Basic Research on Application of Airborne Ventilation and Dust Removal in Fully Mechanized Mining Face with Large Mining Height

Yongwen Guo¹, Jinming Mo ² *, Yunqiu Liu¹, Wei Ma², Sheji Zhang²

¹ China Shenhua Shendong Coal Group Co., Ltd., Ordos, China
² China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing, China

*Corresponding author e-mail: 1028313467@qq.com

Abstract: Taking the fully mechanized mining face of bulianta 12511 as the research object, the distribution law of dust movement in fully mechanized mining face with 8m large mining height was numerically simulated by using CFD software. Through the simulation results of the original dust field, it is found that the dust produced by the collapsed coal seam diffuses to the rear of the shearer under the action of wind flow, the highest point of movement of high-concentration dust mass can reach 4m, and the dust concentration gradually decreases along the roadway. High concentration dust is mainly concentrated in the 10m range before and after the shearer and on the side of the bottom plate close to the coal retaining plate, with a maximum of 3500mg/m³. In order to effectively reduce the dust in the working face, prevent dust accumulation and pollute the underground working environment, this paper innovatively proposes to install an airborne dust collector in the large mining height working face to control the dust spreading to the pedestrian side at the dust source and purify the dust. By studying the influence of dust collector placement position and treatment air volume on the dust movement and distribution rule and dust removal effect of the working face, the optimal dust removal efficiency of the working face with large mining height is obtained by the dust collector placement position and treatment air volume adaptation combination, and the maximum dust removal efficiency can reach 100%.

1. Preface

Fully mechanized mining face has the characteristics of high mining intensity and large dust production. In recent years, with the continuous improvement of automation degree, the mining height and speed of the working face have been continuously increased, resulting in a significant increase in the dust concentration of the working face. According to relevant on-site measurements, the total dust concentration of the fully mechanized working face can reach a maximum of 5000mg/m³ without any dust prevention measures, seriously affecting the physical and mental health of workers [1-3].

At present, the main control measure for dust in fully mechanized mining face is spray dust removal. However, due to the problems that pipelines are not easy to arrange when spraying dust removal, water mist seriously affects the line of sight of workers, and excessive water leads to coal metamorphism, etc., in recent years, relevant scholars have begun to conduct new research on dust removal in fully
mechanized mining face. Wang Haiqiao et al [4] studied an air dust isolation technology according to the theory of fluid mechanics air jet. Chen Dawei et al [5] designed a new type of wet dust collecting net system, which includes a wet rolling shutter door in the coal mining area, a dust collecting net and a full cross-section wet dust collecting net in the air return duct to control dust. Liu Qiang et al [6] studied the dust diffusion law and dust control effect analysis of multi-path cyclone air curtain position on fully mechanized coal face. Although these measures have greatly reduced the dust concentration in the fully mechanized mining face, they cannot purify the dust at the dust source, resulting in the dust still spreading to the working face. Therefore, this paper takes the fully mechanized mining face of bulian tower 12511 as the research background, and through analyzing the characteristics of dust migration and distribution in the face with large mining height, proposes to install a dust collector to control dust diffusion to the pedestrian side and purify dust at the dust source. Through simulation analysis, the influence of dust remover installation position on dust migration distribution and dust removal effect in working face is recorded, so as to obtain the best dust removal effect of airborne dust remover arrangement position, so as to effectively control dust pollution in working face.

2. Mathematical model

The movement of dust in fully mechanized coal face with airflow can be regarded as gas-solid two-phase flow, dust is regarded as sparse phase, gas in roadway belongs to continuous phase, and gas flow is often regarded as turbulent flow. Therefore, the diffusion movement of dust and turbulent flow of airflow in fully mechanized coal face can be solved by Euler-Lagrange model and k-ε model respectively [7-10].

In the process of solving fluid continuous phase, we must follow the laws of mass conservation, energy conservation and momentum conservation. These three equations are often combined into N-S equations.

If the gas is considered as incompressible fluid, the continuity equation can be expressed as [11]:

$$ \frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 $$

(1)

N-S equation: (where fluid is incompressible)

$$ \rho \frac{du_i}{dt} = \rho \nabla \mathbf{u} + \mu \nabla^2 \mathbf{u} $$

(2)

In formula (2), $\nabla^2 = \left( \frac{\partial^2}{\partial x_i^2} + \frac{\partial^2}{\partial x_j^2} + \frac{\partial^2}{\partial x_k^2} \right)$. If it is an incompressible fluid $\nabla \cdot \mathbf{u} = 0$, $\mu = 0$. Equation (2) can be simplified as:

$$ \frac{du_i}{dt} + (\mathbf{u} \cdot \nabla) \mathbf{u} = f - \frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u} $$

The two important parameters describing turbulent flow are turbulence kinetic energy $k$ and turbulent diffusivity respectively $\varepsilon$. The $k$ equations and $\varepsilon$ equations can be described as follows:

$k$ equations:

$$ \frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \left( \frac{\mu + \frac{\mu_t}{\sigma_k}}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_h - \rho \varepsilon - Y_m + S_k $$

$$ G_k = \mu_s S^2, \quad S = \sqrt{2 S_\theta S_u}, \quad S_\theta = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_i} \right) $$

(3)
\[ \varepsilon \text{ equations:} \]

\[
\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_j}(\rho u_j \varepsilon) = \frac{\partial}{\partial x_i} \left[ \left( \mu + \frac{\mu_t}{\sigma_f} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + \rho C_s \varepsilon - \rho C_v \varepsilon^2 \left( \frac{k}{\varepsilon} + \frac{\varepsilon}{\kappa} \right)^{\frac{1}{2}} + C_i \frac{\varepsilon}{k} \left( \frac{\kappa}{\varepsilon} \right)_s G_b + S_\varepsilon \quad (4)
\]

\[ C_i = \max \left( \sqrt{0.43 \frac{\eta}{\eta+5}}, \varepsilon \right) \eta = S \frac{k}{\varepsilon} \]

Among them \( \mu_t, \mu \) for the speed in the direction of the component \((m \cdot s^{-1})\), \( \rho \) indicating the airflow density \((kg \cdot m^{-3})\), \( \mu, \mu_t \) respectively, indicating laminar flow, turbulence in the viscosity coefficient \((Pa \cdot s)\), \( C_i = 1.92, \sigma_f = 1.0, \sigma_s = 12, C_{v_1} = 1.44 \), because this article assumes that the gas is incompressible gas, so \( \gamma_c \) take 0.

3. Establishment of Numerical Calculation Model and Grid Partition

3.1. Model Building

Based on the fully mechanized mining face of bulian tower 12511, this paper uses CAD software to establish a calculation model according to the actual situation on site, as shown in fig. 1. X The model mainly consists of goaf, material roadway, transportation roadway, shearer, hydraulic support and coal retaining plate. The tunnel has a regular rectangular section with a mining area of \(300.8 \, m^2 \times 8.0 \, m \times 6.8 \, m\) and a material tunnel of \(110.0 \, m^2 \times 6.0 \, m \times 4.3 \, m\). The tunneling roadway is \(116.0 \, m^2 \times 5.8 \, m \times 4.5 \, m\), and the goaf is \(300.8 \, m^2 \times 12.0 \, m \times 6.8 \, m\). This paper only studies the distribution law of dust produced by caving coal seam in roadway, and the dust source setting is shown in Figure 1. At the same time, the following assumptions are made without affecting the simulation results [11]:

1. The air in the coal roadway is regarded as incompressible fluid, and the airflow density in the coal roadway is constant, which is \(1.225 \, kg/m^3\);

2. The temperature in the tunnel is set as constant temperature by default. Assuming that the temperature in the tunnel has no influence on the result, it is ignored;

3. Each variable in the flow field is considered as a steady flow field independent of time.

Fig 1. Model of fully mechanized mining face of bulian tower 12511
3.2. Grid division
The established fully mechanized mining face model is imported into ICEM-CFD for grid drawing. Due to the fact that the actual situation of the tunnel is rather complicated in the actual simulation calculation, it is decided to use unstructured grid with better adaptability to divide it [12-13]. A total of 3.057407 million grids were generated. Since the number of grids has a great influence on the accuracy of numerical simulation results, the grids were adaptively adjusted to ensure smaller size distortion rate and angle distortion rate.

3.3. Parameter Setting
The parameters of simulation parameters are set according to the actual situation on site. The solver adopts steady state and absolute velocity when solving the ventilation dust field. As dust particles are affected by gravity in the roadway, the gravity acceleration is set during simulation calculation. Specific parameters are shown in Table 1.

| Boundary conditions          | Parameter setting | Boundary conditions          | Parameter setting |
|------------------------------|-------------------|------------------------------|-------------------|
| Inlet Boundary Type          | velocity-inlet    | Injection Type               | Rosin-Rammler     |
| Velocity Magnitude(m/s)      | 1.2               | Diameter Distribution        |                   |
| Turbulent Intensity(%)       | 5                 | Min. Diameter(m)             | 1e-06             |
| Turbulent Viscosity Ratio    | 10                | Max. Diameter(m)             | 1e-04             |
| Outlet Boundary Type         | Outflow           | Mid. Diameter(m)             | 2e-05             |
| Wall Shear Condition         | No Slip           | Number of Diameters          | 150               |
| Interaction with Continuous Phase | On                  | Spread Parameter             | 3.5               |
| Number of Continuous Interaction per DPM Iteration | 300                          | Total Flow Rate(kg/s)        | 0.01              |

4. Numerical simulation results
In this paper, the problems of dust migration and distribution in the original dust field with 8m mining height in the fully mechanized mining face of bulianta 12511 are analyzed by numerical simulation method. Then, aiming at the existing problems, the airborne dust collector is proposed to purify the dust at the falling dust source and prevent the dust from spreading to the pedestrian side. Moreover, in order to achieve better dust suppression effect, the airborne dust collector can obtain the best dust suppression effect by analyzing the distribution law of dust movement in the working face and the influence of dust suppression effect by the installation position of the airborne dust collector.

4.1. Simulation Results of Original Dust Field with 8m Mining Height in 12511 Fully Mechanized Mining Face

![Fig 2. Dust concentration distribution diagram of XOY section.](image)
Fig. 2 shows the concentration distribution of the original field when no airborne dust remover is installed in the fully mechanized mining face of bulian tower 12511. From the above figure, it can be seen that: (1) dust generated by coal seam collapse diffuses to the rear under the drive of wind flow (z-axis positive direction). Due to the blocking of the shearer, the movement direction of dust changes when encountering the shearer, moving along the shearer body to the top plate, and then starting to move backward. (2) The highest point of high-concentration dust mass movement can reach 4.5-5m and move backward to the side of the coal mining machine. Due to the gravity of the dust particles themselves, the large-particle dust gradually settles and the small-particle dust continues to move along with the wind flow and is suspended in the working face. The high-concentration dust mainly accumulates in the 10m range before and after the coal mining machine and the side of the bottom plate close to the coal retaining plate, reaching a maximum of 3500mg/m³, which greatly exceeds the dust concentration range [14] specified in the coal mine safety regulations. The high concentration of dust near the coal mining machine will seriously affect the driver's sight, and will also cause severe equipment loss and greatly affect the safe mining of the coal mine. (3) Between 20 and 30 meters from the end, dust began to spread to the side where people walked. The dust concentration measured by the people on the top of the coal baffle was as high as 2,500 mg/m³. The dust concentration exceeded the limit seriously, which seriously affected the health and safety of the staff. Thus, the dust pollution in the original 12511 fully mechanized mining face was serious, and it was urgent to carry out underground dust prevention research.

4.2. Analysis of Numerical Simulation Results of Airborne Ventilation and Dust Removal

According to the actual situation of the fully mechanized mining face and the structural characteristics of the shearer, there are two layout positions of the airborne dust collector, as shown in fig. 3. Arrangement: the first airborne dust collector is arranged on the top of the shearer body, and the second airborne dust collector is arranged on the windward side fuselage end face of the shearer.

4.2.1 Dust Concentration Distribution at Different Positions of Dust Collection Mouth. Figs. 4 and 5 respectively show the dust concentration distribution of the working face when dust collectors are respectively installed at the top of the shearer body and the end face of the windward side body of the shearer. It can be seen from the figure that: (1) along the wind flow direction, the dust concentration gradually decreases with the increase of distance from the shearer, but the dust diffusion range gradually increases, especially when the dust collector is arranged at the top of the shearer body; (2) High concentration dust mainly accumulates in the range of 5m before and after the shearer. The maximum height of dust diffusion to the roof is 2.5m After 15m from the windward end of the shearer, almost no high concentration dust mass appears. (3) The installation position of the dust collector has obvious influence on the dust concentration distribution in the working face. Compared with Figures 4 and 5, it can be seen that the dust collector installed at the windward side fuselage end face of the shearer has obvious dust collection effect and the working face environment has been significantly improved.
4.2.2 Dust concentration distribution along the route. Fig. 6 shows the dust concentration distribution along the working face. Compared with the above figure, it can be seen that (1) the dust concentration along the coal winning machine is obviously higher than that on the side of the coal blocking plate close to the pedestrian. The high concentration dust on the side of the coal blocking plate close to the pedestrian is mainly concentrated in the range of 20-30 m from the air inlet, and the high concentration dust on the dust remover is mainly concentrated in the range of 40-60 m from the air inlet. (2) The use of dust remover has obviously improved the working face environment. When the dust remover is not installed on the side of the coal baffle near the pedestrian, the maximum concentration of the original dust field can reach 3600 mg/m³, and the dust concentration after installing the dust remover can be reduced to 2500 mg/m³; Similarly, the concentration of the original dust field at the dust collector position is 4000 mg/m³, and the dust concentration drops to 700 mg/m³ after the dust collector is installed. (3) The installation position of dust remover has obvious influence on dust removal effect. Compared with the above figure, the dust removal effect is the best when the dust remover is arranged on the windward side fuselage end face of the shearer.

Fig 6. Dust concentration distribution along the working face.
4.3. Dustfall Effect Analysis

In order to analyze the influence of dust remover installation position on dust removal effect of working face, the dust removal effect before and after installation of airborne dust remover is analyzed by selecting the side of coal baffle plate and the highest dust concentration point along the dust remover position (as shown in fig. 6). As can be seen from Table 2, the installation of airborne dust remover has greatly improved the dust pollution of the working face. In position 1, the dust removal efficiency is 13.5% when the airborne dust remover is arranged according to mode 1 and 32.4% when it is arranged according to mode 2. In position 2, the dust removal efficiency is 57.4% when the airborne dust remover is arranged according to mode 1 and 99.7% when it is arranged according to mode 2. Therefore, when the airborne dust remover is arranged according to mode 2, the dust removal effect is the best.

Table 2. Dust Removal Efficiency when Airborne Dust Removers are Arranged at Different Positions.

| Position | Original dust concentration (mg/m³) | The airborne dust collector shall arrange the dust concentration according to mode 1.(mg/m³) | Dustfall efficiency | The airborne dust collector shall arrange the dust concentration according to mode 2.(mg/m³) | Dustfall efficiency |
|----------|----------------------------------|-------------------------------------------------|--------------------|-------------------------------------------------|--------------------|
| Position 1 | 3700 | 3200 | 13.5% | 2500 | 32.4% |
| Position 2 | 4085 | 1740 | 57.4% | 14 | 99.7% |

5. Conclusion

1) With the increase of the distance from the end, the dust concentration in the working face gradually decreases along the way. Due to the wind flow and the gravity of the dust itself, the dust finally settles near the side of the coal retaining plate close to the shearer. The high-concentration dust mass is mainly concentrated on the side of the shearer within 20m of the front and rear of the shearer, and the diffusion height to the roof can reach about 4m, with the highest concentration reaching 3500mg/m³. Due to the effect of the coal retaining plate, the dust diffusion on the side of the bracket is relatively small.

2) The location of airborne dust collector has obvious influence on the dust concentration distribution in the working face. The dust collection effect is obviously better when the dust collector is arranged at the windward side fuselage end face of the shearer than when the airborne dust collector is arranged at the top of the shearer. For working face position 1, the dust removal efficiency is 13.5% when the airborne dust remover is arranged according to mode 1 and 32.4% when it is arranged according to mode 2. In the second place, the dust removal efficiency is 57.4% when the airborne dust remover is arranged according to mode 1 and 99.7% when it is arranged according to mode 2. Reasonable dust collector location arrangement can obviously reduce dust concentration distribution in working face and improve underground working environment.

3) In order to achieve better dust removal effect at the fully mechanized mining face of the supplement tower 12511, the airborne dust remover should be arranged at the windward side fuselage end face of the shearer.
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