International Journal of Mining Science and Technology 24 (2014) 385–389

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Advances in gas content based on outburst control technology in Huainan, China

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A R T I C L E I N F O

Article history:
Received 10 October 2013
Received in revised form 15 November 2013
Accepted 8 December 2013
Available online 29 April 2014

Keywords:
Coal mining
Outburst
Outburst prediction
Gas content
Numerical modelling

A B S T R A C T

The sudden and violent nature of coal and gas outbursts continues to pose a serious threat to coal mine safety in China. One of the key issues is to predict the occurrence of outbursts. Current methods that are used for predicting the outbursts in China are considered to be inadequate, inappropriate or impractical in some seam conditions. In recent years, Huainan Mining Industry Group (Huainan) in China and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia have been jointly developing technology based on gas content in coal seams to predict the occurrence of outbursts in Huainan. Significant progresses in the technology development have been made, including the development of a more rapid and accurate system in determining gas content in coal seams, the invention of a sampling-while-drilling unit for fast and pointed coal sampling, and the coupling of DEM and LBM codes for advanced numerical simulation of outburst initiation and propagation. These advances are described in this paper.

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1. Introduction

Coal and gas outburst is that a large quantity of gas in conjunction with the ejection of coal and associated rock is rapidly released into the working face or mine workings. Outbursts are hazardous through the mechanical effects of particle ejection and by asphyxiation and possible explosion from the gas produced. With an increase in depth of mining and production, outburst intensity and frequency tend to increase, although this trend is somewhat masked with advances in understanding the phenomena and application of new prediction technologies and control measures. One of the key challenges to effectively manage and control outbursts is to develop practically appropriate technologies to predict the occurrence of outbursts.

Based upon the understanding that the outbursts occur as a result of mutual interaction of a number of factors such as rock pressure, gas present in coal, and physical and mechanical properties of coal, a number of indices have been developed, and are in use to predict the occurrence of the outbursts in China. These indices include mainly cutting volume (S), gas desorption and diffusion indices ($K1$, $\Delta h2$, and ΔP), gas flow indices (q and α), gas pressure (P), and Protodyakonov index (f) [1,2]. Practical experience reveals that there are three main shortcomings in the use of these indices. The first issue is to set outburst threshold values for seams of various geological, and mining conditions. Experience has shown that the outbursts do occur while the indices are below the preset threshold values. The second shortcoming is the impracticality of some indices in some seam conditions. Some indices, when applied in certain seams, lack reproducibility, which makes the use of such indices inappropriate and impractical. The last challenge is severe impediments to development rate in the use of some indices. The current prediction methods can predict less than 10 m ahead a development face, which makes it almost impossible to achieve a high development rate.

In comparison, the method used to predict the occurrence of outbursts in Australia is based on the rapid direct measurement of gas content in coal seams. This method enables the prediction distance reaching 50–200 m in a coal seam and has been practiced successfully in Australia for 18 years. Though gas content, as a basic coal seam parameter, has been used and practiced for outburst prediction in Australia, surprisingly this has not been widely used in practice elsewhere. This may partially be due to different coal seam conditions outside Australia and the lack of the development of a rapid gas content measurement method and directional

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http://dx.doi.org/10.1016/j.ijmst.2014.03.017
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borehole drilling technology. Because of its expediency and less impact on mining operation (coal sampling can be taken well ahead of a working face for determination of its gas content), Australian coal industry essentially bases its outburst management on gas content. This reliance on one index was criticised by some researchers; however its success at preventing outbursts cannot be disputed. Over the last 18 years only a handful of small outbursts have occurred in Australia in extracting coal in which gas content was below preset threshold values.

To overcome some shortcomings of the prediction methods used in China and take advantages of the successful experience in Australia, Huainan and CSIRO entered into an agreement a few years ago to undertake joint research to develop a gas content based technology to predict the occurrence of outbursts in Huainan. The main scopes of the joint research include: (1) establishment of the standard laboratory and calculation methods for determining gas content with the rapid direct desorption method; (2) development of an innovative coal sampling technique suitable for soft coal seams; (3) laboratory and field investigations of gas diffusion and desorption characteristics of coal seams; (4) development of a coupled numerical program to simulate the process of outburst initiation and propagation; (5) determination of an outburst threshold value of gas content for coal seams; and (6) development of a complete set of gas content based technologies to predict the occurrence of outbursts in Huainan.

The joint research effort has achieved significant results and continues to power ahead. These results include the development of a more rapid and accurate method for determining the gas content in coal seams, the invention of a sampling-while-drilling system for fast and pointed coal sampling, and the coupling of discrete element method (DEM) and Lattice Boltzmann method (LBM) codes for advanced numerical simulation of outburst initiation and propagation. These progresses are discussed below.

2. Determination of gas content

Methods used for determining the gas content can be divided into two categories: indirect methods and direct methods. Indirect methods are based upon either the gas adsorption characteristic of coal under a given pressure and temperature condition, or other empirical data that relate the gas content of coal to other parameters such as gas pressure, gas emission rate, coal rank, or depth of cover. Direct methods are based on the actual measurement of the volume of gas released from a coal sample. Direct methods can be further divided into slow and fast desorption methods. In the slow desorption method, a coal sample is allowed to desorb until a low desorption rate cut-off point is reached or desorption stops, which can often take weeks or months. In the fast direct desorption method, instead of waiting weeks or months, the sample is crushed when received by the laboratory, and the gas content of the sample can often be obtained in days. The direct desorption method is widely used in the coal mining industry.

Since Bertard et al. introduced the direct gas content measurement method in 1970, a number of systems have been developed to measure the gas content of coal by direct methods [3,4]. Bertard et al. used three containers (initial measurement, transport, and crushing), a U-tube manometer, and a crusher to measure the gas desorption volume of a 10 g coal sample collected from an underground borehole. Kissell et al. modified Bertard's devices, eliminated the need for multiple containers, and used replacement containers constructed from 0.3 m long sections of 0.1 m diameter aluminium pipe [5]. These modified devices were used to measure the gas content of larger sized virgin coal core samples. The method associated with the modified devices is referred to as the United State Bureau of Mines (USBM) direct method. The Standards Association of Australia (AS3980-1999) recommended a gas content test procedure based on the USBM direct method and addressed equipment construction, sampling and testing procedures, and methods of calculating the final gas content results. Saghafi et al. proposed a method that places stainless steel balls in a coal sample container for subsequent crushing of the sample in the laboratory without transferring the sample to another container [6]. Despite these significant developments, issues remain about the rapidity and accuracy in measuring the gas content of coal in underground coal mining. One of the main issues in the estimation relates to soft coal seams. In a soft or friable coal seam, it is impossible to obtain a relatively complete coal core, leaving coal cuttings as the only practical alternative. There are two obvious challenges in coal cutting: how to quickly obtain the coal cutting at a given position, and how to estimate gas lost during sampling. A new sampling unit was invented for sampling and a computer program was developed to estimate the gas lost during sampling. Due to its significance and relative independence from gas content measurements, the new sampling unit is described in Section 3.

The gas content determination system was developed to not only comply with gas content determination standards in China (GB/T 23250-2009) and Australia (AS 3980-1999), but also to rapidly measure the gas content of coal (normally in a few hours) with improved accuracy to meet the requirements of underground coal mining. The system consists of several integrated components, namely a sampling-while-drilling (SWD) unit for coal sampling (refer to Section 3), a canister to contain the coal sample, a portable unit used underground for the initial gas desorption measurement, a surface-based unit for gas desorption measurement, a sample crushing and gas desorption measurement unit, a weighing device, a gas composition measurement unit, and gas content calculation software [7]. Each of these elements except the SWD unit is briefly described below.

A canister is used to contain a coal sample during its transport and gas desorption. The canister body is made from stainless steel pipe. The diameter and length of the canister body depend on the size and amount of samples, with minimum air space to reduce the effect of changes in atmospheric conditions on the gas volumes to be measured. The canister diameter is in the range of 10–20 cm (internal diameter) and the canister body length is in the range of 50–80 cm. The canister is sealed at one end and the other end has a removable gastight cap fitted with a bi-directional and gastight valve. For convenience of transporting, a set of handles are fitted on the canister body.

The portable unit is used to measure the initial gas desorption by the water replacement method in the field. The method is similar to the one that was described by Kissell et al. [5]. The unit consists of two inverted and scaled cylinders, a water pan, a PVC tube for gas flowing from the canister to the cylinders, and other fittings such as stands, bracket, switch, pump and battery. The size of the cylinders is in the range of 100–800 mL to cater for various gas desorption rates. The water in the unit is fully saturated salt water to reduce the solubility of desorbed gas in water and coloured for easier reading against the measurement scales. The cylinders are secured to the stands and filled with water by drawing water into them by applying suction to the tube passing through the pan. The tube is raised to a level above the cylinder and supported horizontally to reduce the likelihood of the water being drawn into the canister if the ambient temperature falls sharply. With this unit, the desorbed gas flow rate is measured. The measurement is directed towards determining gas lost from the sample, subsequent to being removed from its in situ position and prior to its containment in the gas canister.

Similar to the portable unit used in underground, this unit was developed to measure gas desorption by the water replacement

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