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Investigation of airflow and respirable dust flow behaviour above an underground bin

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ABSTRACT

To mitigate the problem of dust contamination to the intake air of an underground coal mine, a study was carried out to understand the airflow and respirable dust flow behaviour for the development of effective dust suppression strategies. Three dimensional (3D) Computational Fluid Dynamics (CFD) modelling was used to predict airflow field around the crusher and transfer point above the underground bin and along the belt roadway. The CFD model was validated using average velocity and dust concentration profiles obtained from ventilation surveys in the belt roadway. The stochastic particle tracking model was adopted in the Lagrangian scheme to study the respirable dust dispersion behaviour and predict dust concentration distribution in the belt roadway. To overcome the uncertainty produced by the stochastic tracking, sufficient numbers of particles were employed to obtain a stable concentration field. Modelling results show that areas of airflow turbulence and circulation occur once the fresh ventilation emerges from the bin bottom and intercepts airflow from another intake. Dust particles from the underground bin will be dispersed extensively in the belt roadway once they become airborne, contributing to the high dust contamination in the intake fresh air. To mitigate dust contamination to the mine ventilation system, the dust clouds from the bin have to be intercepted and suppressed before they become airborne over the bin. Results from the CFD modelling will be used for the design and installation of a more effective dust control system.

1. Introduction

The extraction, crushing, and transport of coal in mining operations can generate significant amounts of airborne respirable coal dust. The overexposure to respirable coal mine dust can lead to Coal Workers' Pneumoconiosis (CWP), which is also known as black lung disease that can be disabling and fatal in its most severe form [1]. To protect coal miners' health, a series of regulations have been promulgated and put into place in different countries. However, due to the lack of effective dust mitigation strategies and specific mining conditions, some coal mines fail to meet the requirements [2,3].

This study is based on a real scenario occurring in an underground coal mine which is located in the Mandalong Valley of Newcastle Coalfield, Australia. The mine produces 5.5 million tonnes of coal each year from its underground longwall operations. After many years of underground mining, a complex ventilation system has been developed as shown in Fig. 1, in which the position of the bin in the ventilation system is also indicated. To prevent the accumulation of potentially explosive methane gas in the bin, the ventilation system has been designed to allow a large volume of fresh air (23 m^3/s) to pass through the bin to the belt roadway. Fig. 2 provides a closer view of the ventilation and roadway layout around the bin, where it can be seen that the MT01 belt roadway intercepts the underground bin and serves as the main roadway carrying the intake air to underground workings. This is the actual configuration used in the mine and compromisingly the upcoming ventilation airflow becomes the main source of dust pickup and subsequent dispersion along the belt roadway.

The underground bin is an important coal transfer station in the entire coal transport system of the mine. All the coal extracted from the longwall face and development heading is transported to the MT01 belt roadway and then crushed and dumped to the bin before being lifted to the surface. The bottom of the underground bin is about 20 m below the floor of the belt roadway. Once the crushed coal blocks fall into the bin, significant amount of dust particles is blown up by the upcoming airflow from the bottom of the bin, i.e., the large volume of rising airflow is the major factor leading to dust pickup and transport in the ventilation system. Fig. 3 illustrates the dimension of the belt roadway and the infrastructure layout around the bin. It has been observed that dust was mostly generated during production shifts when the coal was dumped on the sizer and subsequently dropped into the underground bin. These dust clouds then disperse into the belt roadway during the dropping process of coal as air flows in from the bottom of bin. Although there was dust suppression system

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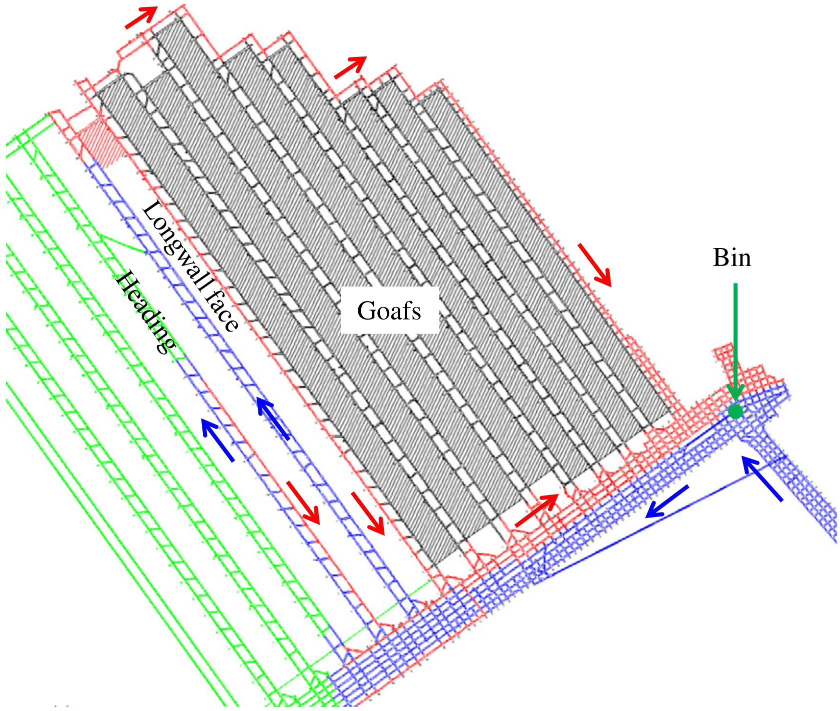

Fig. 1. Mine ventilation system of the mine (arrows showing the airflow direction).

installed on top of the bin, it has not been successful in mitigating this problem. There is a need to understand the complex ventilation airflow and dust dispersion patterns around the bin areas before a more effective dust control system can be designed and implemented on site.

Three approaches are generally used to investigate the dust behaviour in the coal mining industry, namely, field monitoring, mathematical models and computational models. Methods of measuring and sampling respirable dust particles are quite numerous but can be classified into several distinct categories, including the particle count methods, gravimetric methods, photometric (light-scattering) methods, and personal samplers [4]. With the exception of the particle count methods, the other three methods are now commonly used for dust evaluation in underground coal mines. Each of these methods has its own advantages and disadvantages. The gravimetric methods are typically used for long-term (usually a work shift) time-weighted average dust measurement either for personal sampling or area sampling, however, instant readings are not available. In New South Wales, Australia, the personal gravimetric sampling method is adopted and legislated to evaluate the operators' dust exposure level [5]. The photometric dust instruments were developed on the basis of scattering of light by dust particles, which can be employed for short term and long term sampling with immediate or any given time interval readings provided. The National Institute for Occupational Safety and Health (NIOSH) has completed the pioneer work on personal samplers which are able to monitor temporal variation of dust concentrations to which the operators are subjected. The monitor was further modified to be person-wearable Personal Dust Monitor (PDM) can accurately predict a miner's dust exposure [6,7]. This equipment has also been used in Australian coal mines for real time dust monitoring at development headings and longwall faces [8,9].

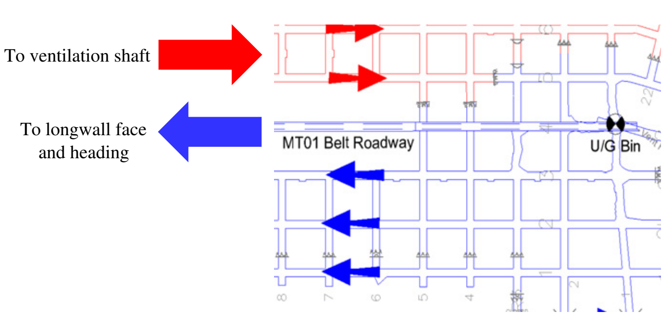

Fig. 2. Mine ventilation system around the underground bin.

Hwang et al. [10] developed a mathematical model using an Eulerian approach, which was capable of modelling four different types of dust source: point source, line source, moving line source and flat plane. However, no comparisons with field data or experimental results were made at that stage. Courtney et al. [11] proposed models to investigate deposition of respirable dust for underground coal mines, and found that the respirable dust deposition rate decreased as a function of distance from the source. Taking into account the convective diffusion, gravity, coagulation, collision mechanisms and re-entrainment of particles, Bhaskar and Ramani [12] proposed another dust deposition model, which was applicable to various dust particle sizes. Using a statistical method, the model developed by Chiang and Peng [13] was able to predict the dust concentration distributions along a longwall face with satisfactory agreement with field data. It is noted that these mathematical models use either Eulerian or Gaussian algorithm.

With the development of computer technology, computational modelling is becoming a more powerful tool in studying particle transport. One of the most common computational approaches has been the use of Computational Fluid Dynamics (CFD) models, through which the dispersion and spatial distribution of dust particles can be predicted. Srinivasa and his colleagues predicted the dust concentration around the longwall shearer using Lagrangian method [14]. It was reported that both the airflow velocities and dust concentration agreed well with experimental data. Ren et al. [15–17] conducted extensive CFD modelling work on dust flow behaviour using the Lagrangian particle tracking method, and based on modelling results, a new shearer scrubber was developed for dust mitigation at the shearer operators'