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Abnormal gas emission in coal mines and a method for its dilution using ventilator control

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A B S T R A C T

During coal mining, gas concentration transfinite usually occurs when gas emission increases, and in this paper, we analyzed the reasons that lead to an increase in gas emission. Based on field investigation data, three types of gas concentration transfinite were identified: transitory, continuous, and abnormal fluctuation gas emissions. We draw gas concentration change curves for each type. In the presence of gas concentration transfinite, wind quantity can be increased by varying the frequency of the mine ventilator to dilute the gas. In this paper, we propose two methods for varying the frequency of the ventilator, using a frequency-concentration (*f-w*) control of the follow-up wind quantity and automatic control of the curve value. The transfer function of the *f-w* control method and a database of ventilator characteristic curves at different frequencies were established. Using the Da Liuta mine ventilation system, an experimental model for wind quantity adjustment was setup in a ventilation network branch using a variable-frequency ventilator. Considering the fire and explosion risks associated with the real gas, carbon dioxide was instead released to simulate gas emission in the experiment. A carbon dioxide release model was set up using the gas concentration change curves. The experimental results show that the mine ventilator variable-frequency control automatically adjusted the branch wind quantity, which strictly followed the *f-w* control method and the automatic control of the curve value. Increasing the carbon dioxide concentration caused the mine ventilator variable-frequency controller to increase the branch wind quantity automatically to keep the carbon dioxide concentration under the threshold value. The experimental results demonstrate the feasibility and efficiency of the two methods, and theoretical guidance for adjusting the ventilation branch quantity for a variable-frequency mine ventilator is provided.

1. Introduction

Coalbed methane, commonly called “gas”, is generated during the formation of coal (Liu and Harpalani, 2013), and is stored in coal seam (Clarkson and McGovern, 2005; Pan and Connell, 2012). It is a clean and efficient energy source (Flores, 1998). However, abnormal gas emission is the most important factor that leads to gas accidents, and gas concentration transfinite can cause gas explosions, gas combustion, and other disasters under certain conditions, and high concentrations of gas may also result in personnel suffocation events (Guo et al., 2014). In recent years, although gas emissions are very small in some coal mines, the frequency of gas accidents has seriously affected normal mine production. During 2008–2012, there were 509 major coal mine accidents in China. Among these, there were 134 major gas explosion accidents, causing 1308 deaths and accounting for 43.6% of total accidents and 51.8% of total deaths (Cheng, 2012). In the presence of a gas concentration transfinite in a mining tunnel, the response is typically to increase the ventilation wind quantity in order to dilute the gas.

Predicting gas emission and discerning the emission law are the basis for effective control of gas concentration transfinite (Liu et al.,

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2016). Research in Russia promoted global technological progress in gas emission prediction (Connell et al., 2010). German researchers created a dynamic model for use in gas emission prediction technology. Based on the comprehensive consideration of mining and existing conditions, US researchers proposed a prediction method for gas emission that features dynamic changes with gas emission changes, visualization and graphics for gas emission prediction have been realized (Zipf and Mohamed, 2010). In the technology development of gas emission prediction at home and abroad, the following objectives are common: (1) Predict technological methods and standardize them. According to different conditions in different mines, develop corresponding regulations for different mines under the premise of considering the occurrence of coal seams and production conditions (Ilson and Card, 1999). (2) Prediction method dynamics. Domestic and foreign scholars have developed a dynamic prediction model for gas emission through years of research. Using this dynamic mathematical model, incorporate various factors into its functions, and through its results accurately predict the dynamic values for gas emission in order to realize gas prevention and control (Czeczott, 2012). (3) Use of prediction content for diverse applications. Modern gas emission technology can be used not only for prediction of gas emission, but can also forecast gas reserves and gas properties in different regions (Adhikary and Guo, 2015).

Ventilation technology is an important measure not only for preventing all kinds of disasters, but also to control, reduce, and resolve disasters once they occur. In recent years, many scholars at home and abroad have performed much fruitful research about air exchange and ventilation network solution techniques, and they have accumulated substantial experience (Wang et al., 2013). With increasing demand for real-time monitoring of mine parameters, the requirement for appropriate data management in many mining applications is also increasing (Agioutantis et al., 2014). Real-time analysis adds complexity to the system since data validation and storage should be completed independently of filtering, data reduction operations, or visualization. Real-time processing may include statistical evaluation, trending, cross-correlation, and real-time alarm or warning generation. Petrov used a statistical method and proposed that the reliability of mine ventilators is the basis of mine safety and system stability. Fans are typically used in these ventilation systems to supply airflow to mines. The analytic hierarchy process method was used for this task, along with multi-criteria decision making methods, to select a main fan for an underground coal mine in Turkey (Kursunoglu and Onder, 2015). Mitchell proposed a method of partial ventilation using programmable electronic systems (Marjanovic et al., 2016). The structure of control information system in the Senje mine and the ergonomic analysis of measurement and control devices in this mine have been presented. Further modes of development of control information systems in underground mines in Serbia and solutions for their reconstruction are proposed. The need for safe production procedures requires adjusting mine ventilators' operating pressure, wind speed, air quantity, temperature and other aspects (Wierzbicki and Młynarczuk, 2013). Wei etc. developed a windows-based ventilation network visualization management system (Wei et al., 2008; 2010; Zhu et al., 2009). At the same time, many articles were written that provided a powerful body of reference for the solution of complex ventilation networks. Li etc. considered the synchronization of a class of nonlinear network flow systems. Motivated by the air distribution problem in air conditioning and mechanical ventilation systems, they proposed a class of coupled nonlinear multi-agent systems that can model a wide class of network flow systems (Li et al., 2014). By analyzing mine ventilator operating characteristics, Shang and Wang explored the feasibility and economical applicability of variable-frequency technology. Variable-frequency mine ventilator controls in mine ventilation systems with associated gas monitoring systems have been presented to prevent gas explosions (Wang et al., 2015; Shang and Wang, 2006). Many scholars worldwide have conducted fruitful research on ventilation system stability. However, intelligent mine ventilator variable- frequency control with branch quantity adjustments using ventilation network calculations, mine ventilation monitoring systems, and abnormal branch airflow causality analyses have not been as thoroughly researched.

Therefore, when abnormal gas emission occurs, fast and efficient processing of the gas concentration transfinite achieves proper ventilation, which plays an important role in the prevention and control of gas explosions, gas burning, suffocation, and other accidents. Studies have been carried out on coupling the required airflow volume of the branch to the variable-frequency control of the ventilator. Some relevant theories have analyzed intelligent mine ventilator variable-frequency control. Meanwhile, it has great significance for the protection of personnel and ventilation system safety.

2. Factors and characteristic analysis of gas fluctuation emissions

Gas is the general term for the gas that is released from coal. In the process of coal formation, this gas existed both free and adsorbed into the coal seam, and these two states were generally held in a dynamic balance. When excavation activities undermine the integrity of coal and rock, fractures, relief swelling deformation, and stress cause redistribution, and free gas gushes into the mining space under the seam pressure, breaking the existing dynamic equilibrium (Li et al., 2014; Zang and Wang, 2016; Li et al., 2013). Meanwhile, in the process of coal mining, surrounding rocks and coal seams are damaged, causing uneven emission of gas from coal that shows the characteristics of a volatility anomaly (Yang et al., 2016; Turcotte et al., 2002).

2.1. Factors affecting gas fluctuation emission

Main factors that affect the gas abnormal emission in coal seams include geological and mining technology factors. The occurrence of gas in coal seams is affected by different geological conditions such as small-scale geologic structure, igneous rock intrusion into the seams, caves and collapse columns, the degree of destruction of coal seams, and hydro-geological conditions (Arshadnejad and Goshtasbi, 2011). Mine ventilation plays an important role in controlling abnormal gas emission, especially in adjusting local wind quantity frequently when excavation takes over. However, even a slightly improper operation process can easily cause a gas concentration transfinite in some branches. The occurrence of coal seam gas can change with changes in the stress of the coal seam, which can change the gas emission quantity in the mining space (Karaman et al., 2015). When the goaf appears to leak or so as to adjacent layer gas is poured into the goaf, and the gas emission from the goaf to the mining face increases. If gas emission quantity increases greatly during blasting and mechanical coal dropping, it is easy to cause a gas concentration transfinite in the region of the mining face and return airways. With the improvement of mechanized coal caving mining technology in thick coal seams, the rate of workface advancement has become increasingly rapid and the volume of production has increased. Therefore, the gas emissions from workfaces have increased dramatically in certain parts of China (Yu et al., 2000; You et al., 2008). With the continuation of mining work, the goaf is gradually enlarged, and the overlying strata are destroyed under the dual action of the ground stress and weight. When its own strength cannot resist this amount of force, it