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Gas emission quantity prediction and drainage technology of steeply inclined and extremely thick coal seams

Liu Cheng [a,b,c,*], Li Shugang [a,b], Yang Shouguo [a,b]

[a] College of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an 710054, China
[b] Key Laboratory of Western Mine Exploitation and Disaster Prevention and Control of Ministry of Education, Xi'an 710054, China
[c] Chongqing Research Institute of China Coal Technology Engineering Group, Chongqing 400039, China

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ABSTRACT

Gas emissions of workfaces in steeply inclined and extremely thick coal seams differ from those under normal geological conditions, which usually feature a high gas concentration and a large emission quantity. This study took the Wudong coal mine in Xinjiang province of China as a typical case. The gas occurrence of the coal seam and the pressure-relief range of the surrounding rock (coal) were studied by experiments and numerical simulations. Then, a new method to calculate the gas emission quantity for this special geological condition was provided. Based on the calculated quantity, a further gas drainage plan, as well as the evaluation of it with field drainage data, was finally given. The results are important for engineers to reasonably plan the gas drainage boreholes of steeply inclined and extremely thick coal seams.

1. Introduction

It has long been an issue to safely and efficiently exploit the coal from steeply inclined and extremely thick coal seams. To solve problems occurring in normal extraction methods, such as the low mining efficiency, expensive cost and high roadway drivage ratio (the ratio of the length of the roadway to the amount of coal produced within a certain period), the fully mechanized sublevel caving method through a horizontal slice of thick coal was provided [1,2]. However, this method cannot escape the poor extraction environment. It is difficult to arrange hydraulic supports along coal seams with a large angle. In addition, the extraction may produce a low recovery ratio, leading to more gas emission [3]. A large amount of gas stored in coal or desorbed in tunnels will increase the risk of outburst and gas explosion [4–10]. Gas content of 8 m^3/t is considered to be the outburst limit and gas concentration of 5%-15% is the explosion limit. Therefore, gas hazards become much more serious and complicated by this method compared with normal methods.

For the past few years, studies on the gas hazard and its prevention during the mining of steeply inclined and extremely thick coal seams have been rarely conducted. Most research focused on the caving-range calculation of the upper rock or coal, which is usually used by engineers to eliminate roof collapse and to keep the roadway stable [1,11–15]. With respect to the gas control method or technology, there are only a few results on one of two characters: either steeply inclined coal seams or extremely thick coal seams. No studies consider these two factors to design the gas control or drainage system [16,17]. Chen once used specialized gas drainage methods to reduce the gas hazard risk in steeply inclined coal seams [18]. Yuan et al. employed numerical simulations and field experiments to investigate the influence of extremely thick rock on the gas occurrence of underlying coal seams [19–22]. When the steeply inclined and extremely thick coal seams are extracted, the rock and coal around the mining area will generate breaking or strain, which changes fields such as the stress field and the fracture field. Finally, a new gas distribution will be produced that differs from gently inclined coal seams.

How to calculate the gas emission quantity in the workface and to determine the main source of gas emission is the basis of designing the gas drainage plan. This study took the 45# coal seam in the Wudong coal mine as the research objective and put forward a new method to predict the gas emission quantity for the steeply inclined and extremely thick coal seams. The research route is shown in Fig. 1. The gas occurrence and numerical simulation provide a distribution law of gas content and the pressure-relief range, and through the new model, this law determines the result of the gas emission quantity, providing a reference for the drainage plan design.

* Corresponding author at: Chongqing Research Institute of China Coal Technology Engineering Group, Chongqing 400039, China.
E-mail address: lc.cqccri@163.com (L. Cheng).

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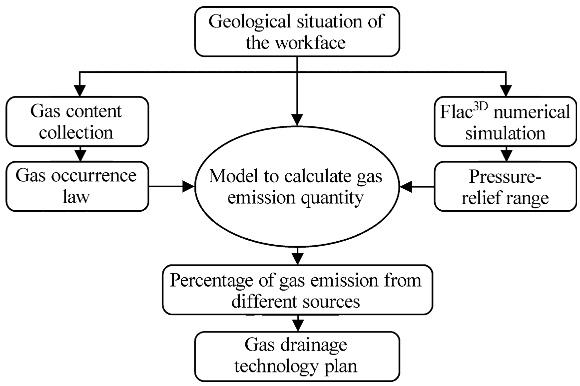

Fig. 1. Research route.

2. Geological background

2.1. Regional geology

The Wudong coal mine is located in the Xinjiang coalfield, which is approximately 10.8 km long in the east-west direction and 0.7–2.7 km long in the north-south direction. The area is approximately 19.9357 km^2. There are several geological structures in this region. The Qidaowan Anticline and the Badaowan Syncline are two main structures that dominate the coal occurrence in this area (Fig. 2). The mining workface is in the 45# coal seam of the +575 m level with a length of 30.6 m (perpendicular to the strike direction of the coal seam). This workface has a simple geological structure, but it has a large dip angle, approximately 45°, and a large thickness (approximately 22.5 m).

2.2. Gas occurrence

The law of gas occurrence is the foundation of the gas emission calculation that provides information about the gas content for a given depth. According to the ISO 17246:2010 (coal, proximate analysis) and the MT/T752-1997 method for determining the methane adsorption capacity in coal, the proximate analysis was conducted, and a Langmuir isotherm at 30 °C was drawn. The experimental results of 45# coal samples are listed in Table 1. With actual data of gas content in other places with different depths, the relationship between the gas content and the sample depth can be obtained (as shown in Fig. 3). According to Fig. 3, the mathematical relationship between the gas content and the sample depth can be obtained:

$$W = 0.0163H - 0.3195 \tag{1}$$

where W means the gas content, m^3/t; and H means the sample depth, m.

Based on Eq. (1), the gas content gradient can be obtained, which is 0.0163 m^3/(t·m). Then, with the actual gas content at the +500 m (6.43 m^3/t), the gas content at the +575 m level can be obtained (5.21 m^3/t). In accordance with China's national standard (AQ 1024-2006 specification for identification of coal and gas outburst mine, State Administration of Work Safety of China), if the gas content of a coalbed is more than 8 m^3/t (an empirical limit based on the gas content statistics in several outbursts in China), the coalbed is considered to have high outburst risk. From Fig. 3, we can find the gas content of this coal seam has exceeded 8 m^3/t, indicating a high gas outburst risk for mining. Thus, gas drainage should be applied to eliminate the high energy stored in coal seams before any coal extraction begins.

3. Numerical modeling and determination of the pressure-relief range

3.1. Geometric and mechanical characteristic setting

The mining-induced stress distribution, fracture distribution and their variation with mining activity were investigated with the FLAC^{3D} software [23–27]. The numerical simulation took the 45# coal seam in the Wudong coal mine as the design prototype, and a model with 500 m × 300 m × 250 m (Length × Width × Height) was constructed. The working face was set to be mined along the strike direction (i.e., the Y direction). The model was composed of 411,000 elements and 429,328 nodes, as shown in Fig. 4. Based on the experimental results of coal/rock core mechanics from the geological prospecting report of the Wudong Coal Mine, the initial properties of coal/rock were set as listed in Table 2.

In Fig. 4, the upper boundary of the cube was a pressure boundary with a load of 1.26 MPa (50 m of rock), while the other five boundaries were fixed in displacement. The simulation proceeded according to the Mohr-Coulomb failure criterion. As the mining began, the workface in the 45# coal seam was extracted along the Y direction, and the mining-induced stress distributions of the roof and floor were recorded.

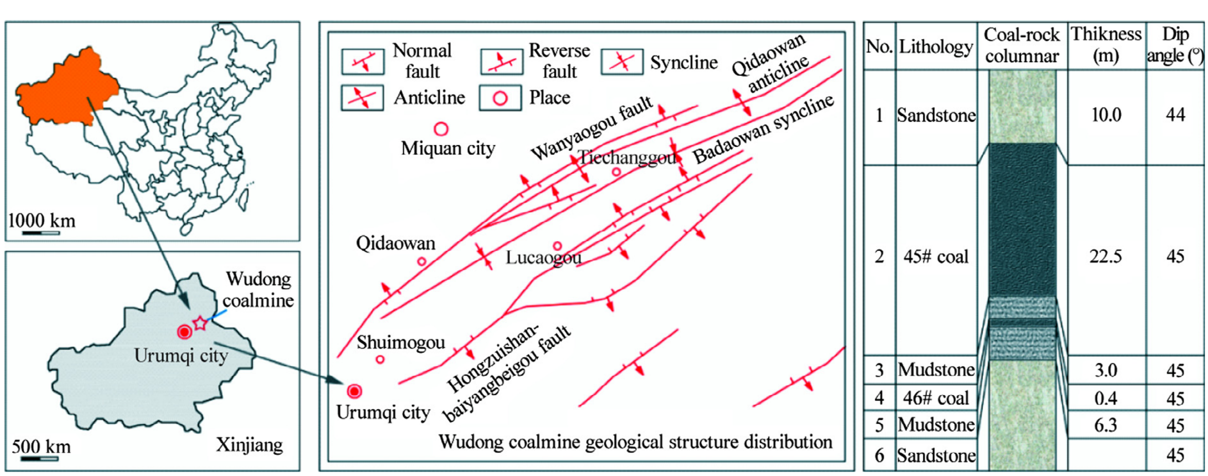

Fig. 2. General situation of the Wudong coal mine.