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Application of ventilation simulation to spontaneous combustion control in underground coal mine: A case study from Bulianta colliery

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ABSTRACT

Spontaneous combustion of residual coal in longwall goaf is a long standing hazard. Airflow leakage into goaf is a major driver to the hazard and this issue deteriorates where longwalls are operating in multiple seams and shallow covers because mining-induced cracks are very likely to draw fresh airflow into goaf due to presence of pressure differential between longwall face and surface. To study the problem more critically, a ventilation simulation package "Ventsim" is used to conduct a case study from Bulianta colliery. It was found that isolating and pressurizing active longwall panel can mitigate the problem and the pressure differential can be adjusted by varying performance of auxiliary fan and resistance of ventilation regulator. A booster ventilation system can also mitigate the problem by adjusting fan duties. Ventilation simulation is a powerful tool to study spontaneous combustion control in underground coal mine.

1. Introduction

Coal, as a carbonaceous material, is capable of being oxidized and generating heat from ambient temperatures [1–4]. Self-heating or even spontaneous combustion of coal mass is likely to outbreak under favorable circumstances during many processes of coal extraction and utilization [2,5,6]. Especially underground coal mine fires have been identified as one of the most devastating mining hazards for posing a great threat to miners, burning out valuable coal mine assets, and giving off toxic and greenhouse gases [7,8]. Reviewing Australian coal mining history more than 125 fire incidents have been recorded in New South Wales whilst at least 68 incidents have been reported in Queensland from 1960 to 1991 and most of them occurred in underground workings [9]. From 1990 to 1999, approximately 17% of the 87 total reported fires for U.S. underground coal mines were caused by self-heating [10]. In India 75% of the coal mine fires occurs due to spontaneous combustion [11]. In China more than 50% of coal mines have had self-heating incidents and there are estimated to be 360 fire incidents each year caused by the spontaneous combustion within only several key coal mines [12]. A third of the 254 mine fires reported during the period from 1970 to 1990 was caused by spontaneous combustion of coal in South Africa [13].

Generally several internal and external factors can contribute to spontaneous combustion of coal in underground coal mine [14]. Intrinsic factors like coal properties and geological conditions are beyond control of coal operators. While Extrinsic factors such as longwall (LW) panel layout, ventilation deployment, and mine planning can be managed by coal operators. Among those external factors ventilation arrangement is possibly of the utmost importance because airflow leakage into goaf from ventilation in LW working is a necessary element of fire. The primary duties of mine ventilation are to dilute hazardous accumulation of gas and dust, to dissipate heat primarily produced by mining machines, and to supply respirable air to underground working force [15–17]. A proper ventilation network is capable of fulfilling this duty in an economical means while a poorly managed ventilation system is very likely to fail the duty and even worse, to facilitate development of some mining hazards. Spontaneous combustion is one of them as coal mine ventilation is inevitably feeding oxygen rich air into longwall goaf where a significant amount of coal is left. Today there is a strong move to longer panels, wider faces, greater extraction heights, increased production rates, more efficient ventilation and decreased personnel in longwall coal mine [18]. The coal seams in newly developed mines or sections are generally thick and the risk of spontaneous combustion increases significantly during longwall mining due to the large quantities of broken coal

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left behind the chocks and its exposure to high oxygen levels in the goaf [19]. Due to depletion of the first coal seam, many coal mines in China have extracted the second seam or mined multi-seams simultaneously. The trending can now be found in Australian mining industry as well. It undoubtedly will pose more complexities to ventilation circuits and difficulties to manage coal spontaneous combustion because mining-induced cracks are more developed and more likely to propagate to surface to draw more air leakage for multi-seam LW operations. In exhaust ventilation system fresh air is drawn from surface to LW working face through the interconnected mining-induced cracks and vice versa for the force ventilation system. The pressure differential between LW working and surface is the major driver for the leakage, so minimizing the pressure differential is another important duty of ventilation for LWs operated in multiple coal seams and under shallow cover. A popular philosophy in dealing with spontaneous combustion hazard is prevention is always better than cure. Although many advances in gas monitoring techniques, sealing and stopping construction, and proactive inertisation plan have been achieved, a more competent ventilation system which can reduce the leakage into goaf is the first and also the most important shield to the hazard. To quantify the pressure differential and investigate the issue with more details, a ventilation simulation program called "Ventsim" is used to perform a case study based on a real ventilation network of Bulianta colliery. The colliery is one of the most productive LW operations in China and also a very representative LW operated in multiple coal seams and under shallow cover.

2. Project description

2.1. General introduction

Bulianta colliery is situated 13 km south to Ordos city of Inner Mongolia Autonomous Region of Northern China (see Fig. 1). The colliery is operated in Shendong coalfield which is featured with flat and thick coal seam under shallow cover. Mining area of the colliery is approximately 34 km^2 and the total proven reserve exceeds 506 million tons of coal. Due to recent upgrade of mining technology and equipment, extraction height of LW working face has increased to 7 m and annual production of the coal mine has exceeds 15 million tons of coal. Bulianta colliery and several other coal mines in Shendong coalfield have become the most productive underground LW operations in China.

2.2. Geological conditions

According to the data interpretation of drilling core, the outcrop of strata and the proven geological information of the coalfield, the stratigraphy of the colliery is estimated. Fig. 2 shows a simplified

Fig. 1. Location of Bulianta colliery.

distribution of the strata. Main extraction coal seam 1^{-2} seam is located in upper part and the other two main seams 2^{-2} and 3^{-1} seam are distributed in middle part. The average thicknesses of three coal seams are 4.1 m, 6.8 m, and 3.2 m respectively. Spacing of them is approximately 32 m between 1^{-2} seam and 2^{-2} seam and 28 m between 2^{-2} seam and 3^{-1} seam, respectively. The mining region is part of the Ordos early-middle Jurassic coal bearing basin and no big faults are found in the basin. The basin is developed in the platform on the basis of inheriting type basin in which the strata lies towards the N20° to 30°W and the tendency is S60°-70°W. The incline of the strata varies slightly from 0° to 3° and the floor of coal seam has slight fluctuation with gentle lift in the east. It is noticeable coal seams in this colliery are closely distributed and operated under very shallow cover.

2.3. Problem identification

Currently the coal mine is extracting two coal seams, namely 1^{-2} coal seam and 2^{-2} coal seam. 3^{-1} coal seam is on standby. Fig. 3 shows the overall layout of Bulianta coal mine. The whole mine is divided into five sections with several longall panels within each of section. 1^{-2} coal seam and 2^{-2} coal seam has been totally extracted in section one and two. At present section four and section five are mining 1^{-2} coal seam and section three is mining 2^{-2} coal seam as 1^{-2} coal seam has been extracted and it is believed overlying goaf has been interconnected via mining-induced cracks. Contaminated air is taken out of pit via two main exhaust fans. One is installed in north exhaust shaft and another one is installed in south exhaust incline. Fresh air is mainly taken from intake incline and intake shaft (see Fig. 3). Intake shaft serves to section five and main intake inclines serves to section three. Fresh air is supplied from both intake shaft and intake incline for section four.

Since the commencement of extraction of panels in section three, several serious coal oxidation and self-heating incidents have occurred and culminated in one open fire incident at LW22306 working panel (see Fig. 3). It was found the fire originated from overlying 1^{-2} coal seam goaf because high concentration of CO (exceeds $10,000 \times 10^{-6}$) was initially detected from several boreholes drilled to overlying 1^{-2} coal seam goaf. The fire caused closure of the panel for more than six months and costed hundreds of millions of dollars to quench it by slurry injection through hundreds of downholes. After undertaking investigation and incident review, the possible reason of the occurrence of the fire incident was revealed and can be illustrated in Fig. 4. As is widely accepted, a major consequence of coal extraction is ground subsidence and creation of factures and cracks to the overlying or underlying strata. In this case, after 1^{-2} seam was mined, the induced cracks may have already developed to surface due to shallow cover of the coal seam. As 2^{-2} coal seam was further extracted, more developed and wider cracks were likely to be induced because of higher mining height of this coal seam. These channels are very likely to become interconnected and propagate to surface. Fig. 5 presents real images of mining-induced cracks developed to surface. These channels can function as air leakage path from surface to active working face if any pressure differential presents. As this mine is currently using an exhaust ventilation method, the pressure of the airflow in working face is possibly much lower than surface atmospheric pressure. Therefore, the pressure differential is very likely to draw a certain amount of fresh air from surface to active longwall face through these channels. In addition, the immediate roof of Shendong coalfield is very fragile, and as a result, approximately 0.5 m top coal is reserved to facilitate chock support and will be left in goaf as LW advances. With continual supply of fresh air, smoldering of coal developed to an open fire as the heat generated from coal oxidation is not sufficiently dissipated. The pressure differential not only aggravates the self-heating process