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Researches and applications on geostatistical simulation and laboratory modeling of mine ventilation network and gas drainage zone

Haoran Zhang[a,*], *Lluis Sanmiquel Pera*[a], *Yaojiang Zhao*[b], *Vintro Sanchez Carla*[a]

[a] *Department of Mining Engineering and Natural Resources, Universitat Politècnica de Catalunya, Av. Bases de Manresa, 61-73, Manresa 08242, Barcelona, Spain*
[b] *Department of Safety Engineering, Taiyuan University of Technology, No. 79 West Yingze Street, Taiyuan 030024, Shanxi, China*

ABSTRACT

The mine disaster of gas at working face and goaf creates a risky working environment for miners, and causes a mass of casualties in mining industry around the world. The key points of resolving the gas problem are to properly increase fresh air volume in ventilation network, exactly determining the gas emission zone, and implementing a reasonable gas drainage plan. This article provides multiple gas control methods with the aim of improving the gas drainage knowledge and techniques. Both of the CFD model and the mini mine gas emission zone based on U + L type ventilation network are established, and the gas distribution and movement rules of working face and goaf are accurately obtained during the numerical and laboratorial simulation experiments are performed. The results reveal that gas problems at working face and goaf cannot be effectively resolved by only increasing the air volume; instead, it must be combined with optimizing the ventilation network and excavating special gas drainage tunnels. The experimental results also demonstrate that the most effective gas extraction spot constantly varies with the zone where mining activities are performed. Therefore, the arrangement of gas drainage tunnels is determined according to the obtained rules and experimental results. The field verification results show that the layout of the drilling boreholes is rational and effective; the gas drainage quantity is reliable and stable, which indicates that it is valid and feasible to arrange the layout of gas drilling tunnels based on the combination experimental results of numerical simulations and laboratory tests.

Keywords: Gas hazard; U + L ventilation; Numerical simulation; Laboratory test; Gas drainage

1. Introduction

High concentration gas in deep goaf and mining adjacent layers continuously pours into working as the air pressure in different parts of underground mine is imbalanced (Noack, 1998a,b). For example, an outburst ejected over 2000 tones of oil-bearing sandstone with 900,000 m^3 of gas at the 554 m depth in the air shaft of Haishiwan Colliery in 1995 in China; a gas and dolomite outburst took place in Rudna copper mine in 2009, which was the most serious natural hazards in Polish copper mines (Mirosław, Mariusz). Strata gas problems have created severe difficulties for the mining industry all over the world, leading to high expenditures and intensity research efforts, and determined attempts to enhance the various ventilation and gas drainage techniques (Leszek and Lunarzewski, 1998; Sander and Connell, 2012). Meanwhile, gas research is thriving in recent years, and gas drainage technology will continue to be a growing industry over the coming

* Corresponding author. Tel.: +34 698302705; fax: +34 938777202.
E-mail address: haoranbasketball@gmail.com (H. Zhang).
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decades in many countries (Díaz Aguado and González Nicieza, 2007).

The key points of resolving the gas disaster are constantly optimizing the ventilation network, exactly determining the gas emission zone, and implementing a reasonable gas drainage plan. On the one hand, working areas in underground mines have become further and deeper from several inlets and exhaust shafts while mining activities are performed (Widodo et al., 2008). A reasonable ventilation network exerts a long-term effect on mine safety and economic benefits. On the other hand, the zone of deformation, known as the 'gas emission zone' of a longwall mine, hosts the sources of longwall gas providing gas to the boreholes, leads to in-mine emissions (Noack, 1998a,b), and interferes with the stability of boreholes. Therefore, determination of the size of the gas emission zone, the locations of gas sources within, and especially the amount of gas retained in those zones is one of the most crucial steps for designing a successful gas control strategy and an efficient ventilation system in longwall coal mining (Özgen Karacan et al., 2012).

Safety mining technologies including field investigation, numerical simulation (Hamm and Sabet, 2010) and laboratory experiments (Packham et al., 2012) have also been improved over the past decade. However, even if the size (height) of the gas emission zone can be estimated globally using various methods or assumptions, it is not uncommon that gas emission predictions may be under- or over-estimated due to the lack of sufficient spatial information defining the quantity and location of the gas sources in the overlying strata (Kurnia et al., 2014). Therefore, multiple gas control strategies should be developed, including optimizing the ventilation network, preventing goaf spontaneous combustion, enhancing gas risk management, determining the gas emission zone, and implementing a reasonable gas drainage plan.

2. Statement of the problem and research methods

2.1. *Statement of the problem*

Liliu mining area, located in Shanxi province, China, contains 15 coal seams with the average thickness of 2.45 m. Coal seam #4 in Shaqu mine with large gas content (approximately reaches up to 30 m^3/t) has created severe difficulties in mine safety and production. The working face length and the strike length of coal seam #4 are 200 m and 950 m respectively. Extracting method is longwall retreating extraction with U type ventilation network. It is obtained that gas drainage quantity of 14,205 working face of coal seam #4 can approximately reach up to 100 $m^3\,min^{-1}$ (Table 1). A number of gas drainage methods have been performed by Shaqu coal mine for the purpose of mine safety. However, the results of goaf gas drainage have been far from satisfactory. A great deal of gas fails to extract, but has directly flow into the goaf instead, which constantly leads to the overrunning of gas concentration in upper corner. This exerts a negative influence in mine safety and working schedule. Gas emission of Shaqu coal mine involves various physical and human factors including the geological conditions, the degree of strata destruction, permeability of the coal seam, the scale coal occurrence, mine ventilation quantity and method of the mining activities, etc.

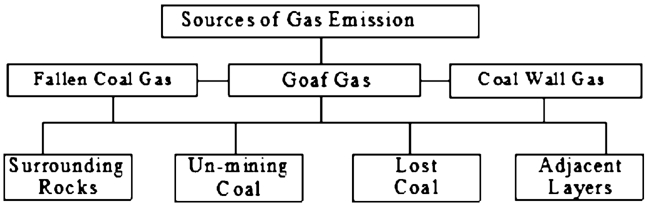

Fig. 1 – Flow chart of gas sources.

2.2. *Research methods*

Mining activities disturb existing stress equilibration in the rock mass and create variations to the structural attribute of the affected strata. The characteristic fracture process zones are opened and developed by existing and mining-induced fractures (Lunarzewski, 1998). A mass of gas emission can be expected after the coal mining, loose floor and roof strata. The specific places where coal seam loose occurred are determined by multiple factors including physical properties of seam system, the geometry of the longwall panel, the volume of the trapped gas sources, and the destructive condition of the relaxed zone (Noack, 1998a,b). Fig. 1 shows gas sources derived from different parts of the coal mine.

In fact, the highest gas emission deprives from working face and goaf since it constantly and alternately destruction and re-compaction (Hao et al., 2012). Therefore, the most effective and accurate gas drainage borehole can be expected to pave in this zone (Zhang et al., 2012). Based on problems mentioned above, multiple research methods will be adopted to determine the most effective gas drainage zone (gas emission zone). The numerical simulation experiments and laboratory method (Zhang et al., 2011) was combined with core data, including thickness, depth and inclination of major coal and non-coal formations, and obtained from field measure.

3. CFD numerical simulation

3.1. *Numerical simulation*

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. FLUENT is a finite volume computational fluid dynamics code that solves the Navier–Stokes equations for both incompressible and compressible flows. An elementary calculation of transfers to and from the neighboring volumes is performed for each surface of the mesh. These exchanges depend on the incoming and outgoing flows and on the intrinsic characteristics of the flow regions (Chanteloup and Mirade, 2009). A key feature of this code is its user-defined function capability, or UDF, which allows the user to develop stand-alone C programs that can be dynamically linked with the FLUENT solver to enhance the standard features of the code. Applying the fundamental laws of mechanics to a fluid gives the governing equations for a fluid (Travis et al., 2013). The conservation of mass equation is:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho v) = S_m \quad (1)$$

where ρ is density, t is time, v is speed, S_m is the continuous phase mass including dispersive second constituent and user-defined source. Eq. (1) is the general form of mass conservation equation for both incompressible and compressible flows. The