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Numerical study on dust movement and dust distribution for hybrid ventilation system in a laneway of coal mine

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ABSTRACT

Coal dust disaster is the most serious problem in a laneway of coal mine. Dust movement regularity for comprehensive mechanized heading face is the key scientific issues for the principle and technology of dust prevention. The special topic on systematic study of the variation regularity of dust movement and dust distribution is presented with hybrid ventilation for the comprehensive mechanized heading face: Euler–Euler method was firstly established on the numerical platform for gas–solid two phase flow in a laneway. And the forces and the dynamic model of dust particles were performed in three-dimensional flow field. Then based on the visible simulations, the movement characteristics of diffusion, sedimentation and accumulation of dust particles were investigated under the action of the complex air flow, and the spatiotemporal variation of dust distribution was studied with hybrid ventilation system. Meanwhile, the obtained dust distribution regularities were compared with the obtainable experimental results. Finally, selected method on different ventilation patterns for dust control was brought out for the heading face according to the gained regularity. The research results is helpful for further understanding of the essence of dust movement with air flow, which could provide more suitable guidance for the principle of dust control and technology of ventilation.

1. Introduction

With the rapid development of full mechanized mine and production intensity, coal dust has become the most serious problem, especially for comprehensive mechanized heading face. Thus dust control and prevention is necessary and urgent (Rout et al., 2014; Fabiano et al., 2014; Wang et al., 2012, 2014). According to local measurement, dust concentration could reach up to 6000 mg/m^3 in comprehensive mechanized heading face without any measures for dust control and prevention. However, when the external spraying have been adopted for the comprehensive mechanized heading face, dust concentration for the location of motorman could also reach 1200 ~ 1300 mg/m^3. Meanwhile, respirable dust concentration is up to 800 ~ 900 mg/m^3, which is far beyond the relative standard. As is known to all, the high dust concentration can cause permanent physical and psychological harm to the local workers, such as coal workers' pneumoconiosis (CWP), silicosis, and progressive massive fibrosis (PMF), which shows an upward trend since 2000 after years of decline according to Coal Workers X-Ray Surveillance Program (CWXSP) from 1970 to 2009 (Cheng et al., 2011, Social Security Administration (SSA), 2013, National Institute of Occupational Safety and Health (2011)). Moreover, high dust concentration could also result in coal dust explosion, which is a serious disaster for the mine industry (Dong et al., 2012; Kollipara et al., 2014). Additionally, the dust problem could reduce the longevity and the precision of apparatus. And the low visibility for the working place, the spontaneous combustion and other damages might occur due to the high dust concentration. Therefore, it is necessary to perform effective measures to reduce the dust concentration in the underground workplace of coal mine (Wang et al., 2011a; Wang et al., 2011b).

According to analysis on the measures for dust control and prevention, the present methods on dust prevention and dust removal are very limited, and dust removal efficiency is not as good as expected (Zhang et al., 2013; Li and Liu, 2012). Thus the first thing to address is the dust collection efficiently, and how to efficiently control the dust flow has been brought out. The essential problem is the unclear knowledge with dust distribution regularity,

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which often leads to unreasonable design for dust control and could make dust control equipment irrelevantly disposed. Though there are many relative researches, the basic problems are still unclear, including the changing regularity of dust movement, dust diffusion and dust distribution as well as their connection, which is mainly due to the polymorphism and complexity of dusty air flow in the comprehensive mechanized heading face. Therefore, dust movement characteristics and its distribution regularity in comprehensive mechanized heading face is the key scientific issues for the principle and technology of dust removal system.

There are many methods on dust prevention and control, such as coal bed affusion, physical chemistry prevention, dust suppression by spraying, ventilation and foam (Wang et al., 2012; Li, 2013; Gurley et al., 2012). The present methods all have their advantage, but there still exist obvious limitations on dust prevention and dust removal, which induce some unexpected problems, such as the high cost on dust control solution, the deterioration of working conditions and unsatisfied effect for dust removal. According to the obtainable comparison, the technology of ventilation and dust control is relatively proper with easy operation and low cost, which has been widely used as the basic method for dust prevention and control in the comprehensive mechanized heading face. What's more, hybrid ventilation system with both pressing air and absorbing air associated with external spraying are commonly adopted to control coal dust for comprehensive mechanized heading face in a laneway of coal mine in China recently (Li and Liu, 2012). However, there exist difficulties on flow control for hybrid ventilation system, which could result in secondary pollution and finally influence the dust control efficiency associated with the complicated condition of working place. What's more, once the ventilation method and ventilation parameter are not suitable, the effect of dust control will be directly influenced (Li, 2013). Therefore, it is necessary to improve ventilation method and optimize ventilation parameter for hybrid ventilation system based on the results of dust distribution regularity, which could provide better working place with low dust concentration.

The special topic on systemic study of the variation regularity of dust movement and dust distribution is presented, which associates with hybrid ventilation system in a laneway with the comprehensive mechanized heading face. Firstly, the numerical platform of Euler–Euler method was performed for particle system under different mesh, meanwhile the forces and the dynamic model of dust particles was established in three-dimensional flow field. Then, based on the visible simulation and experiment platform, the air flow behavior and the movement characteristics of dust diffusion, sedimentation and accumulation in the laneway were investigated under the action of the mixed-mode ventilation system, and the spatiotemporal variation regularity of dust distribution with the complex air flow was posted for the comprehensive mechanized heading face. Moreover, the computational results are compared with former findings to validate the established model. Finally, selected pattern on the technology of hybrid ventilation system and dust control was brought out for the heading face according to the gained regularity. The research results is helpful for further understanding of the essence of dust movement with the air flow, which could provide more suitable guidance for ventilation and dust control, as well as the measures for dust prevention and removal.

2. Mathematical models

This study is based on the data for the practical local condition and the former research (Li and Liu, 2012). The simplified model of the laneway in coal mine is shown in Fig. 1. It consists of a heading face, an outlet, a blast pipe, an exhaust pipe and a cuboida body, with rectangular cross-section, which is the main part of the laneway. During the coal mining, coal dust generate at the heading face, release into the laneway, then are delivered under the combined action of pressing air and exhaust air, finally, some of the dust are removed from the exhaust pipe, while others are removed through the outlet. During the process, dust movement, dust diffusion and dust distribution as well as their connection are important problems for dust control and prevention, which belongs to gas–solid two phase flow. Therefore, the process of dust movement was numerically simulated in the present work.

The computer simulation of gas–solid two-phase flow in the laneway is based on the two-fluid approach, and relative simulations are usually performed with both Euler–Euler model and Euler-Lagrange model. Euler–Euler model can be adopted for relatively high volume fraction of the dispersed phase without the consideration of discrete details, like particle–particle collisions (Geng et al., 2009; Fluent, 2006a; Fluent, 2006b). And Euler-Lagrange model can track each or a large number of particles through the flow field in detail, but a high particle concentration may cause convergence problems. Therefore, Euler–Euler model was adopted with the consideration of large amount of dust particles and the present compute capability of computer, which is based on the following assumptions: (a) heat and mass transfer are ignored in flow process. (b) normally air and other gases are used as operation gas, which are defined as the continuous phase. (c) the particles are treated as spherical particles. Since it is difficult to predict the fluid dynamics of each particle individually, the solid phase is assumed as the continuous phase with consideration of the large amount of dust particles in the laneway.

2.1. Euler–Euler model

A three-dimensional Euler–Euler model is established to investigate dust movement in the laneway. For this model, gas and solid are assumed to be continuous and fully interpenetrating in each control volume. Meanwhile, the dust particles are defined as the second phase and the air is treated as the primary phase. The conservative equations of mass and momentum originally derived from single-phase flow can be extended to describe the hydrodynamics of gas–solid two-phase flow (Fluent, 2006a; Fluent, 2006b; van Wachem et al., 2003; Geng et al., 2009). The main features of the model are briefly described as follows.

2.1.1. Volume fractions and conservation laws

The two phase flow was described as of as interpenetrating continua, and volume fractions was introduced to represent the space occupied by each phase. The conservation laws of mass and momentum are separately satisfied by each of the two phases, which are described in former research and relative information (Geng et al., 2009; Fluent, 2006a; Fluent, 2006b).

2.1.2. Turbulence in the dispersed phase

When the concentration of the second phase is relatively small, it is necessary to select the dispersed model from k-epsilon multiphase models. Though particle contact is ignored and the leading function on the second phase is primarily come from the primary phase, the action of the second phase can be determined by the balance feature of the primary phase, the relaxation time and the interacting time of particles. Furthermore, dispersion coefficients, correlation functions, and the turbulent kinetic energy of each dispersed phase are evaluated with time and length scales, which could characterize the motion. The characteristic particle relaxation time connected with inertial effects acting on a dispersed phase$p$ is defined as: