened and closed individually. The first hole is 50 m away from the working face open-off cut; the interval in the rest of boreholes is 150 m. Table 2 provides detailed information on the modelling parameters.

Fig. 5 shows the methane distribution in the working face. It indicates that gas concentration in the upper corner ranges between 2% and 6%, which fits with site measurements. Fig. 5 also indicates that due to the low density of methane, there is a small concentration at the upper part of the inlet roadway. According to the simulation, it is better to arrange for drilling the holes around the inlet roadway from the ground surface.

2.3. Gas migration and emission regularity in low permeability coal seam

During extraction, abutment pressure ahead of the working face will subject the coal to a different degrees of deformation, and coal permeability changes with its deformation. This affects the coal gas deposit and transport conditions in the coal, thus influencing the drainage effect of coal seam gas drainage hole.

Table 1
Percentage gas content of coal of different schemes.

Scheme	Description	Coal 11.1	Coal 11.2	Coal 13.1	Coal 16.1	Coal 17.1
1	One borehole in the goaf, low gas content in coal 11.1 and 11.2	3.84	3.84	10.4	9.6	8.0
2	One borehole in the goaf, high gas content in coal 11.1 and 11.2	4.6	4.6	10.4	9.6	8.0
3	One borehole in the goaf, low gas content in coal 13.1 and 16.1	4.6	4.6	9.3	9.3	8.0
4	No borehole, high gas content in coal 11.1 and 11.2	4.6	4.6	10.4	9.6	8.0