Study on Dust Diffusion Law and Application of Wet Vibrating Wire Dust Removal Fan in Fully Mechanized Excavation Face

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Abstract. Fully mechanized excavation face is the main place of dust generation in coal mines. Due to the huge dust production and long ventilation distance, the dust concentration is difficult to reach the safety standard. The purpose of this study is to improve the dust removal efficiency of 2410 roadway in Yuhua Coal Mine. Firstly, this paper carried out dust concentration and roadway wind speed measurement on the 2410 fully mechanized excavation face of Yuhua Coal Mine. According to the actual layout of fully mechanized excavation face, the geometric model is established. The distribution of wind field in fully mechanized excavation face is simulated and analyzed by Fluent software. The correctness and feasibility of the model and simulation method are verified by comparing the simulation results with the measured data. Then the paper studies the influence of the air duct outlet installation position on the airflow field and the dust distribution, and analyzes the dust removal effect of the existing wet vibrating wire dust collector dust removal system in Yuhua Coal Mine. The research conclusion is that the wet string vibration dedusting fan has remarkable dedusting effect, and the dedusting efficiency is the highest when the air duct is installed near 10 m from the working face.

1. General
The wet vibrating wire dust removal system is composed of negative pressure fan and wet vibrating wire filter dust remover. During the tunneling operation, a large amount of clean air is blown out from the forced air duct to the working face to ensure the air supply in the tunnel. The negative pressure air duct installed on the roadheader sucks in a large amount of dust generated by the tunneling operation, and then the clean air is discharged after filtering the dusty air flow by the wet vibrating string dust remover. This system is widely used in the dust reduction work of the fully mechanized excavation face[1]. It is difficult to control the flour dust in the roadway, and the problem of dust exceeding the standard seriously threatens the health and production safety of the underground workers. Therefore, the research on the application of the wet vibrating string dust removal fan is of great practical significance.

2. Research on Site Situation and Data Measurement
The 2410 comprehensive excavation roadway of Yuhua mine is 2200 m in total length, 4.4 m in width and 3.6 m in height; the excavation section area is 12.4 m². Kcs-225d wet vibrating string dedusting fan and fbdno7.1 local fan are used to form a combined ventilation system. The air volume of tunnel air supply duct is 540m³ / min, and the rated parameter of negative pressure fan is -1200pa,350m³/min. One measuring point shall be arranged every 5m at the position of pedestrian breathing belt with a height
of 1.6m from both sides of the tunnel wind to the floor, according to dust velocity measurement in the air of workplace. In order to study the dedusting efficiency of kcs-225d wet vibrating wire dedusting fan, the dust concentration was measured when the distance (L) between the air duct and the working face was 7m, 10m and 13m respectively under the two conditions of opening and closing the dedusting fan. The average value of the measurement results is recorded in Table 1 and table 2.

![Figure 1. Layout of fully mechanized excavation face](image1)
![Figure 2. Model of fully mechanized excavation face](image2)

**Table 1. Field measurement data of dust concentration**

| measuring point | Distance (m) | Concentration L = 7 m (mg/m³) | Concentration L = 10 m (mg/m³) | Concentration L = 13 m (mg/m³) | measuring point | Distance (m) | Concentration L = 7 m (mg/m³) | Concentration L = 10 m (mg/m³) | Concentration L = 13 m (mg/m³) |
|-----------------|--------------|-------------------------------|-------------------------------|-------------------------------|-----------------|--------------|-------------------------------|-------------------------------|-------------------------------|
| 1               | 5            | 780.31                        | 736.45                        | 1080.05                       | 1               | 5            | 120.20                        | 220.24                       | 120.71                       |
| 2               | 10           | 1051.93                       | 969.43                        | 1051.95                       | 2               | 10           | 260.94                        | 260.36                       | 260.06                       |
| 3               | 15           | 971.24                        | 701.35                        | 871.55                        | 3               | 15           | 422.73                        | 322.31                       | 322.71                       |
| 4               | 20           | 769.14                        | 569.89                        | 969.32                        | 4               | 20           | 352.46                        | 282.94                       | 252.44                       |
| 5               | 25           | 699.85                        | 563.40                        | 699.60                        | 5               | 25           | 332.37                        | 211.01                       | 332.18                       |
| 6               | 30           | 642.20                        | 442.25                        | 642.54                        | 6               | 30           | 301.16                        | 201.34                       | 301.65                       |
| 7               | 35           | 496.39                        | 396.54                        | 496.89                        | 7               | 35           | 253.86                        | 186.85                       | 253.86                       |
| 8               | 40           | 374.95                        | 374.41                        | 360.26                        | 8               | 40           | 243.45                        | 150.73                       | 243.47                       |
| 9               | 45           | 346.64                        | 340.26                        | 346.71                        | 9               | 45           | 160.12                        | 160.91                       | 160.85                       |
| 10              | 50           | 359.23                        | 359.06                        | 329.47                        | 10              | 50           | 148.06                        | 148.28                       | 148.34                       |

**Table 2. Wind speed record table under L = 10m working condition**

| measuring point | Distance (m) | Wind speed (m/s) | measuring point | Distance (m) | Wind speed (m/s) |
|-----------------|--------------|-----------------|-----------------|--------------|-----------------|
| 1               | 5            | 1.721           | 6               | 30           | 0.661           |
| 2               | 10           | 1.736           | 7               | 35           | 0.604           |
| 3               | 15           | 1.554           | 8               | 40           | 0.629           |
| 4               | 20           | 1.036           | 9               | 45           | 0.601           |
| 5               | 25           | 0.690           | 10              | 50           | 0.602           |

### 3. Model of Fully Mechanized Excavation Face

In this paper, the software croe5.0 is used to model the 2410 fully mechanized excavation face of Yuhua mine. The wet vibrating string dust removal fan is used. The air supply duct is hung at the position 0.5m away from the coal wall on the left side of the roadway and 2.5m high. The position of the air outlet of air duct changes within 5-15m away from the working face with the increase of the excavation depth. The air inlet of the dust removal fan is installed at the junction of the end of the cutting arm and the fuselage of the roadheader. Considering the research content and the actual situation, the model diagram of the fully mechanized excavation face is shown in Figure 2. Mesh using the meshing component. Select the pressure based solver based on the pressure method, and the time type is steady state. The Eulerian multi flow model is used, and the standard k-epsilon model is selected as the turbulence model.[2] In the discrete term model, the solid material is medium volatile pulverized coal, and the particle size distribution conforms to Rosin Rammler distribution.[3] The particle size range is set as $2.19e^{-04}$-3.21e$^{-07}$m, the medium diameter is 3.52e$^{-05}$m, the dispersion is 1.81, the mass flow rate is
0.008 kg/s, and the working face is set as the jet source which type is surface. The distribution index is 1.821. The tunnel air supply duct is set as the velocity inlet, and the parameters of the pressure exhaust duct are 11.4 m/s, -7.6 m/s, the hydraulic diameter is 1 m, 0.8 m, and the turbulence intensity is 3.11%, 2.97%. The end section of the tunnel is set as the outflow boundary, and the wall boundary condition is set as the static wall. The simple pressure velocity correlation algorithm is selected by using the separation solver, and the residual convergence standard is $10^{-3}$.

4. Study on the dust transport law when the dust removal fan is closed

4.1. Analysis of air flow field and dust field when dust removal fan is closed

The movement of dust is mainly affected by air flow. The simulation results of air flow field are shown in Figure 3. Because of the wall attachment effect, the air flow from the air duct adheres to the coal wall and flows to the working face. Because the air flow continuity is impacted by the working face barrier, the air flow flows out along the return side after two deflections, forming the return air flow. The crosswind speed of return air decreases rapidly at a distance of 0-5 m from the working face. Due to the narrow space formed between the main part of the roadheader and the tunnel wall at a distance of 5-11 m, the wind speed slows down. The wind speed continues to decrease at a distance of 12-25 m. After 25 m, the wind speed is stable at 0.65 m/s. Due to the obstruction of the air flow by the roadheader, the air flow will generate vortex in the space between the roadheader and the working face, forming a low wind speed vortex area, resulting in dust accumulation. Due to the existence of eddy current, the wind speed in the 5-17 meter range is unstable, and the wind speed tends to be stable at 0.65 m/s after 30 m from the working face.

![Figure 3. Wind speed vector streamline](image)

Figure 3. Wind speed vector streamline

Figure 4 shows the dust distribution in XZ plane with the height is 0.5 m, 1 m and 1.6 m respectively. The wind speed decreases with the increase of the height from the floor of the roadway, and the dust concentration decreases gradually along the way. The large particle dust is greatly affected by gravity, the deposition speed is faster, and the resistance coefficient of small particle dust is smaller. The Saffman lifting force and gravity are easy to reach a balance state, so that the dust suspension in the whole tunnel is not easy to settle. Observing the whole flow field, the dust diffusion at the head-on dust source is mainly affected by the air flow at the return side. At 5-10 m, the space between the roadheader and the coal wall is narrow, resulting in a large number of dust accumulation, with a concentration of up to 600-1000mg/m$^3$; with the increase of the distance from the head, the dust concentration of the roadways along the way presents a decreasing trend, and tends to be stable after 40 m from the head. However, the dust concentration is still as high as 300mg/m$^3$. The simulation results show that the dust concentration exceeds the safety standard of coal mine seriously when the dust removal fan is not turned on and only relies on ventilation to reduce dust.

![Figure 4. XZ plane dust distribution contour (Y=0.5m, 1.5m, 3.5m)](image)
4.2. Verification of simulation results

The comparison between the simulation data of dust and wind speed in the breathing zone of the return air side and the measured data is shown in Figure 5, 6. Considering the complex environment of the working face, the model ignores the adhesion of the tunnel seepage to the dust particles, the hardness and softness of the coal quality, the dust during the transportation and other factors, and there is a certain error between the simulation and the measured data. But the error is controlled within 5%, the attenuation trend of the two is consistent and the correlation is good, which shows that the simulation results can reflect the change of the dust concentration in the whole driving work.

![Figure 5. Comparison of the speed along the return air side](image1)

![Figure 6. Comparison of dust along the return air side](image2)

5. Study on the dust transport law when the dust removal fan is turned on

5.1. Analysis of dust field and air flow field when the dust removal fan is turned on

Considering the actual working conditions of the working face when the dust removal fan is turned on, the dust distribution under the five working conditions of 5 m, 7 m, 10 m, 13 m and 15 m from the air outlet to the working face is simulated and analyzed. The cloud chart of dust concentration distribution in XZ plane at different distance from the working face YZ plane and breathing zone height y = 1.6m was intercepted, as shown in Figure 8. The dust in the roadway is mainly affected by the return air flow. With the increase of the distance from the working face, the dust concentration in the return air side and the air duct side decreases first, then increases, and then continues to decrease. Compared with the closed condition of the dust removal fan, the dust concentration decreased significantly. When the air outlet is installed between 7-10m from the head-on, the dust concentration of working flour is significantly lower than that of other working conditions, the dust removal effect is better, and the dust concentration at the return air side is controlled at about 200mg/m$^3$, which is consistent with the actual operation experience on site.

![Figure 7. Dust Distribution under Different L](image3)

Through the analysis of the dust field, it is found that the different position of the air duct outlet has a great influence on the dust removal efficiency. In order to explore the reasons, the air flow field after the dust removal fan is turned on is analyzed. Figure 8 shows the flow field in the tunnel near the air outlet air duct 5m away from the working face. The air outlet is too close to the working face, which makes the air duct jet speed too high when it reaches the working face, and a large number of vortices
are produced due to the obstruction of the roadheader, which causes some dust to gather in the vortices area near the working face and it is difficult to discharge. And the other part of dust is blown away by the wind flow and diffused to the whole tunnel the dust collector can not be effectively captured by the negative pressure air duct, which is not conducive to high efficiency dust removal. When the air outlet is 7-10m away from the working face, as shown in Figure 9, the dust collector can effectively capture and handle most of the dust, a small amount of dust diffuses with the return air flow, the dust concentration of the working flour is low, and the dust removal effect is obviously better than other working conditions. When the air outlet is 13m away from the working face. As shown in Figure 10, it is not easy to form a suitable suction and extraction air flow. The air flow field in the tunnel is very complex, and the air flow forms a return flow under the side of the air duct, spreading a large amount of dust to the depth of the tunnel. When the distance between air outlet and working face is more than 13m, the air outlet is too far away from the dust source point, the tunnel air duct jet has been attenuated before it reaches the working face. A circulating air is formed between the dust extraction fan and the tunnel air duct, and a large number of clean air flows directly to the negative pressure air duct. As a result, the dedusting fan can not effectively capture the dust laden air flow, the dedusting effect will be weakened, and the high concentration dust will gather between 5m away from the working face, causing potential safety hazards.

5.2. Verification of simulation results and analysis of dedusting efficiency

When the distance (L) from the air outlet of the air duct to the working face is 7m, 10m and 13m, the comparison between the measured data of dust concentration along the return air side and the simulated data is analyzed. The results are shown in Figure 11-13. The error between the simulated data when the dust removal fan is turned on and the field measured data is within 5%, and the change trend is the same, which shows that the experimental simulation results are effective. Based on the analysis of the simulation results of the dust field in the air flow field after the opening of the dust removal fan, it is determined that the dust removal efficiency is the best when the air outlet is about 13m away from the working face. According to the measured data, the average concentration of the tunnel is 637mg/m³ when the dedusting fan is closed, and 236mg/m³, 203mg/m³ and 249mg/m³ when the air outlet of the air duct is 10, 13 and 15 meters away from the working face. After calculation, the efficiency of dust removal is increased by 63%, 68% and 61% respectively when the dust removal fan is turned on compared with the condition that only ventilation is used to reduce dust.
6. Conclusion

This study provides a theoretical basis for the practical application of the wet vibrating string dust removal fan in 2410 fully mechanized face of Yuhua Coal Mine, and draws the following conclusions:

1) Under the condition that only ventilation is adopted to reduce dust, the air flow field is stable 35 m away from the working face, the dust mainly diffuses with the air flow at the return air side, and the dust concentration at the return air side is higher than that at the air duct side. The range of dust concentration in roadway is 600-1000 mg/m$^3$, which is much higher than the safety standard of coal mine.

2) Compared with the working condition of closing the fan, the efficiency of wet vibrating wire dust removal fan is increased by more than 60%. And the dust removal effect is the best when the distance between the air duct outlet and the working face is about 10 m, reaching 68%.

3) When the distance between the air duct outlet and the working face is more than 13m, it is easy to form a circulating air between the forced air flow and the air inlet of the dust removal fan, resulting in the reduction of dust removal efficiency. When the distance between the air duct outlet and the working face is less than 7m, the air flow at the dust source is too large, resulting in the aggravation of dust diffusion. These two situations should be avoided in practical application.

References

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