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Numerical Simulation of Ventilation and Dust Removal and the Dust Collection of inside Inhaling and outside Pressing Particle Collector in a Fully Mechanized Excavation Face

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Abstract The mine dust influence worker's health seriously. The research of dust concentration distribution is the foundation of the dust treatment. As the main place of dust producing, the fully mechanized excavation face is an important study object. Applying theoretical analysis and numerical simulation method, the paper used FLUENT software to simulate the distribution of dust in the roadway when the far-pressing-near-absorption ventilation and the inside inhaling and outside pressing particle collector were applied in the fully mechanized excavation face. The results show that the dust concentration of the roadway is larger in the range of 10m from the working face when the far-pressing-near-absorption ventilation is adopted while the dust concentration is larger in the range of 4m from the working face when the inside inhaling and outside pressing particle collector is adopted in the fully mechanized excavation face, the dust pollution on the fully excavation roadway is significantly reduced and the working environment of the fully mechanized excavation face is improved effectively.

Keywords Dust distribution; Fully mechanized excavation face; Inside inhaling and outside pressing; Far-pressing-near-absorption; Numerical simulation

1. Introduction

With the continuous improvement of mining mechanization level, the production efficiency is continuously being improved, in the meantime, dust production is also increasing. As one of the five major disasters in coal mines, dust exists in almost all links of the underground operations, for example, drilling operations, tunneling operations, mineral loading and transportation will all produce a lot of dust, there are great differences in the amount of dust produced by different coal mines, mining methods, operation modes and mechanization degrees , etc.[1] Under the current conditions of dust control measures, the proportions of dust amounts produced in the various links of production process in coal mines are as follows: Dust production on coal mining surface accounts for 45% ~ 80%;Dust production on tunneling surface accounts for 20% ~ 38%; Dust production at anchoring and shotcreting operation point accounts for 10% ~ 15%; Dust production at transportation ventilation drift accounts for 5% ~ 10%; Dust at other operating points accounted for 2% ~ 5%[2]. Thus it can be seen that the tunneling working face is one of the main sources of dust in underground of coal mine.

Dust control should start with dust source, the dust on the fully mechanized mining working face mainly comes from coal and rock crushing, friction effect, geological action, airflow drag-in, and secondary airborne dust, etc. [3] Dust does not only threaten the safety production on fully mechanized mining working face, and it seriously affects the miners' physical health, especially that the respirable dust is extremely hazardous to miners' physical health [4-6]. Therefore, it has very important significance for safety production and physical health of underground workers of coal mines to study dust distribution and migration law on fully mechanized mining working face [7-8] .

2. Numerical simulation of dust distribution law on fully mechanized mining surface in far-pressing-near-absorption ventilation

2.1. Far-pressing-near-absorption ventilation

Far-pressing-near-absorption ventilation can also be referred to as front-absorption rear-pressing ventilation, it is a type of hybrid ventilation. The fresh air arrives at the working face through the press-in air duct, and the polluted air flow on the working face is exhausted out of the working face by a suction type air duct. The layout is as shown in figure 1:

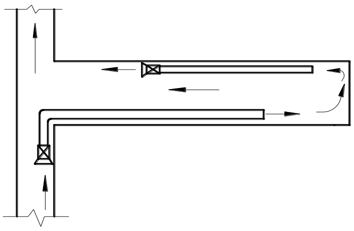

Figure 1: The far-pressing-near-absorption ventilation

2.2. Establishment of mathematical model

This paper adopts Euler Lagrange method to simulate the distribution law of dust in fully mechanized mining roadway, regards roadway air flow as continuous phase, regards dust particles as discrete phase, first simulates airflow field, and then simulates the dust field [9-11]. This paper regards the gas flow lane of the roadway as incompressible adiabatic flow during simulation. Therefore, it does not solve the energy equation, it only solves the continuity equation and momentum equation. The governing equation of the continuous phase and the discrete phase is shown as follows [12]:

Continuous phase governing equation:

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \quad (1)$$

Momentum conservation equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j)= -\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\left[(\mu+\mu_t)\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)\right] \quad (2)$$

K equation:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}= \frac{\partial}{\partial x_j}\left[(\mu+\frac{\mu_t}{\sigma_k})\right]+G_k-\rho\varepsilon \quad (3)$$

ε equation :

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

$$\frac{\partial}{\partial x_j}\left[(\mu+\frac{\mu_t}{\sigma_\varepsilon})\right]+C_{1\varepsilon}\frac{\varepsilon}{k}G_k-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{4}$$

In the formula:

x_i 、 x_j —coordinates in x , y , z directions , m ;

u_i 、 u_j —speeds in x , y , z directions, m/s ;

ρ --Roadway gas density, kg/m^3 ;

p --Effective turbulent pressure, pa ;

μ --Turbulent kinetic viscosity coefficient;

G_k --Turbulent energy generation rate caused by time averaged velocity gradient, % ;

μ_t --Turbulent kinetic viscosity coefficient, $\mu_t=\frac{C_u\rho k^2}{\varepsilon}$;

k --Turbulent kinetic energy, J ;

ε --Turbulent kinetic energy dissipation rate, % ;

$C_{1\varepsilon}$, $C_{2\varepsilon}$, C_u , σ_k , σ_ε are empirical constants, and $C_{1\varepsilon}=1.44$, $C_{2\varepsilon}=1.92$, C_u =0.09, $\sigma_\varepsilon=1.3$, $\sigma_k=1.0$

Particle phase control equation:

$$\frac{du_p}{dt}=F_D(u-u_p)+\frac{g_x(\rho_p-\rho)}{\rho_p}+F_x \tag{5}$$

$$F_D=\frac{18\mu}{\rho_p d_p{}^2}\frac{C_D R_e}{24} \tag{6}$$

$$C_D=\alpha_1+\frac{\alpha_2}{R_e}+\frac{\alpha_3}{R_e} \tag{7}$$

$$F_x=\left(\frac{\rho}{\rho_p}\right)u_p\frac{\partial u}{\partial x} \tag{8}$$

In the formula: $F_D(u-u_p)$ --Unit mass drag force of dust particle, N ;

C_D --Drag force function

F_x --Other forces received by dust particles, N ;

u --Gas phase flow rate, m/s

u_P --Particle phase flow rate, m/s

For spherical particles, α_1 , α_2 and α_3 are constants, and they can computed through the formula.

2.3. Establishment of geometric model

This paper selects a rectangular roadway with length 5m, width 3.5m, height 3m in west main roadway in certain mine of Lu'an Group, Size of the fully mechanized mining machine is length 7.5m, width 1.8m, height 1.5m, press-in type air duct is a flexible air duct with diameter of 600mm, suction type air duct is a rigid air duct with a diameter of 600mm, suction type air duct is 3m from the fully mechanized mining face, press-in air duct is 7m from the working face (surface). Thus, the geometric model and meshing of the far-pressing-near-absorption ventilation and dust removal system established by GAMBIT are shown in Figure 2 and 3:

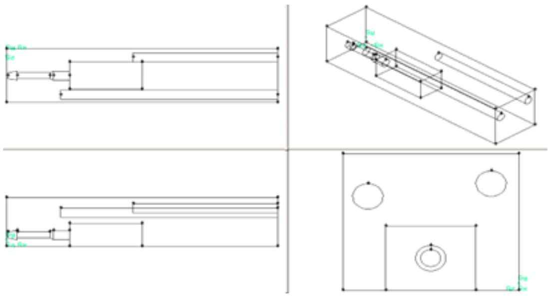

Figure 2: The geometric model of far-pressing-nearing-absorption comprehensive mechanized heading face

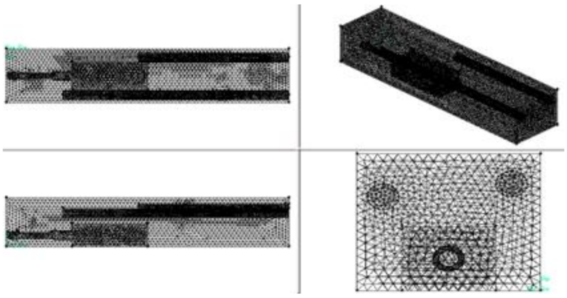

Figure 3: The meshing of far-pressing-near-absorption comprehensive mechanized heading face

2.4. Setting of boundary conditions and simulation parameters

The mathematical model is built and introduced into the FLUENT to set the boundary conditions and the basic parameters of the dust source [13-14]. As shown in Table 1, 2, 3, 4:

Table 1: Defining of computational model

Model	Setting
Solver	Pressure based
Turbulence model	k-ε double equation model
Energy equation	Off
Discrete phase model	Open

Table 2: Defining of discrete phase model

Discrete type model	Setting
Interphase coupling frequency	10
Calculation steps	10000
Time step	0.01
Resistance characteristics	Spherical particle

Table 3: Defining of boundary conditions

Boundary condition	Parameter setting
Inlet boundary type	Velocity inlet
Inlet velocity	18 m/s
Hydraulic diameter	0.6 m
Turbulence intensity	3.0%
Outlet boundary type	Outflow
Turbulence diffusion model	Stochastic trajectory model
DPM boundary	Capture and reflection
Shear boundary	No slip

Table 4: Parameter setting of injection

Jetting source parameter	Setting
Jetting source type	Surface jetting
Material	High volatile coal
Particle diameter distribution	Rosin-Rammler distribution
Initial speed	0.5 m/s
Mass flow rate	0.01 kg/s
Minimum particle size	2×10-6 m
Maximum particle size	1×10-4 m
Medium diameter	2×10-5 m
Distribution index	2.1
Tracking number	10
Integral scale	0.15

In table 3, the calculation method of hydraulic diameter is shown in formula (9):

$$d_H = \frac{4A}{S} \tag{9}$$

In the formula: d_H -- Hydraulic diameter, m ;

A --Overcurrent cross section area, m^2 ;

S --Wet peripheral, m .

the calculation method of turbulent flow intensity is shown in equation (10):

$$I = \frac{u}{v} = 0.16(\mathrm{Re}_H)^{-\frac{1}{8}} \tag{10}$$

In the formula: u --Turbulent pulsation velocity, m/s ;

v --average velocity, m/s ;

I --Turbulence intensity;

Re_H --Reynolds number calculated by hydraulic diameter.

In table 4, the calculation method of mass flow rate is shown in equation (11):

$$Q_m = cvA \tag{11}$$

In the formula: Q_m --Mass flow rate, kg/s;

c --Dust concentration at dust source, kg/m^3;

v --wind velocity in the roadway, m/s;

A --Roadway section area, m^2.

2.5. Simulation results and analysis

After the end of FLUENT solution, the airflow field vector, the roadway concentration distribution of dust clouds, dust movement trajectory and the dust concentration change map along the roadway can be obtained through aftertreatment, as shown in figure 4,5,6,7.

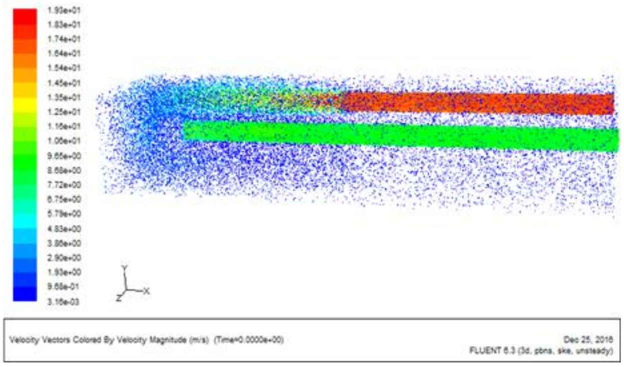

Figure 4: The vector of airflow field

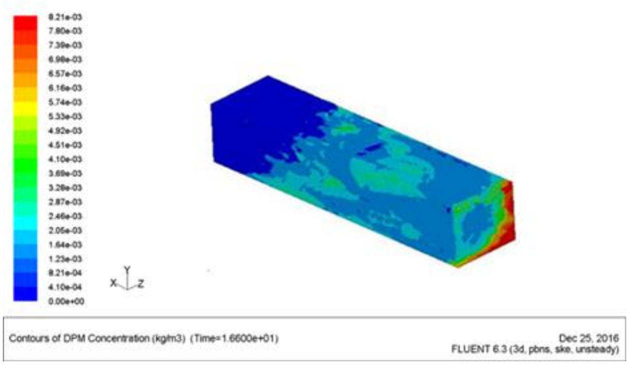

Figure 5: The concentration distribution of far-pressing-near-absorption dust

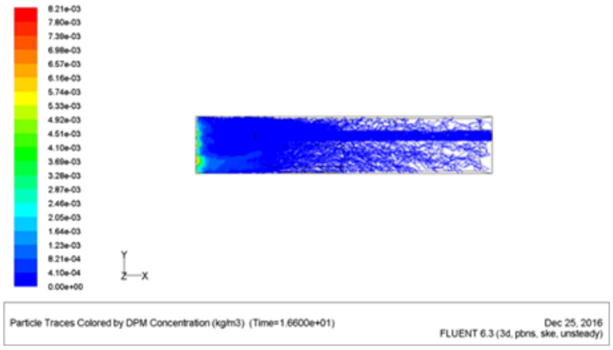

Figure 6L Trajectries of dust moverment

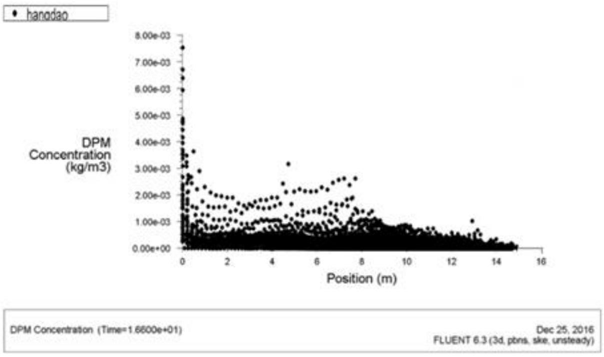

Figure 7: Dust concentration changes of roadway excavation along the roadway

The following conclusions can be drawn from figures 4, 5, 6 and 7: When working face of the fully mechanized mining adopts far-pressing-near-absorption ventilation, air flow is reflected after being jet to the working face from the press-in air duct, carrying dust generated by on the tunneling face to flow to the side of the suction type air duct, the suction type air duct only discharges a small part of the dust-carrying airflow, most of the airflow carries dust and flows to the roadway at rear of the tunneling face, causing increase of dust concentration in roadway; the areas with large variation of dust concentration in the roadway are mainly concentrated in the 4m area of the excavation face and its 4m scope at rear area. After 10m, the dust concentration begins to decrease, the farther away from the tunneling face, the lower the concentration of dust.

3. Numerical simulation of the application effect of the outside absorption inside pressing dust collector in fully mechanized mining face

3.1 The structure and working principle of the inside-absorption-outside-pressing

The main the inside-absorption-outside-pressing dust collector is mainly composed of inner cavity & outside cavity and bellmouth, air duct, dust collector and connecting device. Its working principle is to use the airflow flow field of the external cavity to control the dust in the minimum range, the dust is then passed through the inner chamber to the dust collector for processing [15]. The inner cavity is installed with an suction type fan pipe, the external cavity can be connected with a press-in type air duct, bell mouths (trumpets) are connected with the openings of the inner cavity and the outer cavity, to increase the control area of flow field of the cavity, the inside-absorption-outside-pressing collector can be used in any section of the roadway by changing the size of the bell mouth (trumpet).The schematic diagram of the structure is as shown in figure 8:

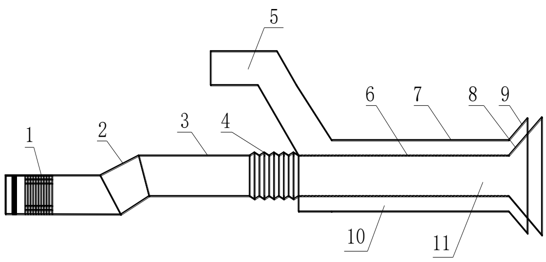

Figure 8: Structure of the inside inhaling and outside pressing particle collector
1 dust collector 2 transformation duct 3 lron duct 4 telescopic duct 5 external duct mouth 6 inner barrel 7 outer barrel 8 the inside trumpet 9 the outside trumpet 10 external cavity 11 lumen cavity

The inside-absorption-outside-pressing dust collector is improved on the basis of pure press-in or pure suction type dust collector commonly used in underground of the coal mines. this has the advantages of greatly improving the pure press-in dust collector, which is simply spray and dilute and can't remove dust, as well as improving the simple suction dust collector which has the shorter suction stroke, resulting in the working face vortex, but this has the shortcoming of expanding the scope of dust pollution. The installation of the inside-absorption-outside-pressing dust collector in the tunneling roadway is as shown in figure 9:

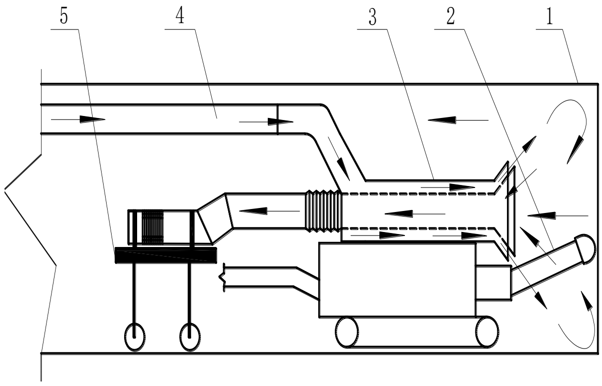

Figure 9: The installation drawing of the inside inhaling and outside pressing particle collector in the roadway
1 excavation roadway 2 lumen cavity 3 inside inhaling and outside pressing particle collector 4 the pressing type duct 5 car

3.2 Establishment of geometric model and meshing

We also selects a rectangular roadway with length 15m, width 3.5m, height 3m in west main roadway in certain mine of Lu'an Group as the prototype, the diameter of the inner cylinder of the inside-absorption-outside-pressing dust collector is 600mm, the outer tube diameter is 700mm.We use GAMBIT software to establish a simplified geometric model, and carry out meshing as shown in figures 10 and 11:

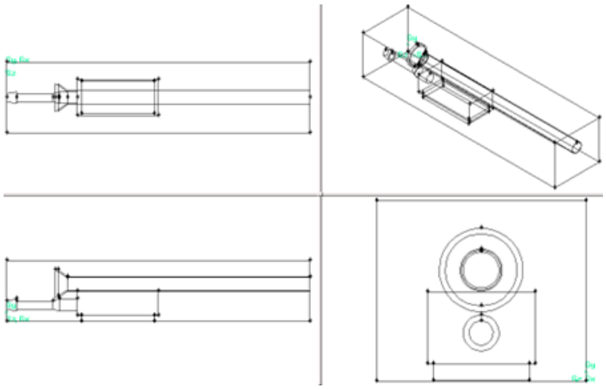

Figure 10: The geometric model of inside inhaling and outside pressing particle collector in the excavation roadway

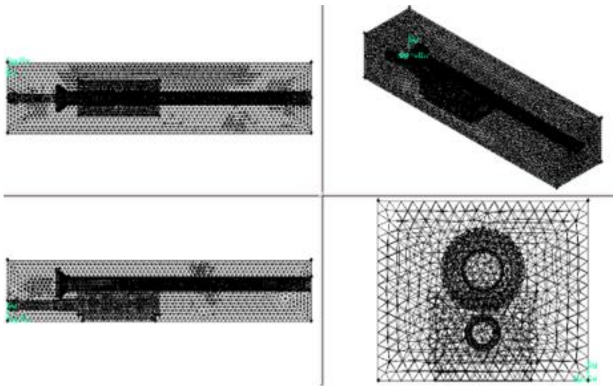

Figure 11: The meshing of inside inhaling and outside pressing particle collector in the excavation roadway

3.3 Numerical simulation results and analysis

Carry out after-treatment after the simulation of the continuous phase and discrete phase, Take the airflow field vector, the roadway concentration distribution of dust clouds, dust movement trajectory and the dust concentration change map along the roadway as shown in Figure 12, 13,14 and 15:

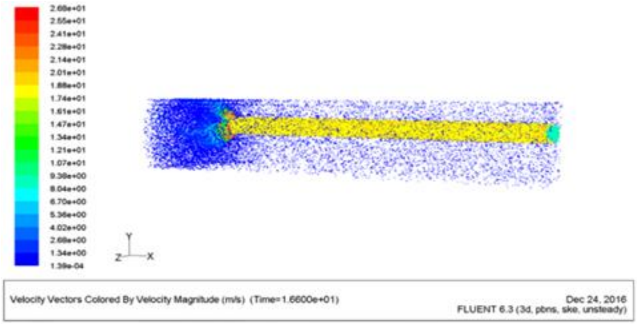

Figure 12: The vector of airflow field

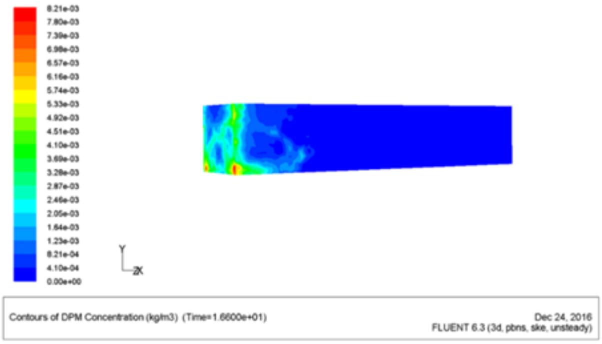

Figure.13: The concentration distribution of the roadway

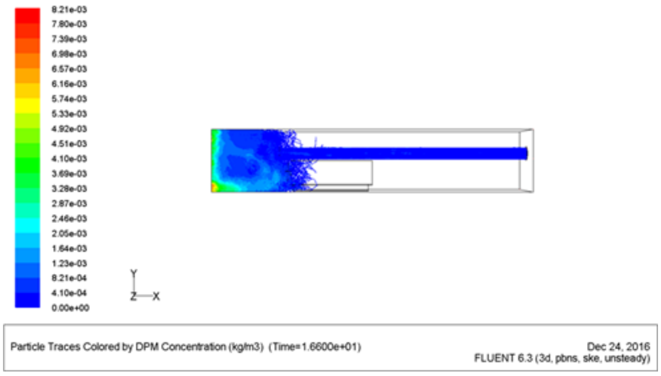

Figure 14: Trajectries of dust moverment

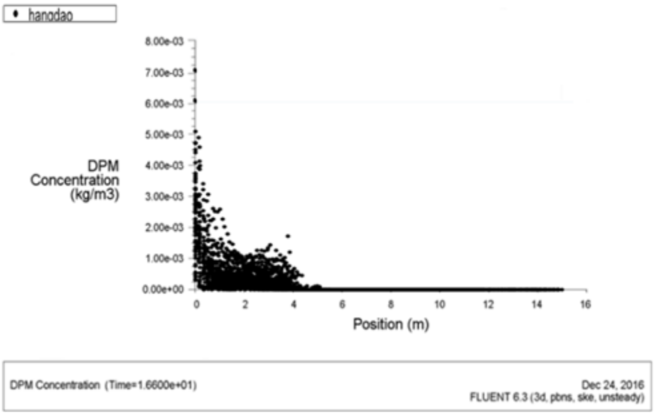

Figure 15: Dust concentration changes of roadway excavation along the roadway

The following conclusions can be drawn from figures 12, 13, 14 and 15: After the air flow is jet from the outside cavity of the inside-absorption-outside-pressing dust collector to the tunneling surface, it surrounds the dust generated on the tunneling face, The inner cavity extracted air is pumped out by the dust controlled by the external cavity flow field, most of the dust produced on the tunneling surface is collected by the inside-absorption-outside-pressing dust collector and processed, and only a small part of the dust flows to the roadway on the rear together with the wind; the areas with large variation of dust concentration in the roadway are mainly concentrated in the 4m area of the excavation face and its rear area, the dust concentration is kept at a lower concentration outside the 4m area.

4. Conclusion

(1) When working face of the fully mechanized mining adopts long pressure and short draft ventilation, it only reduces the dust concentration on the tunneling working face, most of the dust disperses in the roadway with the wind during fully mechanized mining, resulting in a larger range of pollution.

(2) When the tunneling working face adopts internal draft external pressure dust collector, most of the dust produced on the tunneling surface is collected by the gas flow generated by flow field of the dust collector, and then treated by the dust collector on the rear, the generated pollution area is mainly concentrated between the dust collector bell mouth (trumpet) and the tunneling surface, the range is relatively small.

(3) Compared with long pressure and short draft ventilation, the internal draft external pressure dust collector can effectively reduce the dust concentration in the tunnel, the improvement effect on the working environment of fully mechanized mining working face is more obvious, therefore, it is worth popularizing.

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