Numerical Simulation of Dust Dispersion and Pollution in Breathing Zone of Fully Mechanized Mining Face

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Abstract. In order to more accurately analyze the law of dust escape in the position of breathing zone of fully mechanized coal face, a geometric model of fully mechanized coal face is established in 1205 fully mechanized coal face of Xinan Coal Mine. The movement law of dust with the wind field in the fully mechanized coal face is simulated by FLUENT software, and the dust in the area of breathing zone at different positions is also simulated. The situation is analyzed in detail. The simulation results show that the overall movement law of air flow in the whole working face is from small to large and then to small. When the air flow passes through the area near the shearer, the local space becomes smaller, the wind speed increases and transverse movement occurs. The dust produced by the shearer cutter diffuses into the space of the shearer and its downwind side roadway accompanied by the air flow. A high concentration dust belt is formed in the area near the shearer. The dust contaminated area in front of the Hydraulic support and the space breathing belt of the sidewalk increases gradually with the prolongation of dust production time and covers the height of the whole breathing belt after 80 s of dust production.

1. Introduction

With the continuous improvement of the comprehensive mechanization degree of coal mines, the mining methods and coal mining processes of mines have developed rapidly, and mine dust seriously threatens the safe and efficient production of coal mines and the health of underground workers [1, 2]. The fully mechanized mining face is one of the main dust-producing sites in coal mine production. According to the actual measurement of the coal mining machine cutting and moving, the dust production at the local working site is as high as 4000 mg / m³. Whether it is full dust concentration or respiratory dust concentration, the dust concentration is seriously exceeded, and the number of people suffering from pneumoconiosis is increasing year by year [3-5]. At present, domestic and foreign scholars mainly carry out numerical simulation research on the migration law of dust in the roadway of fully mechanized mining face, and analyze the migration and diffusion law of dust in the working face with the wind flow [6-8], but the above studies have not The study on the migration of dust in the respiratory zone was carried out in detail. To this end, the author uses fluent software to analyze the pollution of the respiratory zone during the dust-discharge process of the fully mechanized mining...
face under different dust-producing time, and provides a theoretical basis for effectively controlling the dust concentration in the breathing zone.

2. Turbulent-discrete phase numerical simulation

The flow of wind and dust in the fully mechanized mining face belongs to the gas-solid two-phase flow in essence. The mathematical model of turbulent flow of gas-solid two-phase flow should be selected for description. Aiming at the characteristics of gas-solid two-phase flow in fully mechanized mining face, the k-ε two-equation model of Euler method is used to establish the mathematical model of single-phase airflow in fully mechanized mining face. A random orbital mathematical model in the Lagrangian coordinate system is used to describe the trajectory of the particle [9].

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$k$ equation:

$$\frac{\partial}{\partial t} \rho_k = \frac{\partial}{\partial x_i} \left( \rho u_i \frac{\partial k}{\partial x_i} \right) - \frac{\partial}{\partial x_i} \left( \nu + \frac{\mu_T}{C_v} \frac{k}{\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_i}$$

(1)

ε equation:

$$\frac{\partial}{\partial t} \rho_\varepsilon = \frac{\partial}{\partial x_i} \left( \rho_\varepsilon \frac{\partial \varepsilon}{\partial x_i} \right) - \frac{\partial}{\partial x_i} \left( \rho_\varepsilon \frac{\partial \varepsilon}{\partial x_i} \right) - \frac{\partial}{\partial x_i} \left( \rho_\varepsilon \frac{\partial \varepsilon}{\partial x_i} \right)$$

(2)

Where $x_i, x_j$ are the coordinates ($i \neq j$) in the $x, y, z$ directions, $m$; $u_i, u_j$ are the speeds ($i \neq j$) in the $x, y, z$ directions, m/s; $\rho$ is the gas density, Kg/m$^3$; $\mu$ is laminar viscosity coefficient, Pa•s; $k$ is turbulent kinetic energy, m$^2$/s$^2$; $\varepsilon$ is turbulence kinetic energy dissipation rate, m$^2$/s$^3$; $C_{\mu}, C_{\varepsilon}, C_{\alpha}, \sigma_\varepsilon, \sigma_k$ is k-ε model. The constants in the are 1.44, 1.92, 0.09, 1.3, and 1.0, respectively.

The differential equation of the dust force in the Lagrangian coordinate system is integrated to obtain the migration orbit of the dust particles. The force balance equation for the particle phase is:

$$\frac{du}{dt} = \frac{18 \mu_c \varepsilon C_{\mu}}{\rho_p d_p^2} \left( \mu - \mu_p \right) + \frac{g_x (\rho_p - \rho)}{\rho_p} + F_x$$

(3)

Where $u$ is the airflow velocity, m/s; $u_p$ is the dust transport velocity, m/s; $\mu$ is the wind flow viscosity, Pa/s; $\rho$ is the wind flow density, kg/m$^3$; $\rho_p$ is the dust density, kg/m$^3$; $d_p$ is the dust particle diameter, m; $Re$ is the relative Reynolds number; $CD$ is the drag coefficient; $g_x$ is the X-direction gravitational acceleration, m/s$^2$; $F_x$ is the other force in the X direction, N.

3. Construction of finite element model

3.1. Model construction and meshing

According to the actual size of the 1205 fully mechanized mining face in Xin'an Coal Mine, the geometric model of the equal proportion fully mechanized mining face was established by Solidworks. The geometric model consists of coal mining machine, hydraulic support, scraper conveyor and cable trough. The model is named and meshed, and the shearer is attached with a cuboid of length × width × height = 90m × 5.4m × 4.8m. Using ICEM to perform local mesh encryption on the near-region of the geometrical model of the fully mechanized mining face, more accurate and reasonable simulation results can be obtained. Figure 1 is a schematic diagram of the geometric model and mesh division of the fully mechanized mining face.
3.2. Determination of boundary conditions and calculation methods

According to the analysis of the measured data at the site of the fully mechanized mining face, the parameters related to the boundary conditions are set, and the corresponding calculation model is selected according to the theory of fluid mechanics. The numerical simulation calculation process is realized by Fluent.

The specific parameter settings are shown in Table 1.

Table 1. Boundary condition main parameter setting

| name                          | parameter settings            | name                      | parameter settings |
|-------------------------------|------------------------------|---------------------------|--------------------|
| Turbulence model              | Standard k-ε double equation | Maximum particle size / (um) | 454.1              |
| Entrance boundary condition   | VELOCITY-INLET               | Minimum particle size / (um) | 3.7               |
| Export boundary type          | OUTFLOW                      | Medium particle size / (um) | 42.9              |
| Air flow speed (m/s)          | 1.2                          | Mass flow rate / (kg/s)    | 0.082              |
| Turbulent kinetic energy / (m²/s²) | 0.8                        | Particle size distribution | Rosin-Rammer      |

4. Numerical simulation results and analysis

4.1. Analysis of the law of airflow movement in working face

In order to analyze the flow distribution of the wind field in the fully mechanized mining face more clearly and intuitively, this paper analyzes the numerical simulation results of the wind field in the fully mechanized mining face. The section of the roadway intercepting the working face is the wind flow field at different positions in the direction of the bottom plate-top plate, which are y=1.2m, y=2.4m and y=3.6m (sidewalk center). The wind speed and vector distribution of the working face are shown in Fig. 2.

As can be seen from Figure 2:

1) The wind flow on the sides of the hydraulic support is disturbed severely, especially in the rear of the hydraulic support, and there is a significant uneven flow of the wind. In the shearer area, due to
the blockage of the shearer and the increase of wind speed, the wind flow is forced to shift toward the hydraulic support, so that a high wind speed belt is also appeared behind the hydraulic support, and the wind speed is about 2.4 m/s. On the upwind side and the downwind side of the roadway, there is a significant wind speed gradient, the wind flow is not very stable, and a small range of high wind speed belt appears in the local area.

(2) At the same time, it can be found that the sidewalk space is relatively closed, and the distributed wind speed is small, but the flow field is relatively uniform, and only the disturbed wind flow area appears locally. The wind speed increases and then decreases along the air intake - return air direction, and the wind speed of the sidewalk space increases significantly due to the lateral offset of the high-speed wind flow area in the front space. As a result, the front roller center to the downwind side is 21.1 m, and the bottom plate the upper part of the space from 0.9 m to the top plate is combined into a high-speed wind flow area with a maximum wind speed of 2.4 m/s. The high-speed wind flow gradually collects toward the vicinity of the top plate in the air intake - return air direction, and the cover size in the direction of the top plate-floor is gradually reduced.

4.2. Dust distribution in the breathing area of personnel

During the production operation, the cutting and moving operations are mostly parallel, and the operators often go to the front of the Hydraulic support and the sidewalk to meet the needs of the site. For this reason, the dust of the working surface after dust generation for 20 s, 40 s and 60 s is analyzed. The granules and their migration trajectories are used as the breathing zone for the height of the miners' noses and noses 1.6 m away from the base of the support, and the cross-section of the respiratory belt is y=1.8 m (front) and y=2.1 m (sidewalk). Moreover, since the dust is affected by the wind flow, the degree of pollution on the windward side is very small, so only the dust escape of the shearer and the leeward side area is analyzed, as shown in Fig. 5.

![Figure 3](image1.png)  
**Figure 3.** Dust concentration distribution in the space breathing zone before the Hydraulic support (y=1.8m)

![Figure 4](image2.png)  
**Figure 4.** Distribution of dust concentration in the breathing zone of the sidewalk space (y=2.1m)
Can be seen from Figure 3 ~ Figure 5:

1. The dust pollution area in front of Hydraulic support and sidewalk breathing belts is mainly distributed near the downwind side of the cutting roller, and the dust generated by the rear roller of the cutting bottom coal is blocked by the shearer during the process of diffusing to the front of the Hydraulic support and the sidewalk. The dust concentration on the downwind side of the rear roller is relatively smaller than that of the front roller. With the prolonged dust generation time (20 s~80 s), the front and rear roller cutting and moving dust are gradually collected in the breathing zone during the dispersion process, and the three are superimposed. This causes the dust to spread over a wide range of breathing zones in the work area of the person.

2. The dust concentration in front of Hydraulic support breathing zone increased first and then decreased, then increased and then decreased. The dust concentration between 16.4 m and 47.2 m on the downwind side of the Hydraulic support was maintained above 200 mg/m³. The dust concentration at about 7.2 m on the downwind side of the center of the rear roller increased significantly and increased to the peak at about 2.1 m on the leeward side. The dust side of the front roller is about 8.3 m at the lower wind side, the dust concentration increases to the maximum value, and the dust concentration in the vicinity of 3 m is maintained at 1000 mg/m³. In addition, as the dust-producing time is prolonged, the dust-contaminated area gradually increases and after the dust is produced for 80
s, the height of the breathing zone covering the entire space in front of the Hydraulic support is maintained and the dust concentration is maintained above 100 mg/m³.

(3) The dust concentration of the sidewalk breathing zone is significantly lower than that of the space in front of the Hydraulic support. At the same time, the dust concentration of the breathing zone after the dust production for 20 s is relatively low. The reason is that the dust scattered in the sidewalk is mainly from the coal mining machine Hydraulic support and the space in front of the Hydraulic support. The lateral flow of the dust flow is offset, and the dust flow has a time and space lag during the migration process. The dust concentration after dust production for 40 s and 80 s was similar in the range of 22.6 m to 49.2 m on the downwind side of the moving Hydraulic support, and the dust concentration was maintained above 300 mg/m³. The concentration peaks appear at about 16.9 m on the downwind side of the center of the rear roller and about 18.5 m to 22.7 m on the downwind side of the front roller. In addition, the dust-contaminated area gradually increases with the extension of the dust-producing time. After 80 s of dust production, the dust covers the height of the breathing zone before the entire hydraulic support and the dust concentration is maintained above 100 mg/m³.

5. Conclusion

(1) As the dust spreads on the working surface driven by the wind flow, the dust-carrying wind flow moves laterally after the shearer, moving to the sidewalk space and the roadway, causing the dust concentration in the sidewalk space to increase sharply, and near the shearer The dust concentration at the position of 5 to 20 m on the leeward side is the largest, and this area should be the focus of dust control.

(2) In the front breathing belt, the dust concentration between the 16.4 m and 47.2 m on the downwind side of the moving Hydraulic support is maintained above 200 mg/m³, and the dust concentration was increased to the peak at a position of approximately 9.3 m on the downwind side of the center of the rear drum and approximately 8.3 m on the downwind side of the front drum center.

(3) The concentration peaks of the sidewalk breathing zone appear at about 16.9 m on the downwind side of the rear drum and about 18.5 m to 22.7 m on the downwind side of the front drum. After the dust is generated for 40 s and 80 s, the downside of the hydraulic support is about 22.6 m to 49.2 m. The dust concentration in the range is maintained above 300 mg/m³. In addition, after 80 s of dust production, the dust pollution basically covers the height of the breathing zone in front of the rack and in the sidewalk space.

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