Analysis on the Influence of the Diameter of the Suction Air Inlet of the Air Duct on the Wind Flow Field

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Abstract. The comprehensive excavation face is the most seriously polluted place in the underground of coal mine. Using FLUENT software to simulate the influence of the diameter change of the suction air inlet of the extraction duct on the airflow field in the long pressure short draft ventilation system, the roadway in the comprehensive excavation was taken as the research object. From the simulation results, it can be seen that the diameter of the air intake directly affects the air flow distribution in the roadway, the change of the diameter of the suction nozzle will interfere with the inrush jet, Which has the greatest influence on the wind speed within the range of 0-10m from the excavation end. At the same time, it has obvious influence on the vortex in the roadway. When the diameter of the suction air outlet increases from 0.5m to 0.6m, the vortex area decreases, and when the diameter increases from 0.6m to 1.0m, the vortex area gradually expands.

1. Introduction

In recent years, due to the long-distance and large-section tunneling of the comprehensive tunneling face and the continuous breakthrough in tunneling speed, the emission of harmful substances such as gas and dust in the mine is increasing, which seriously threatens the safe production of the coal mine and the physical and mental health of workers [1]. Tunneling ventilation plays a key role in improving the distribution of gas and dust movement and the discharge of harmful substances [2]. Therefore, it is of great practical significance to study the influence of various ventilation parameters on the wind speed distribution and eddy current of the roadway under different ventilation modes so as to obtain the ventilation parameters with the best effect of removing tiles and falling dust [3-6].

Aiming at the long pressure and short pumping ventilation system, the pressure jet will form a discontinuity with the surrounding air. the discontinuity will lose stability and form eddy current when disturbed by wind flow. the generation of eddy current will cause dust and gas accumulation and cannot be effectively diluted and discharged [7]. According to this law, starting from the influence of the diameter change of the suction opening of the suction drum on the wind flow field, using fluent software to simulate and analyze the different suction opening diameters of the actual fully mechanized excavation face to obtain the wind flow and vortex distribution laws under different suction opening diameters, which providing theoretical basis for realizing a safe and green ventilation environment.
2. Theoretical analysis of wind flow field in fully mechanized mining face

In the process of solving the fluid continuous phase, the laws of mass conservation, energy conservation and momentum conservation must be followed. These three equations are often combined into N-S equations [8].

If gas is considered as an incompressible fluid, the continuity equation can be expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$  \hspace{1cm} (1)

N-S equations: (wherein that fluid is incompressible)

$$\rho \frac{du}{dt} = \nabla p + \rho \nabla^2 \mathbf{u}$$  \hspace{1cm} (2)

In formula (2), \(\nabla^2 = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)\), if it is an incompressible fluid \(\nabla \cdot \mathbf{u} = 0, \mu = 0\). The formula (2) can be simplified as follows (3):

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \frac{1}{\rho} \nabla^2 \mathbf{u}$$  \hspace{1cm} (3)

The realizable \(k-\varepsilon\) model is suitable for calculating swirling uniform shear flow, plane mixed flow, plane jet, circular jet, fully developed flow in pipes, boundary layer flow, etc [9]. The tunneling roadway adopts long pressure and short pumping ventilation, the airflow is turbulent, and the streamline curvature at the head-on position is larger. In order to make the simulation result more accurate, the realizable \(k-\varepsilon\) model is adopted. The equation is as follows:

\(k\) equation:

$$\frac{\partial}{\partial t} \left( \rho k \right) + \nabla \cdot \left( \rho \mathbf{u} k \right) = \nabla \cdot \left( \left( \mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right) + \varepsilon_k + \varepsilon_t - \rho \varepsilon \cdot Y_{\varepsilon} + S_k$$  \hspace{1cm} (4)

\(\varepsilon\) equation:

$$\frac{\partial}{\partial t} \left( \rho \varepsilon \right) + \nabla \cdot \left( \rho \mathbf{u} \varepsilon \right) = \nabla \cdot \left( \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + \rho \varepsilon \varepsilon - \rho \varepsilon \cdot Y_{\varepsilon} + C_{\varepsilon} \frac{\varepsilon^2}{k} + C_{\varepsilon} \varepsilon \cdot \varepsilon - S_{\varepsilon}$$  \hspace{1cm} (5)

$$C_{\varepsilon} = \max \left[ 0.001, \frac{\eta}{S_{\varepsilon} + \rho \varepsilon} \right], \eta = \frac{k}{\varepsilon}, S = \frac{\sqrt{kS_k S_{\varepsilon}}}{\rho \varepsilon}$$

Where \(k\) is turbulent kinetic energy, \(J\); \(\rho\) is density; \(\varepsilon\) is turbulent kinetic energy dissipation rate, dimensionless; \(G_k\) is turbulent kinetic energy generated by laminar flow velocity gradient, \(J\); \(G_b\) is turbulent kinetic energy generated by buoyancy, \(J\); \(Y_{\varepsilon}\) is diffusion kinetic energy generated by compressible turbulence, \(J\); \(C_2, C_1e\) is constant, \(C_2 = 1.9, C_1e = 1.44\); \(\sigma_k, \sigma_\varepsilon\) is turbulence number, \(\sigma_k = 1.0, \sigma_\varepsilon = 1.2\); \(S_k, S_{\varepsilon}\) is user-defined source item, kg/(m\(^2\)·s).

3. Establishment of numerical simulation scheme

3.1. Establishment of finite element model

In this study, the length and width height of the tunnel model used to study the influence of the diameter of the air suction opening of the air suction tube on the airflow field under the condition of long pressure and short suction ventilation is as follows: \(30 m \times 5 m \times 5 m\). The tunnel is arched in shape. The press-in ram is arranged on the right side of the roadway, the ram air outlet is 10m away from the tunneling section and the ram axis is 2m away from the bottom plate; The extraction type ram is arranged on the left side of the roadway, the ram air outlet is 3m away from the heading end and the ram axis is 3m away from the bottom plate [7]. The tunnel geometry model is shown in figure 1.

![Figure 1. Geometric model](image)
3.2. Determination of solution parameters
Import the divided grid model into fluent, model entrance micro velocity inlet, uniform speed, the exit boundary is from the roadway to the end face, other parameter settings are shown in table 1 and table 2. Make the following assumptions without affecting the simulation results [10]:
1) The air in the coal roadway is regarded as an incompressible fluid, and the airflow density in the coal roadway is constant.
2) The temperature in the tunnel will be kept constant by default. Assuming that the temperature in the tunnel has no influence on the result, will be ignored.
3) Each variable in the flow field is considered as a steady flow field regardless of time.
4) The resistance caused by the inner wall of the roadway is ignored, and the air leakage of the ram is not considered.

| Table 1. Calculating model parameters |
|--------------------------------------|
| Computational model                   |
| Model setting                        |
| Steady                               |
| Solver                               |
| Absolute Velocity                    |
| Gravity (y=-9.81m/s²)                |
| Viscous Model                        |
| Realizable k-ε                       |

| Table 2. Boundary condition parameter |
|--------------------------------------|
| Projects                             |
| Press - in ram                       |
| Inlet velocity/m·s⁻¹                 |
| 13.27                                |
| Hydraulic diameter/m                 |
| 0.8                                  |
| Turbulence intensity/%               |
| 2.97                                 |
| Suction ram                          |
| -19.66                               |
| 0.6                                  |
| 2.93                                 |

4. Analysis of the influence of the diameter of the draft tube on the wind flow field
There are many factors affecting the wind flow field [11-12], this study only studies the influence of the diameter of the draft tube on the wind flow field under the condition of long pressure and short draft ventilation. Through simulating the variation law of air flow field with diameter of 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0m respectively, in order to provide theoretical basis for seeking the optimal air flow distribution in roadways.

4.1. Analysis of wind speed distribution at axial height of extraction ram

Figure 2. Wind speed distribution cloud picture at axis of extraction ram

Figure 2 shows the wind speed distribution at the axis of the air cylinder when the diameter of the air suction port of the air cylinder is changed. When the air volume is constant, the larger the diameter of the air suction port is, the smaller the speed is. When the diameter of the air suction port is reduced from 1.0m to 0.7m, the speed of the air suction port is relatively small. there is a large area near the end of the axial section of the air suction drum with low wind speed. the expansion of the low wind speed area will lead to the formation of eddy currents, which is not conducive to the discharge of harmful substances such as dust and gas; When the diameter of the air suction port is 0.6m, the wind speed near the air...
suction port is evenly distributed. When the diameter of the air suction port is 0.5m, due to the high speed of the air suction port at this time, the high wind speed area is mainly distributed in near the side wall of the air suction drum. It can be seen that the diameter of the suction port has obvious influence on the airflow distribution in the roadway.

![Figure 3. Vector diagram of wind speed distribution at axis of extraction ram](image)

Figure 3. Vector diagram of wind speed distribution at axis of extraction ram

Figure 3 shows the vector diagram of the wind speed distribution of the tunnel with the axial section of the extraction ram. From the above figure, it can be seen that the change in the diameter of the suction opening can obviously affect the airflow distribution in the roadway, especially the formation of the vortex region. When the diameter of the suction port is 0.6m and 0.7m, there is no obvious vortex area in the roadway; When the diameter of the air suction port is 1.0m and 0.5m, the wind speed may be too small or too large, which may lead to the formation of a large eddy current area at the front end of the air suction port. the formation of the eddy current area is not conducive to the emission of dust and gas, which causing harmful substances to remain in the roadway, polluting the health of personnel and threatening the safe production of coal mines.

4.2. Analysis of wind speed distribution at axial height of compressed air cylinder

![Figure 4. Wind speed distribution cloud picture at axis of compressed air cylinder](image)

Figure 4. Wind speed distribution cloud picture at axis of compressed air cylinder

Figure 4 shows the overall velocity distribution cloud picture of the tunnel with the axial section of the press-in ram. From the figure, it can be seen that the forced jet reaches the tunneling end face, then changes the direction of the wind flow, some of the wind flow moves to the return flow area, and some of the wind flow is blocked by the end face to move reversely. However, the change of the diameter of the suction opening will directly affect the airflow distribution in the roadway. When the diameter of the suction opening increases from 0.6 m to 1.0 m, the eddy current area at the tunneling end surface gradually increases; When the diameter of the suction port is reduced from 0.6m to 0.5m, the eddy current area of the tunneling end face increases. When the diameter of the suction port is 0.7m, the wind speed distribution in the roadway is reasonable.

![Figure 5. Vector diagram of wind speed distribution at axis of ram](image)

Figure 5. Vector diagram of wind speed distribution at axis of ram

Figure 5 shows the vector diagram of the overall velocity distribution of the tunnel with the axial section of the press-in ram. From the figure, it can be seen that the wind speed in the roadway has changed greatly due to the change of the diameter of the suction opening. When the diameter of the
suction port is 1.0m, 0.9m and 0.8m, the low wind speed area of the tunneling end face is relatively large, forming eddy current area, and the wind speed distribution is unreasonable; When the diameter of the suction port is 0.6m and 0.5m, the eddy current area at the tunneling end face is relatively small and the wind speed distribution is relatively reasonable.

4.3. Analysis of wind speed distribution along pedestrian path

Figure 6 shows the wind speed distribution along the travel at the side of the ram. From the figure, it can be seen that with the increase of the distance from the tunneling end face, the wind speed pressing into the ram side, along the travel path of the person, increases first and then decreases. Within the range of 0 - 10m from the end face, the wind speed is greatly influenced by the diameter of the air suction opening. When the diameter of the air suction opening is 1.0m, 0.9m, 0.8m, 0.7m, 0.5m, the wind speed reaches the maximum value at 2m from the tunneling end face, then the wind speed gradually decreases, and the wind speed changes greatly. When the diameter of the air suction opening is 0.6m, the wind speed reaches the maximum value at 5m from the tunneling end face, then slowly decreases, the wind speed is less influenced by the diameter change of the air suction opening, and remains stable after 15m from the end face.

Figure 7 shows the wind speed distribution along the route at the side pedestrian of the suction ram. With the increase of the distance from the tunneling end face, the wind speed at the side of the suction ram shows a trend of increasing - decreasing - increasing - decreasing, and finally keeps stable. Within 2.5m - 7.5m from the end face, under the influence of the change of the diameter of the air suction opening, when the diameter of the air suction opening is 1.0m, 0.9m, 0.8m, 0.7m, 0.5m, eddy current will form in the roadway, the wind speed is relatively low, and the wind speed here will directly affect the discharge effect of harmful substances; between 7.5m and 12m away from the tunneling end face, the wind speed is the lowest when the diameter of the air suction port is 0.6m. At this time, eddy current may be formed here.

5. Conclusions

1) In the long pressure and short pumping ventilation system, the diameter change of the suction opening of the pumping air cylinder has obvious influence on the airflow distribution in the roadway. Through numerical simulation experiments, it is found that the change of the diameter of the suction port has a great influence on the distribution of the flow field formed by the press-in jet. When the position and diameter of the press-in ram are constant, there is a specific diameter of the suction port corresponding to the diameter of the suction port, which makes the distribution of the wind speed in the
tunnel reasonable. For the actual roadway used in this study, the optimum diameter of the air suction opening is 0.6m.

2) The change of the diameter of the suction opening of the extraction type air duct has obvious influence on the eddy current generation in the roadway. Along with the diameter of the air suction opening; When the diameter of the air suction opening increases from 0.5m to 0.6m, the eddy current area of the roadway increases; when the diameter of the air suction opening increases from 0.6m to 1.0m, the eddy current area of the roadway increases. The expansion of eddy current area is not conducive to the discharge of harmful substances and seriously affects the safe production of mines.

3) For the arrangement of long pressure and short pumping ventilation system, the airflow field should be simulated and analyzed by numerical simulation method, and the ratio of the diameter of the pumping air duct under the optimal ventilation condition should be determined based on the wind speed and eddy current distribution of the pedestrian in the roadway, so as to create a good working environment for the underground working conditions.

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