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Numerical Simulation Study on the Coupled Transport Law of Airflow and Dust in Fully Mechanized Top Coal Mining Face

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Abstract

At present, with the large-scale of fully mechanized mining equipment, the air flow and dust transport law in fully mechanized caving face has become more complex. In order to systematically study the dust diffusion characteristics under the influence of air flow in fully mechanized top coal caving face, the dust diffusion pollution law of fully mechanized top coal caving face under the influence of 0.5m/s~2.0m/s air inlet wind speed was numerically simulated and analyzed, and the coupling movement law of air flow and dust in fully mechanized top coal caving face under different wind speeds was revealed. The results show that with the inlet wind speed increasing from 0.5m/s to 2.0m/s, the impact of the wind flow at the roller on the sidewalk is weakened, and the wind speed in the sidewalk and runway area increases to more than 2.80m/s and 2.30m/s respectively. When the inlet wind speed exceeds 1.5m/s, the high concentration dust is diluted rapidly, and the dust concentration in the respiratory zone at the downwind side of the shearer tends to be stable, basically lower than 200mg/m^3, which effectively inhibits the diffusion of dust to the sidewalk.

Keywords

Fully Mechanized Top Coal Caving Face; Airflow; Dust; Coupled Transport Law; Diffusion.

1. Introduction

Fully mechanized top coal caving face is one of the most common workplaces in mine production in China. Its efficient production capacity enables large-scale mining of coal resources [1]. However, in recent years, with the heavy and large-scale of fully mechanized mining equipment, the dust problem of fully mechanized mining face has become increasingly prominent [2-5]. The large-scale equipment not only improves the production efficiency, but also greatly increases the dust production and dust concentration, which seriously pollutes the underground working environment. The risk of pneumoconiosis is significantly increased in miners exposed to high concentration of dust for a long time. In each production system of coal mine, fully mechanized mining (excavation) face is the high incidence area of pneumoconiosis [6-7]. Therefore, the dust control work of fully mechanized caving face is imminent. The traditional research on the air flow and dust movement law in the fully mechanized mining face with common mining height is mainly based on the small-scale equipment and relatively simple working environment. However, with the large-scale of fully mechanized mining equipment, the air flow and dust transport law of the working face become more complex [8-11]. The traditional airflow dust transport model can not accurately describe the dust diffusion and deposition behavior under the background of large-scale equipment. So, it is necessary to deeply study the air flow and dust transport law of fully mechanized mining face under the current background, so as to provide scientific basis for the optimal design of ventilation and dust removal system and the determination of the optimal wind speed under different dust production. Therefore, in order to systematically study the diffusion characteristics of dust under the influence of airflow in fully mechanized top coal caving face, numerical simulation was carried out on the airflow dust coupling migration law of fully mechanized top coal caving face, revealing the migration characteristics of airflow and dust in fully mechanized top coal caving face under the background of large-scale equipment, providing theoretical support for on-site dust control.

2. Establishment of Physical Model and Meshing of Fully Mechanized Top Coal Caving Face

The design mining length of +443 level B_{3-6} fully mechanized caving face in Wudong coal mine is 2209m, the maximum absolute gas emission is 0.55m³/min, and the maximum relative gas emission is 0.13m³/t. The length of the working face is about 44m, and the mining height of the working face is strictly controlled at 3.5±0.1m. According to the actual situation of the fully mechanized caving face in Wudong coal mine, the model of the fully mechanized caving face with equal proportion is constructed by using SolidWorks. The length × width × height is 44.0m×4.8m×3.5m. Among them, the shearer type is MGD-300/355-NWD, the drum diameter is 2.0m, and the support is ZF10000/22/40D hydraulic support.

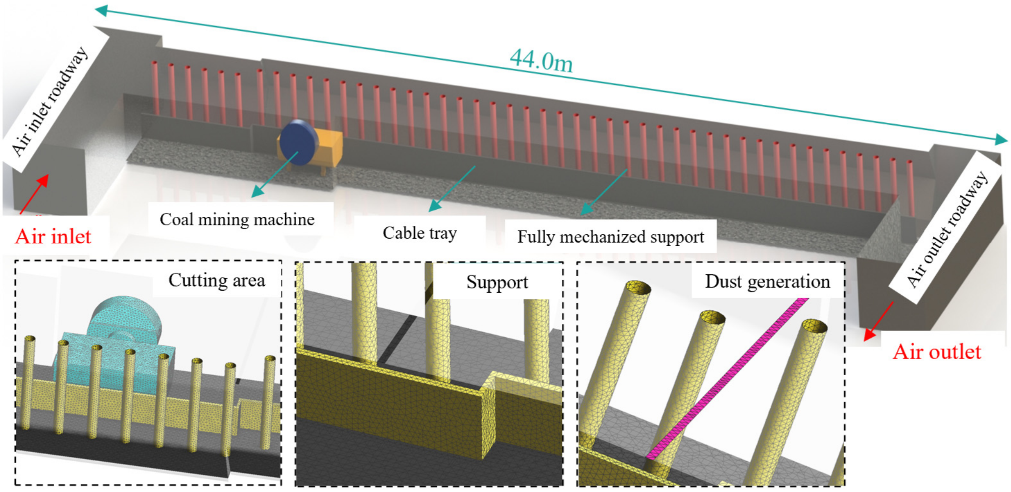

Figure 1. Physical model and grid diagram of fully mechanized caving face

The physical model is meshed by tetra/mixed method, the maximum limit of global grid is 0.35m, and the complex structure is locally encrypted. The dust source of fully mechanized top coal caving face is mainly the coal cut by shearer drum and the dust produced by fully mechanized top coal caving support. The divided grid is imported into the numerical simulation software, and the inlet air velocity is set as 0.5m/s, 1.0m/s, 1.5m/s and 2.0m/s respectively for steady-state iterative solution. Based on the measured data of dust particle size and mass concentration in the working space of the frame moving and cutting process of the fully mechanized caving face, the parameters of the turbulence and discrete phase model are set. The main numerical simulation parameters are shown in Table 1.

3. Analysis of Dust Diffusion Results under the Influence of Airflow in Fully Mechanized Top Coal Caving Face

Due to the small particle size of the dust in the fully mechanized caving face, the airflow field plays a major role in the dust diffusion pollution. From the Figure 2, when the air inlet speed is 0.50m/s, the wind speed at the corner is lower than 0.20m/s due to the 90° corner between the

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air inlet roadway and the working face, and 0.90m/s wind flow is formed near the fully mechanized caving support. When it is transported to the shearer drum, the coal at the drum induces air flow, causing part of the air flow to flow into the rear of the fully mechanized caving hydraulic support, that is, the sidewalk area, and the wind speed can reach 1.40m/s. And the wind speed is about 1.20m/s within 30.0m of the sidewalk area at the downwind side of the shearer, the wind speed from the fully mechanized caving support pillar at the downwind side of the shearer to the coal wall space area (machine Lane area) is about 0.90m/s, and the air flow velocity in the return air roadway is about 0~1.60m/s. When the inlet air speed increases to 1.5m/s, the air flow of the roller part rarely directly enters the sidewalk area. When the inlet wind speed increases from 0.50m/s to 2.00m/s, the wind speed at the corner near the fully mechanized caving support increases from 0.90m/s to more than 2.80m/s, and the wind speed in the sidewalk area increases to 2.80m/s, and the wind speed in the runway area increases from 0.90m/s to more than 2.30m/s.

Table 1. Boundary condition parameters

Category	Project	Parameter setting
Airflow	Solver Type	Pressure-Based
	Time	Steady
	Scheme	SIMPLEC
	Tturbulence Model	Standard k-ε Equation
	Near-Wall Treatment	Standard Wall Function
	Entrance Boundary	VELOCITY-INLET
	Density	1.225 kg/m^3
	Viscosity	1.79e-05 kg/m-s
Dust	Time	Steady
	Exit Boundary	PRESSURE-OUTLET
	Particle Type	Inert
	Injection Type	Surface
	Dust Distribution Function	Rosin-rammler
	Diffusion Coefficient	3.5
	Launch Time	100.0 s
	Stochastic Tracking	Random Walk Model
	Total Flow Rate	0.00059 kg/s
	Diameter	0.85-2.5;2.5-7;7-15;15-50 μm
	Density	1400 kg/m^3
	Drag Law	Spherical

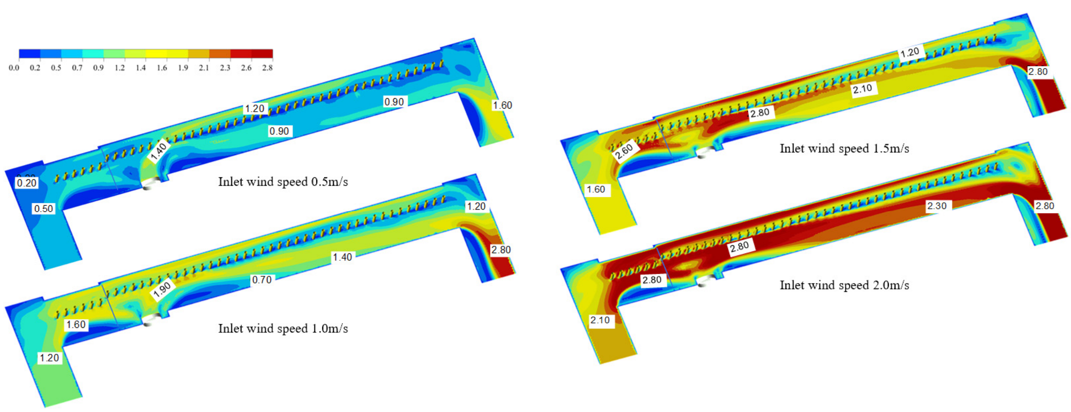

Figure 2. Flow field change results of different inlet wind speeds

The diffusion results of the dust particle field under the influence of different inlet wind speeds in the fully mechanized caving face are shown in Figure 3. The volume rendering and particle color are used to represent the dust concentration. When the inlet wind speed is 0.5m/s, a large number of dust particles with a concentration of more than 700mg/m³ enter the sidewalk area, and the concentration in the runway area is less than 430mg/m³. With the increase of inlet wind speed, the dust concentration entering the sidewalk area for the first time gradually decreases from 700mg/m³ to 30mg/m³, and the concentration in the runway area increases from 430mg/m³ to 640mg/m³. It can be seen from this that the increase of air inlet velocity can restrain the induced airflow at the drum from entering the sidewalk, and quickly discharge the high concentration dust from the working face, which can avoid long-term contact with the coal workers working in the sidewalk.

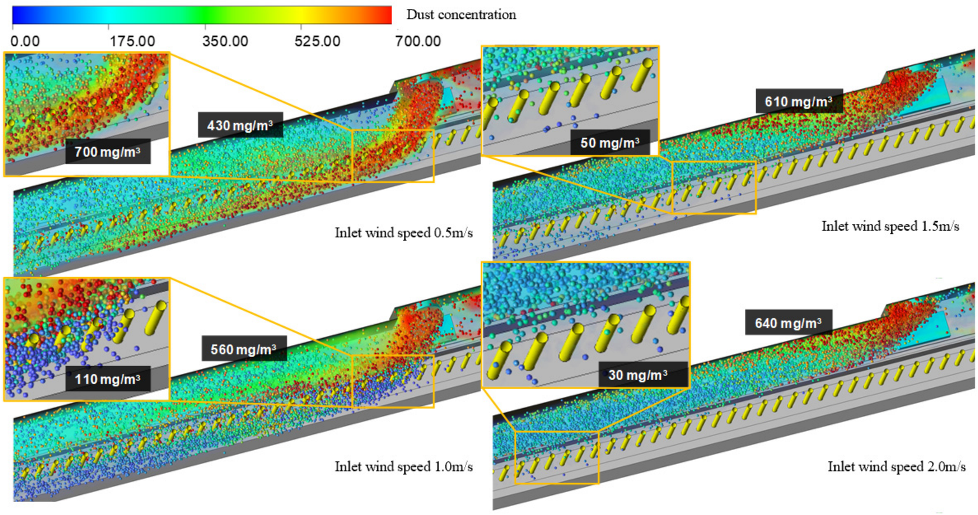

Figure 3. Dust particle diffusion results at different inlet wind speeds

From the above analysis, it is found that the dust diffusion area of fully mechanized top coal caving face can be mainly divided into two areas: sidewalk area and runway area. For this purpose, extract and analyze the concentration of respiratory zone (1.5m) in two areas, as shown in Figure 4.

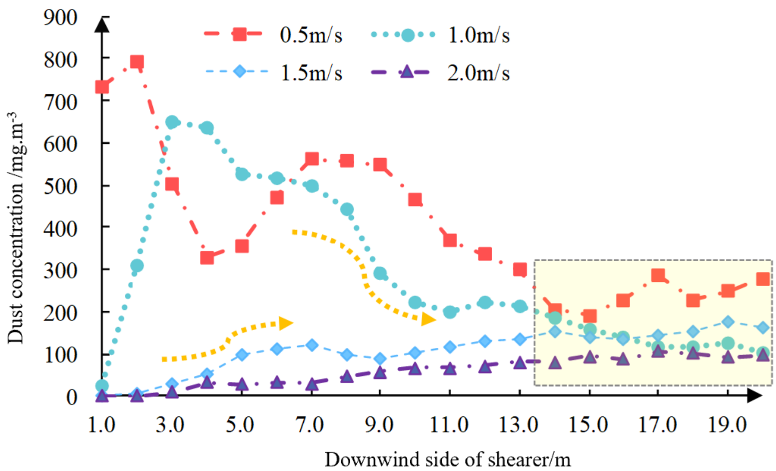

Figure 4. Distribution results of dust concentration in the breathing zone at the downwind side of the shearer

From the Figure 4 that when the inlet air speed is 0.5m/s, the concentration in the area of the fan path at the lower air side of the shearer shows an overall decreasing trend, and the dust concentration gradually decreases from 800mg/m³ to 300mg/m³. When the inlet wind speed increases to 1.0m/s, the concentration in the area of the turbine channel increases first and then decreases, and the dust concentration reaches the maximum value of about 650mg/m³ at about 3.0m downwind side, and then gradually stabilized at about 110mg/m³. When the inlet air velocity exceeds 1.5m/s, the high concentration dust is diluted rapidly by the air flow and discharged from the fully mechanized caving face. The overall trend is to gradually increase and then stabilize, and the dust concentration is basically lower than 200mg/m³.

The coal workers in the fully mechanized caving face mainly work in the sidewalk area. It can be seen from Figure 5 that when the inlet air speed is lower than 1.0m/s, the concentration in the sidewalk area mainly increases first and then decreases. When the inlet wind speed is 0.5m/s, the maximum concentration reaches 800mg/m³ at about 4.0m on the downwind side. When the diffusion distance exceeds 14.0m, the dust concentration is basically stable at about 240mg/m³. It can be inferred that at this time, small particles of respirable dust are suspended in the air for a long time, and targeted measures should be taken to reduce the dust. When the inlet wind speed is 1.0m/s, the maximum concentration reaches about 280mg/m³ at 9.0m/s on the downwind side of the shearer, and then gradually decreases to about 30mg/m³. When the inlet air velocity exceeds 1.5m/s, the concentration of respiratory zone in the sidewalk area is always low, and the dust is lower than 30mg/m³ as a whole, indicating that when the inlet air velocity exceeds 1.5m/s, the diffusion of cutting dust to the sidewalk in the manned operation area can be effectively inhibited, and the exposure probability of high concentration dust to miners can be reduced. At the same time, the dust control in the area from the fully mechanized caving support pillar at the downwind side of the shearer to the coal wall space should be strengthened.

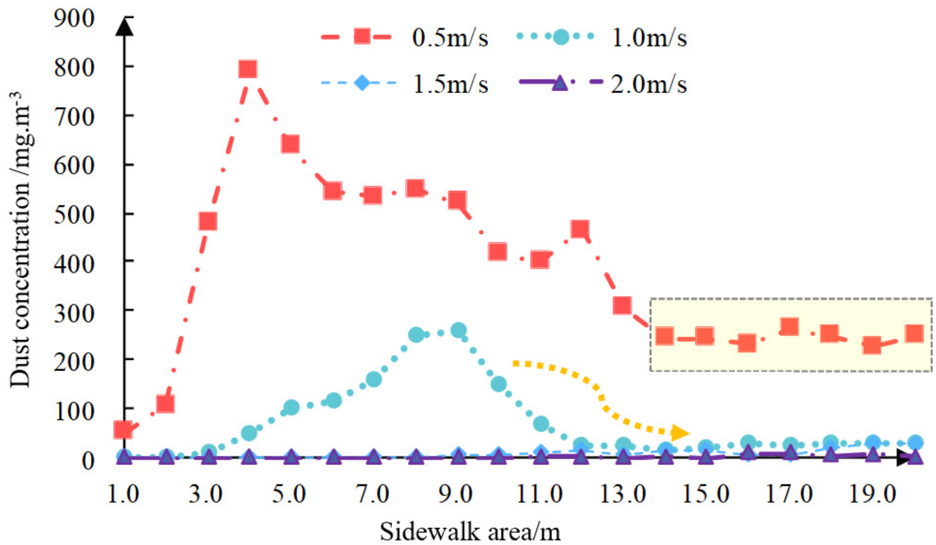

Figure 5. Diffusion results of dust concentration in sidewalk breathing zone

The on-site test and analysis found that the relative error of dust concentration in the runway area was controlled within 17.3%, and the minimum error was -7.1%. The relative error of dust concentration in sidewalk area is less than 15.8%, and the minimum error is 5.6%. Considering the complexity of on-site coal mining operation, the fluctuation of cutting dust production and human error, it can be considered that the error is within the acceptable range, which shows that the simulation results obtained are relatively accurate.

4. Conclusion

(1) When the inlet wind speed is 0.5m/s, the coal induced airflow at the drum causes part of the airflow to flow into the sidewalk area, and the wind speed reaches 1.40m/s. When the inlet air speed increases to 1.5m/s, the air flow of the roller part rarely directly enters the sidewalk area. When it increases to 2.00m/s, the wind speed in the sidewalk area increases to 2.80m/s, and the wind speed in the runway area increases from 0.90m/s to more than 2.30m/s.

(2) When the inlet air speed increases to more than 1.5m/s, the high concentration dust is rapidly diluted by the air flow. The overall trend of dust concentration in the respiratory zone at the downwind side of the shearer is gradually increasing and then stabilizing. The dust concentration is basically less than 200mg/m^3, which can effectively inhibit the diffusion of cutting dust to the sidewalk and reduce the exposure of high concentration dust to miners. At the same time, the dust control in the area from the fully mechanized caving support pillar at the downwind side of the shearer to the coal wall space should be strengthened.

Acknowledgments

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