Numerical Simulation Study on the Movement Characteristics of Dust Flow in Mine Working Face

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Abstract. Based on the computational fluid dynamics and mine ventilation theory, the geometrical model of the fully mechanized excavation face under the conditions of long-short and short-pump ventilation system was established with the comprehensive mining face of the 905 transportation lane in Shanxi Coal Group. The FLUENT software is used to simulate the distribution characteristics and variation of the wind flow field and dust field in the three-dimensional space of the fully mechanized excavation working face at different air supply speeds, and the simulation results are verified by field test. According to the numerical simulation study and the on-site measurement results, the optimal position of the dust migration law of the fully mechanized excavation face under the long-short and short-drain ventilation mode is determined, and the rationalization suggestions for the mine dust control are put forward.

1. Introduction
With the continuous development of the heavy-duty trend of mine equipment, the production and concentration of flour dust in the comprehensive excavation work have increased significantly, seriously polluting the working environment of underground workers, resulting in an increase in the number of patients with pneumoconiosis. On the one hand, dust has an explosion hazard [1], which is harmful to normal production safety; on the other hand, the respiratory dust in the dust is very likely to cause pneumoconiosis after being inhaled into the lungs. Pneumoconiosis is a disease of pulmonary fibrosis that jeopardizes the health of workers themselves. At present, some scholars at home and abroad have carried out numerical simulation research on the dust concentration of mine work, but most of the selected physical models of the working face are small, limited to the range within a few meters near the working face, and rarely involved in actual engineering. Numerical simulation of the background. Taking into account the above factors, the roadway of the fully mechanized excavation face of the 905 transport lane of Shanxi Coal Group was selected as the research object. The Fluent software was used to simulate the dust concentration of the roadway under different wind speeds [2-3].
2. Mathematical model establishment

The wind flow in the mechanized excavation face is regarded as a constant uncompressible flow, and the dust particles are defined as discrete media, and any flow problems must be met and the law of conservation of mass is observed [4]. This law applies to a wide range of subjects and falls within the most basic laws. For this law, it can be briefly stated that the mass increase in the fluid micro-element body per unit time is equivalent to the relevant net mass flowing into the micro-element body in the same time interval, and the mass equation is often called a continuous equation.

\[
\frac{\partial p}{\partial t} + \frac{\partial (pu)}{\partial x} + \frac{\partial (pv)}{\partial y} + \frac{\partial (pw)}{\partial y} = 0
\]

The law of conservation of momentum is also one of the basic laws that must be satisfied by any flow system [5]. The simplification of this law is actually Newton’s second law. The analysis explores the relationship between force and velocity and acceleration. Here, SU, SV, and SW are the generalized source terms of the momentum conservation equation, which broadens the meaning category of the equation.

\[
\frac{\partial (pu)}{\partial t} + \text{div}(pu\text{grad}) = \frac{\partial p}{\partial x} + Su
\]

\[
\frac{\partial (pv)}{\partial t} + \text{div}(pv\text{grad}) = \frac{\partial p}{\partial y} + Sv
\]

\[
\frac{\partial (pw)}{\partial t} + \text{div}(pw\text{grad}) = \frac{\partial p}{\partial z} + Sw
\]

Within a specific system, there may be material exchange, energy exchange or interaction of various chemical components, and the operation of each component needs to follow the rules of the conservation law of component mass.

\[
\frac{\partial (pc_s)}{\partial t} + \text{div}(puc_s) = \text{div}(D\text{grad}(pc_s)) + S_s
\]

3. Geometry model construction and meshing

3.1. Geometric Model

According to the scene of the fully mechanized excavation face of the 905 transportation lane under the Shanxi Coal Group, the SolidWorks is used to construct the geometric model of the working face. The comprehensive excavation working face is composed of four parts: press-in type air duct, extraction type air duct, roadheader and rectangular block roadway [6], the roadway area is 16.72m², and the roadway is one length × width × height = 60m × 4.4m × 3.8m The cuboid. The total length of the comprehensive excavator is 11.5m, which is divided into three parts: the fuselage, the cutting arm and the cutting head. The fuselage is a rectangular parallelepiped with length × width × height = 10m × 2.5m × 2m. The cutting head is long 1.3m, 1.2m diameter cylinder, close to the working surface, as shown in Figure 1.
3.2. Meshing

After drawing with SolidWorks, save the file to x-t format, then import it into ICEM-CFD for meshing [7]. After importing it, the quality of the mesh is first detected, as shown in Figure 2. Then two points form a body, after naming the boundary, then set the inlet and outlet, set the global mesh size for mesh smoothing optimization, and the process of mesh generation is the computer area discretization process, thus forming a three-dimensional model of the comprehensive face meshing simulation map, as shown in Figure 2.

3.3. Simulation Results Analysis

According to the above principle and calculation model, the numerical simulation of the built physical model is carried out by Fluent, and the distribution of the wind flow field on each section and the distribution of the wind flow velocity in the whole roadway are obtained.

(1) On the Y-Z section, a vector diagram of three sections is obtained by taking X = 0.5 m, X = 1 m, and X = 1.5 m, respectively. The model diagrams formed in these three sections are determined by the structure of the long-short-short ventilation system, which is the result of the combined formation of the two types of extraction and indentation, as shown in Figure 3.
(2) On the Y-X section, take \( Z = -10 \text{m}, Z = -20 \text{m}, Z = -30 \text{m}, Z = -40 \text{m} \), respectively, for a total of four sections, showing the vector diagram formed, as shown in Figure 4.

(3) On the X-Z section, take \( Y = 0.4 \text{m}, Y = 0.8 \text{m}, Y = 1.2 \text{m}, Y = 1.6 \text{m} \), and a total of four sections, showing the vector diagram formed, as shown in Figure 5.
Figure 5. Distribution of dust mass concentration in the plane of Y=0.4, 0.8, 1.2, 1.6m

As can be seen from Figure 6 below, the mass concentration of dust in the front and middle of the road head in the roadway is significantly higher than that in the rear of the road header. As shown in the figure, after the dust concentration in the front part of the road header can reach 13800mg/m3, the concentration gradually decreases to 5980mg/m3 as the extension to the middle of the roadway, and the average concentration in the middle of the roadway can reach 5120mg/m3, while the dust concentration in the rear part decreases sharply. At 1710 mg/m3, and significant sedimentation began to occur.

Figure 6. Distribution of dust mass concentration in the roadway

Some large particle dusts will settle due to the influence of air flow and the gravity of the larger particles themselves. The dust mass concentration at the floor of the roadway is significantly higher than the dust concentration at other heights of the roadway from the heading surface to the working space of about 3m of the suction air inlet. The concentration of the bottom plate can reach up to 2900mg/m3, and gradually decreases to 130mg/m3 as the dust migrates backward, and can reach 460mg/m in the middle part of the roadway.
4. On-site measurement

In order to understand in detail the rules of flour dust migration in the mine, the on-site dust measurement was carried out by the dust concentration analyzer [10]. And the measurement results were analyzed. The specific measurement scheme is as follows.

The measured values and numerical simulation values of the dust concentration at each section are shown in Table 1.

Table 1. Measured values and numerical simulation values of measuring point dust concentration.

| Measuring point position | Dust concentration | 5m     | 15m     | 25m     | 35m     |
|--------------------------|--------------------|--------|--------|--------|--------|
|                         | Measured value     | 266.8  | 410.5  | 185.7  | 50.8   |
| (0.4,1.5)                | Analog value       | 238.2  | 382.8  | 196.3  | 48.7   |
|                          | Relative error     | 7.54   | 6.56   | 5.64   | 6.18   |
|                         | Measured value     | 243.6  | 385.6  | 168.4  | 44.3   |
| (1.2,1.5)                | Analog value       | 212.3  | 346.6  | 138.4  | 32.4   |
|                          | Relative error     | 7.12   | 6.38   | 4.86   | 6.48   |
|                         | Measured value     | 238.4  | 368.6  | 172.4  | 40.3   |
| (3.6,1.5)                | Analog value       | 212.6  | 332.4  | 156.6  | 32.2   |
|                          | Relative error     | 7.64   | 6.64   | 4.23   | 6.18   |

When the long-short-short ventilation method is adopted in the comprehensive excavation working face, the measured values of the wind speed in each section are generally consistent with the numerical simulation values. Among the relative errors, the relative error range between the measured value of the dust concentration and the numerical simulation value is between 0~10%, and both of them are within a reasonable range. Therefore, its regular application has certain guiding significance for production practice.

5. Conclusion

Taking the actual mechanized excavation working face as an example, the distribution law of dust under fixed pumping air volume, fixed pumping pressure ratio and fixed pumping air cylinder mouth position is studied. Fluent numerical simulation is used to simulate the more complicated dust field generated under the ventilation condition. Perform a simulation analysis. The press-in type wind flow of the comprehensive excavation will reverse the outflow after leaving the air duct mouth to flush the working surface, and a rotating center with a small wind speed is formed in this process. The center of the revolution has the lowest wind speed and is easy to form a dust accumulation area. Therefore, the integrated dust and dust concentration sensor should be installed near the center of the rotation as much as possible so that the dust concentration of the excavation can be detected more accurately.

Mine dust prevention and control work should be adapted to local conditions. According to the actual situation, a variety of dust reduction and dust removal measures are determined and used in combination, such as spray dust reduction, dust-reducing foam, dust removal fan, dust-reducing water curtain, etc. The combination of various dust control measures can form a relatively complete system, which ultimately maximizes and optimizes the ventilation and dust removal effect.

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