Numerical Simulation of Horizontal Diffusion Resistance of Dust Produced by Shearer Cutting Coal

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Abstract. With the increase of the mining height of fully mechanized mining face, the horizontal diffusion degree of coal dust produced by shearer is obviously enhanced, forcing the amount of dust diffused to the pedestrian side of the support to increase, polluting the regional environment of operators. In order to investigate the inhibition mechanism of horizontal diffusion of coal dust produced by shearer, a three-dimensional model of coal dust produced by shearer in fully mechanized mining face was constructed based on the specific conditions of the working face. The results show that the dust collector arranged on the shearer has a certain effect on the coal cutting dust production, which can reduce the maximum dust concentration from 544 mg/m³ to 464 mg/m³, and the dust removal efficiency is 15%, but the wind speed and flow field have little effect. Compared with the fully mechanized mining face with normal ventilation, the dust baffle plate has a blocking effect on the horizontal diffusion of dust produced by the shearer cutting coal. Under the condition that it is flush with the wind side face of the shearer, the dust in the range of 10 m can be completely blocked, and the dust in the range of 20 m can be controlled to 50 mg/m³.

Keywords: Fully Mechanized Mining Face; Dust Control; Coal Cutting Dust Production; Numerical Simulation.

1. Introduction

The dust production of the mining face accounts for more than 85% of the whole mine [1], and the total dust mass concentration of the fully-mechanized mining face is as high as 4000 mg/m³, far exceeding the limit value stipulated by the state. The dust pollution is serious, which endangers the occupational health of workers in the working area of fully mechanized mining face and return air flow area. According to statistics, 7,577 new cases of occupational pneumoconiosis were reported in 2022 [2], most of which were coal mine operators. The dust in fully mechanized mining face not only produces a large amount of dust, but also does great harm [3~4]. Therefore, targeted research on dust control has become the focus. Studies have shown that dust produced by coal cutting by shearer is one of the main sources of dust for workers in fully mechanized mining face [5~6]. The working mode and mining height of shearer have a significant influence on dust concentration distribution [7~8]. Coal cutting against wind is greater than that against wind, and transverse diffusion {9} is generated by the blockage of the shearer body. To sum up, the dust cutting source of the shearer moves with the shearer, has a wide diffusion area, and is affected by the limited space of the stope, forming a high dust concentration area, and a large amount of dust has horizontal diffusion during the longitudinal movement of the air flow. The comprehensive dust prevention technical measures based on spray have limited dust removal efficiency and cannot achieve the ideal dust removal effect. Second, the intensity of dust production does not match the measures of dust removal, and third, the horizontal diffusion of dust production by shearer cutting coal cannot be blocked. The failure of dust removal measures to achieve the expected effect is closely related to the layout and technical parameters, which should be optimized according to the specific conditions of the site. This paper will not discuss too much. This paper mainly studies the blocking mechanism of horizontal diffusion of dust produced by cutting coal by shearer. 52507 working face is selected as the research object, and numerical simulation is used to study the influence of different positions and different ways of horizontal blocking on the dust concentration at the pedestrian side of the support.

2. Overview of the Working Face

The 52507 working face is arranged along the coal seam dip and intersects with the coal seam dip. The length of the working face is 301 m, and the total advancing length is 4600 m. The average thickness of the coal seam is 6.8 m, and the coal seam inclination is 1~3°. The comprehensive mechanized coal mining method is adopted, which is full-height single-mining with longwall retreating. The treatment method of goaf roof is full caving method. The roof is supported by two-column shield support with the moving distance of 865mm and the end distance of 720 mm. Selected EKF SL1000/6769 shearer, drum diameter 3500 mm, cutting depth 865 mm; The middle support adopts ZY18000/32/70D hydraulic support, 155 sets are arranged, with a width of 2050 mm and a driving stroke of 865 mm. Production of raw coal up to 39,000 t/d. The maximum air supply of the working face is 3209 m^3/min, and the average wind speed is 1.2 m/s. The working face is equipped with two KAMAT-K50070M-5G spray pumps with a flow rate of 1039 L/min and a pressure of 14.3 MPa.

3. Model Grid Division and Boundary Conditions

The working face, shearer, hydraulic support, cable trough, etc. are simplified, and the model is shown in Figure 1. The length × width × width of the model size =301 m×40 m×6.8 m, the shearer is located in the middle of the model, the inlet is the air flow inlet, the outlet is the air flow outlet, and the direction of air flow movement on the working face is -x direction.

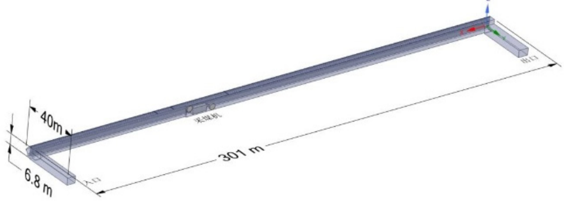

Fig 1. 3D model of fully mechanized mining face

The model was divided into grids, and the influence of different grid sizes on the model was compared respectively, as shown in Table 1. It can be seen from Table 1 that the increase of mesh size reduces the number of nodes and cells, and the average cell quality and skewness. In order to meet the performance of the computer and obtain better calculation results, the grid size of 0.5m was selected to divide the model, with a total of 130,000 nodes and 630,000 units.

Table 1. Grid division and statistical table

Mesh size (m)	Number of nodes (units)	Number of units (units)	Average cell mass	Average skewness
0.1	5966307	31514923	0.83716	0.22766
0.2	1125399	5780758	0.83442	0.23097
0.4	234858	1133736	0.82782	0.24221
0.5	134077	639246	0.82661	0.24262
0.6	93175	431994	0.80621	0.27219
0.8	57069	258259	0.77489	0.30526

The average wind speed of the fully mechanized mining face is low, so the air is assumed to be incompressible. Considering that the volume fraction of dust is less than 10%, DPM model is used to simulate dust. At the entrance of the model, the speed entrance is set, and the wind speed is 1.2m /s. The exit is set to free flow; A dust producing surface is set for both the wind side roller and the downwind side roller of the shearer. Considering the effect of coal stacking in the scraper conveyer and the caving impact of the shearer when cutting coal, a dust producing surface is added.

In order to study the effect of the coal cutting dust being blocked by the shearer, a dust collector and a dust baffle were set up. The dust collector was arranged at the end of the wind side of the shearer, and the dust baffle covered the corresponding position of the center of the wind side of the shearer and the length range of the wind side 10 m, and was fixed on the cable trough to physically separate the coal cutting dust producing area of the shearer from the pedestrian side area of the support. The movement of dust moves with the flow. In order to compare and analyze the retention effect of horizontal diffusion of coal and dust production by shearer, the migration and distribution of air flow in fully mechanized mining face was first simulated, and then the DPM model was used to simulate the coal and dust production by shearer, and then the retention effect of dust filter on coal and dust production by shearer was simulated. Finally, the blocking mechanism of dust collector and dust baffle plate on coal cutting by shearer is analyzed.

4. Shearer Cutting Coal Dust Diffusion Path

The airflow movement of fully mechanized mining face satisfies the three major equations of fluid mechanics, namely, continuity equation, momentum equation and energy equation [10].

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=S_m \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i \tag{2}$$

Where: S_m is he source item, the mass added to the continuous item; P is the static pressure, τ_{ij} is the stress tensor, $\tau_{ij}=\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]-\frac{2}{3}\mu\frac{\partial u_i}{\partial x_i}\delta_{ij}$, g_i and F_i is the gravitational volume force in the direction i/up and the external volume force respectively.

The flow line of airflow obtained through simulation is shown in Figure 2. In the figure, the flow line of the air flow is deflected at the fuselage on the wind side of the shearer, and the flow line density in the corresponding support area also increases, indicating that the air flow on the wind side of the shearer is affected by the blocking of the fuselage of the shearer and the stacking of coal in the scraper conveyer, resulting in transverse diffusion to the support side. In order to determine the influence of transverse diffusion on the dust concentration on the pedestrian side of the support, the cloud diagram of dust concentration distribution before and after the shearer is simulated. As shown in Figure 3, the dust production of the shearer is composed of coal cutting and caving impact by the drum on the wind side of the shearer, and the dust production location is X= 203m ~ 198m. The Z= 3.5m plane was intercepted for analysis of dust concentration distribution. There was no obvious dust in the pedestrian side area of the support at X= 201m, and high-concentration dust began to accumulate around the support column at X= 195m. The area where the dust concentration was greater than 500 mg/m^3 migrated to X= 150m was reduced, but the dust diffusion range increased significantly. In order to quantitatively study the dust concentration at different heights X=150~201 m, Y=2.5 m, Z=2~6 m, in order to facilitate observation, the following takes X=201m as the origin of the X axis, X=150 m as the X axis 51 m position, and the maximum dust concentration occurs at Z= 3.5m. The dust concentration at 5 m downwind of the central plane of the wind side roller of the shearer is 544 mg/m^3. For different height planes, the dust concentration increases first and then decreases, which is mainly because the dust produced by the shearer cutting coal starts to spread from the wind side roller position to the pedestrian side of the support. With the migration process, the dust concentration shows an overall trend of fluctuation and decline.

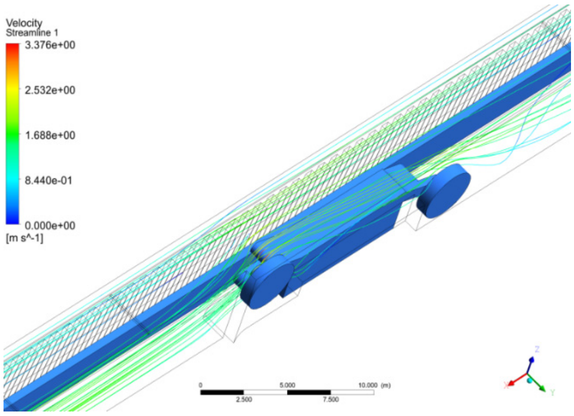

Fig 2. Air flow line at the drum position on the wind side of the shearer

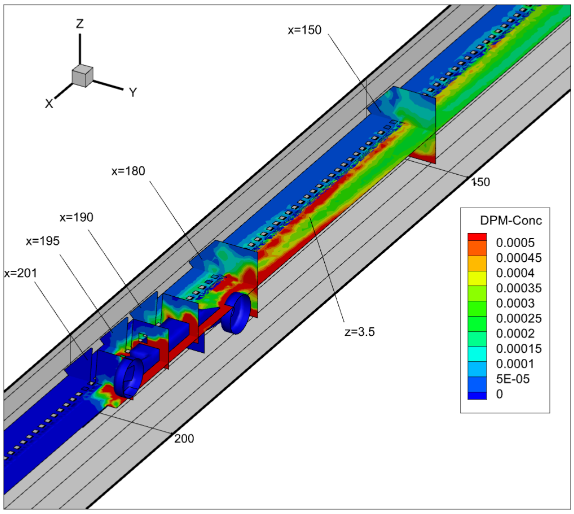

Fig 3. Cloud map of dust concentration distribution before and after shearer

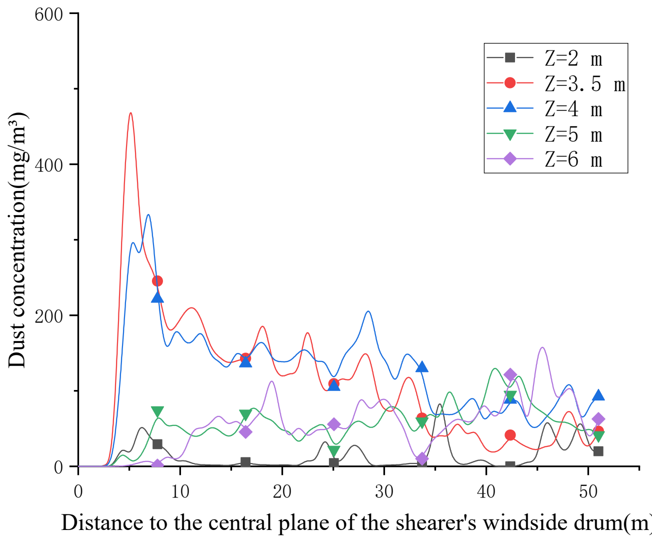

Fig 4. Dust concentration at different height planes

Although the overall dust concentration showed a downward trend, the maximum value appeared at the position 35 m downwind of the central plane of the drum on the wind side of the shearer. Meanwhile, a careful analysis of FIG. 4 found that the dust concentration showed a downward trend of oscillation, indicating that there was a supplement of dust sources during its migration. For this reason, the wind speed of the plane Y=2.5 m was further analyzed, and FIG.5 and FIG. 6 were obtained. They represent the distribution of wind speed and Y-direction wind speed within 51m of the central plane of the wind side roller of the shearer and the leeward side. It can be seen from Figure 5 that the wind speed fluctuates, and the wind speed on the pedestrian side of the support corresponding to the position of the shearer fuselage is obviously greater than that on the leeward side. It can be seen from Figure 6 that the wind speed in the central plane of the wind side roller of the shearer and the leeward side of the shearer has a large negative Y-direction wind speed within 10m of the central plane of the wind side roller of the shearer. The minimum value of the wind speed in the Y direction is -0.2m /s, and it is located at the downwind side of the central plane of the wind side roller of the shearer, which basically coincides with the position of the maximum dust concentration.

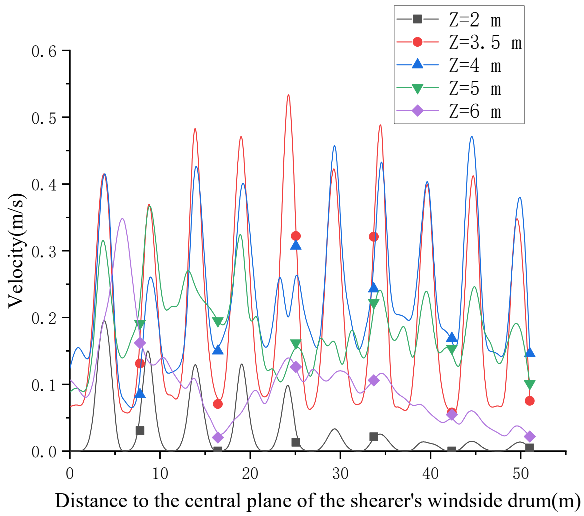

Fig 5. Wind speed distribution diagram

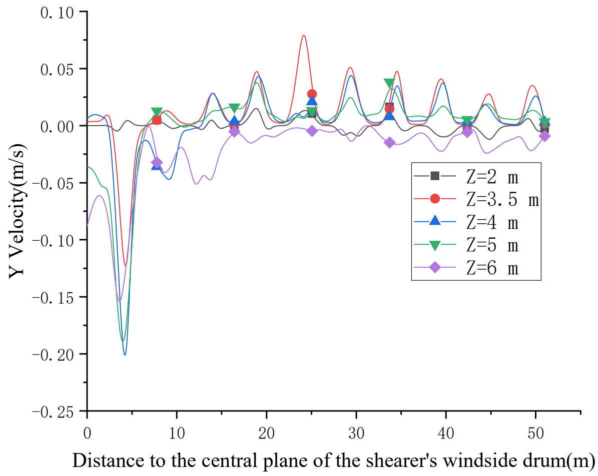

Fig 6. Distribution of wind speed in Y direction

5. Blocking Effect of Dust

In order to investigate the inhibition effect of coal cutting and dust production by shearer, the inhibition effect of dust collector and dust baffle on coal cutting and dust production by shearer was simulated. The simulated dust concentration distribution diagram of Y= 2.5m plane was analyzed and compared with the wind speed distribution diagram in Y direction, so as to judge the effect of dust collector and dust baffle on coal cutting and dust production by shearer.

The dust baffle plate is arranged between the shearer body and the hydraulic support column with a length of 10 m, and one end is flush with the central surface of the wind side roller of the shearer. This area is basically divided into two laterally disconnected areas. The simulated distribution diagram of dust concentration and wind speed in Y direction at Y= 2.5m plane is shown in FIG. 7 and FIG. 8 respectively. In Figure 7, there is basically no dust in the 0-10 m area, and the dust concentration in the 20m range is 50 mg/m³, and the maximum dust concentration is 243 mg/m³, located at the 35 m position. Compared with no barrier, the maximum dust concentration decreased by 55%, and its position moved to the downwind side by 30 m. Considering that the shearer body length was 20 m, the operator area was concentrated around the shearer, so it can be seen that the dust baffle plate has an obvious effect on controlling the dust concentration in this area. In FIG. 8, wind speed in the Z=5 m and 6 m regions in the 0-10 m range is negative in the Y direction. Compared with FIG. 6, it can be seen that wind speed below them is positive in the Y direction, that is, wind movement unfavorable to dust accumulation is generated.

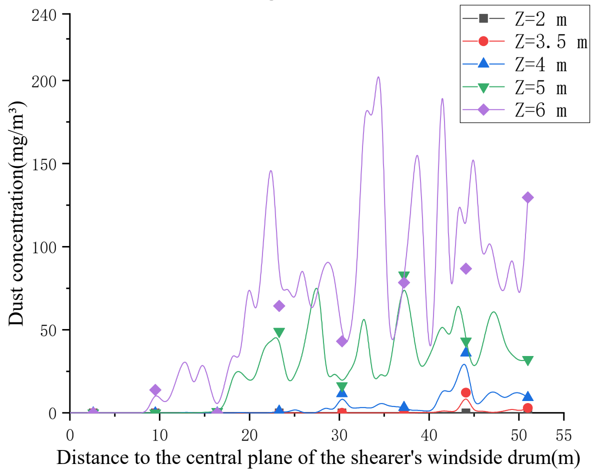

Fig 7. Dust concentration distribution under the influence of dust baffle

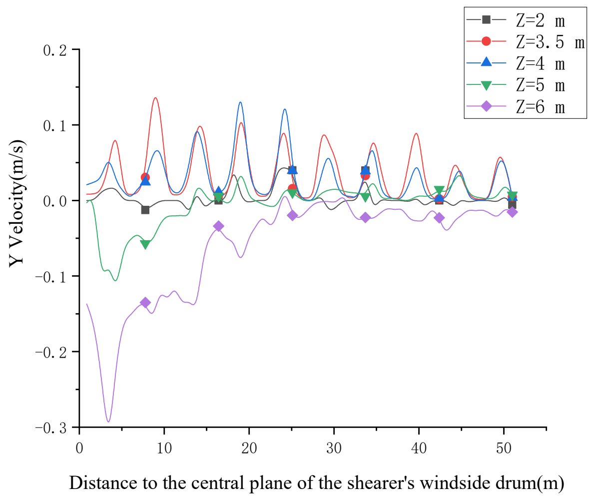

Fig 8. Wind speed distribution in Y direction under the influence of dust baffle

In order to continue to explore the influence of dust collector on the dust diffusion of coal cutting by shearer, dust collector is arranged on the wind side face of shearer, and the distribution diagram of dust concentration and Y direction wind speed at Y= 2.5m plane when the dust collector is treating 180 m³/min is simulated, as shown in FIG. 9 and FIG. 10. As shown in Figure 9, the maximum dust concentration of 464mg /m³ occurs at the position 4 m away from the central surface of the drum on the wind side of the shearer, which is 15% lower than the maximum original dust concentration. Overall, the dust concentration distribution trend is still increasing first and then decreasing, and it always maintains a downward oscillation. In FIG. 10, the minimum value of Y-direction velocity is

-0.276m /s, which is more conducive to the diffusion of shearer cutting dust to the pedestrian side of the support than the original air flow velocity.

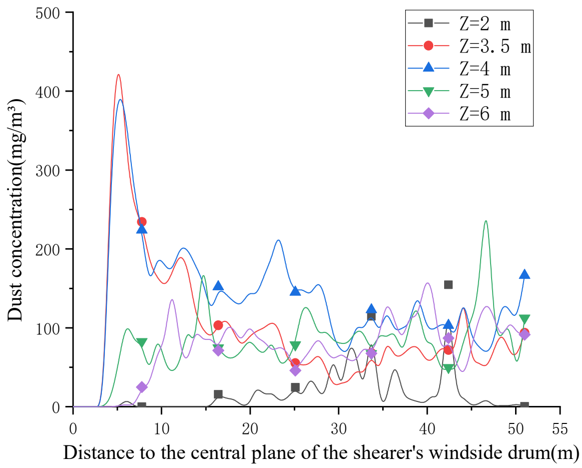

Fig 9. Dust concentration distribution under the action of dust collector

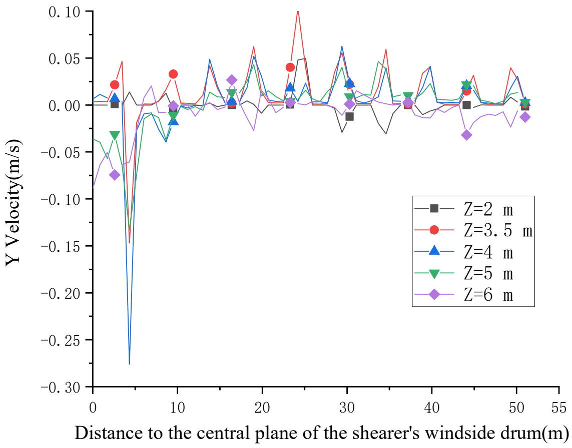

Fig 10. Y-direction wind velocity distribution under the action of precipitator

6. Conclusion

(1) The dust produced by the shearer cutting coal is diffused laterally to the pedestrian side of the support by the shearer fuselage. Quantitative and qualitative analysis shows that the dust produced by the shearer cutting coal is diffused from the position between the end face of the shearer fuselage and the central plane of the windward drum to the pedestrian side of the support, and the distance between the diffusion point and the dust source is no more than 5 m. The maximum dust concentration appeared at the position 5 m downwind of the central plane of the drum on the wind side of the shearer. The dust concentration first increased and then the oscillation decreased. The air flow moving to the pedestrian side of the support along the way supplemented the dust.

(2) The blocking effect of the dust baffle plate and dust collector on the coal cutting by the shearer is obtained through simulation. The dust baffle plate can reduce the maximum dust concentration by 55%, and there is basically no dust in the range of 10 m on the downwind side of the central plane of the drum on the wind side of the shearer, and the dust in the range of 20 m is controlled within 50 mg/m³. The effect of dust resistance is obvious. The dust collector can reduce the maximum concentration of dust by 15%, but it has little effect on the migration of dust produced by the shearer.

In this paper, there is a lack of discussion on the effect of different sizes of dust baffle on the dust production of shearer at different positions, as well as the influence of different air volume dust removers and their combinations. It is hoped that further analysis and discussion will be made.

Acknowledgments

This work was financially supported by Chongqing Natural Science Foundation fund (cstc2021jc yj-msxm X1186).

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