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Effect of suppressing dust by multi-direction whirling air curtain on fully mechanized mining face

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ABSTRACT

A combined method of numerical simulation and field testing was adopted in this study in the interest of solving the problem of hard to control high concentrate dusts on a fully mechanized mining face. In addition, the dust suppression effect of a multi-direction whirling air curtain was studied in this paper. Under the influence of the wall attachment effect, the compressed air which blows out from the two-phase or three-phase radial outlets on the generator of the air curtain can form a multi-direction whirling air curtain, which can cover the whole roadway section of a fully mechanized mining face. The traditional method of controlling dust is a forcing system with exhaust overlap which has the major disadvantage of lacking a jet effect and consequently results in poor dust control. It is difficult to form the air flow field within the range of $L_p \leqslant 5\sqrt{S_r}$. However, due to the effect of this novel system, the radial airflow can be turned into axial airflow allowing fresh air to flow through the length of the heading. The air flow field which is good at controlling dust diffusion can be formed 12.8 m from the heading face. Furthermore, the field measurement results show that before the application of a multi-direction whirling air curtain, the dust concentration is 348.6 mg/m^3 and 271.4 mg/m^3 respectively at the roadway cross-section measurement points which are 5 m and 10 m from the heading face. However, after the application of the multi-direction whirling air curtain, the dust concentration is only 61.2 mg/m^3 and 14.8 mg/m^3, respectively. Therefore, the dust control effect of a multi-direction whirling air curtain is obvious.

1. Introduction

Pneumoconiosis caused by inhalation of high concentrate dust is the most common occupational disease in China. According to the official report published by the National Health and Family Planning Commission of the People's Republic of China, 26,393 cases of occupational disease were reported in 2013. Significantly, 23,152 cases were diagnosed as pneumoconiosis, which accounts for 87.7% of the total number of reported cases. Among those, 22,050 cases of coal industrial pneumoconiosis were reported, accounting for 95.2% of total number of pneumoconiosis cases. Specifically, the number of coal miners with pneumoconiosis working on the fully mechanized mining face accounts for about more than 50% of the total number of industrial pneumoconiosis cases [1,2]. In order to reduce the high concentrate dust on fully mechanized mining face and decrease the probability of coal miners suffering from pneumoconiosis, techniques such as dust spray, chemical dust suppressant, ventilation and dust control have been developed by scholars and researchers at home and abroad. In the above mentioned techniques, ventilation and dust control has the advantages of not disrupting the driver's sight, small water consumption and low operating costs, and, therefore, has become the more extensive dust removal technology applied in fully mechanized mining face [3–5]. At present, the long distance forced and short distance exhausted ventilation dust removal technology with an exhausting fan has been applied extensively in fully mechanized mining face in China. In addition, relative research of several main parameter settings of ventilation was carried out to quantify the relationship of L_p to S_r which was found to be $L_p \leqslant 5\sqrt{S_r}$, where L_p is the distance from the pressure ventilation outlet to the heading face and S_r is the section area of roadway. However, even after applying this relation to the conventional long distance forced and short distance exhausted fully mechanized mining face with the ventilation dust removal technology, the high concentrate dust still spreads largely from the working face. The main reason is that it is difficult to form the airflow field effectively if the airflows all point to the heading face inside the space of the working area and

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heading face [6–10]. Therefore, in this paper, research into the dust removal effect of a multi-direction whirling air curtain on the fully mechanized mining face was carried out, and the method of numerical simulation in combination with field measurements was used. Furthermore, the dust control airflow field, which prevents dust in the heading spreading outside, was expected to form and improve dust prevention and control in the field.

2. Numerical simulation

In this paper, the fully mechanized 3_{down} 610 heading face which was located in the Jiangzhuang coal mine of China was adopted as a typical study case. A fluid mathematical model of gas-phase airflow and solid-phase dust double-fluid field was established. Based on the model and SIMPLE calculation process of collocated grid, numerical simulations of the formation of the multi-direction whirling air curtain and the dust suppression effect were carried out by applying Fluent code.

2.1. Physical model

An isometric physical model of the 3_{down} 610 fully mechanized mining face was established via GAMBIT. In addition, a grid mesh of the model was generated. The physical model consists of roadway, roadheader, forcing duct, exhausting duct and generator of multi-direction whirling air curtain, etc. The shape of the excavation roadway was cuboid with the dimensions of 40 m in length, 4 m in width and 3.1 m in height. The total length of the tunneling machine is 8.8 m. The shape of the tunneling machine's body is cuboid with the dimensions of 6 m in length, 2.4 m in width and 1.7 m in height. The back of the tunneling machine connects the transfer machine and the railed belt conveyor. The forcing duct and the exhausting duct are both cylinders with diameters of 0.6 m. The distance from the axis to the margin of the floor was 2.1 m. The exhausting duct clung to the margin of the tunneling machine, and the distance from the exhausting ventilation outlet to the heading face is 3 m. The distance from the pressure ventilation outlet to the heading face, L_p, was set at 20 m which is higher than $5\sqrt{S_r}$ (17.61 m) and 10 m, respectively. These values are widely used in fully mechanized heading face in China. In addition, the generator of multi-direction whirling air curtain was installed on the forcing duct having the dimensions of 0.6 m in diameter and 0.95 m in length. There were radial air-outlet groups of two kinds of directions, which both distributed along the semi-circle. One kind of semi-circle with radial air-outlet group distribution was equally divided into 5 equal parts according to the 36° angle, which had 3 strips of air-outlet. However, another kind of semi-circle was equally divided into 3 equal parts according to the 60° angle, which had 2 strips of air-outlet. Furthermore, the air-outlet and non-air outlet alternated, and a ductwork entity with a diameter of 0.15 m was in the middle. The minimum distance from the radial air-outlet to the heading face was 20 m. Each kind of air-outlet group had two groups: one group was the air-outlets with the width of 0.1 m and the others had a width of 0.15 m. The two kinds of air-outlet groups were placed in alternating order so as to form the multi-direction whirling air curtain. The physical model pre- and post-mesh generation is shown in Fig. 1. The x positive direction indicates the direction of the heading point to the end of roadway, the y positive direction indicates the direction of the forcing duct point to the exhausting duct, and the z positive direction indicates the direction of the roadway floor point to the top plate.

2.2. Mathematical model

On a fully mechanized working face, the two-phase flow field of the gas-phase airflow and solid-phase airflow was often for a turbulent state, and the time-averaged equations of the two-phase flow field pre- and post-formation of multi-direction whirling air curtain are as follows [11–13]:

The gas-phase airflow continuous equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_j}(\rho v_j)=-\frac{\partial}{\partial x_j}(\bar{\rho}'\bar{v}'_j)+S-\sum \bar{n}'_k\bar{\dot{m}}'_k \tag{1}$$

The solid-phase dust continuous equation:

$$\frac{\partial \rho_k}{\partial t}+\frac{\partial}{\partial x_j}(\rho_k v_{kj})=S_k-\frac{\partial}{\partial x_j}(\bar{\rho}'_k\bar{v}'_{kj})+\bar{n}'_k\bar{\dot{m}}'_k \tag{2}$$

$$\frac{\partial n_k}{\partial t}+\frac{\partial}{\partial x_j}(n_k v_{kj})=-\frac{\partial}{\partial x_j}(\bar{n}'_k\bar{v}'_{kj}) \tag{3}$$

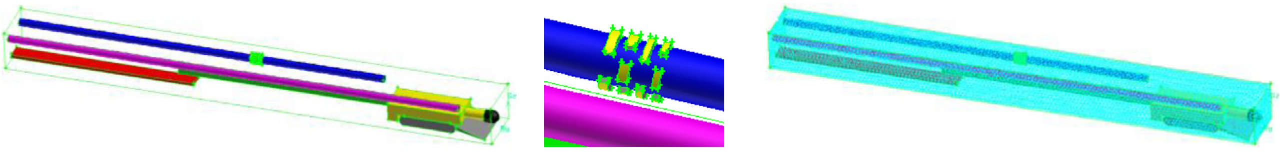
The gas-phase airflow momentum equation:

$$\begin{aligned}&\frac{\partial}{\partial t}(\rho v_i)+\frac{\partial}{\partial x_j}(\rho v_j v_i)\\&\quad=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ji}}{\partial x_j}+\Delta\rho g_i+\sum \rho_k(v_{ki}-v_i)/\tau_{rk}+v_i S+F_{Mi}\\&\qquad-\frac{\partial}{\partial x_j}(\rho\bar{v}'_j\bar{v}'_i+v_i\bar{\rho}'\bar{v}'_j+v_j\bar{\rho}'\bar{v}'+\bar{\rho}'\bar{v}'_j\bar{v}'_i)+\sum\frac{m_k}{\tau_{rk}}(\bar{n}'_k\bar{v}'_{ki}-\bar{n}'_k\bar{v}'_i)\\&\qquad-v_i\sum \bar{n}'_k\bar{\dot{m}}'_k-\sum n_k\bar{v}'_i\bar{\dot{m}}'-\sum \dot{m}_k\bar{n}'_k\bar{v}'_{ki}-\sum \bar{v}'_i\bar{n}'_k\bar{\dot{m}}'_k\end{aligned} \tag{4}$$

The solid-phase dust momentum equation:

$$\begin{aligned}&\frac{\partial}{\partial t}(n_k v_{ki})+\frac{\partial}{\partial x_j}(n_k v_{kj} v_{ki})\\&\quad=n_k g_i+n_k(v_i-v_{ki})/\tau_{rk}+(v_i-v_{ki})n_k\dot{m}_k/m_k+F_{Mi}/m_k\\&\qquad-\frac{\partial}{\partial x_j}\left(n_k\bar{v}'_{kj}\bar{v}'_{ki}+v_{kj}\bar{n}'_k\bar{v}'_{ki}+v_{ki}\bar{n}'_k\bar{v}'_{kj}+\bar{n}'_k\bar{v}'_{kj}\bar{v}'_{ki}\right)\\&\qquad+(\bar{n}'_k\bar{v}'_i-\bar{n}'_k\bar{v}'_{ki})/\tau_{rk}+(v_i\bar{n}'_k\bar{\dot{m}}'_k+n_k\bar{v}'_i\bar{\dot{m}}'_k+\dot{m}_k\bar{n}'_k\bar{v}'_i+\bar{n}_k\bar{v}'_i\bar{\dot{m}}'_i\\&\qquad-v_{ki}\bar{n}'_k\bar{\dot{m}}'_k-n_k\bar{v}'_{ki}\bar{\dot{m}}'_k-\dot{m}_k\bar{n}'_k\bar{v}'_{ki}-\bar{n}_k\bar{v}'_{ki}\bar{\dot{m}}'_k)/m_k-\frac{\partial}{\partial t}(\bar{n}'_k\bar{v}'_{ki})\end{aligned} \tag{5}$$

where d (m) is the diameter of dust particle, ρ (kg/m^3) is the density of dust, n is the number density, m (kg) is the mass of dust particle, g (m/s^2) is the acceleration of gravity, g_i is the size distribution of particle at the inlet, r is the radial position, s is the displacement of source term, ω (r/s) is the spin rate of fluid, τ (s) is the time, λ is the thermal conductivity, Q (m^3/s) is the flow, Q_h is the thermal effect on particle surface, T (°C) is the temperature, k indicates the first k kinds of particles, i and j are the coordinates of a tensor.



(a) Before the generation of grid mesh (b) Generator of air curtain (c) After the generation of grid mesh

Fig. 1. Physical model, pre- and post-generation of grid mesh.