Research and Application of the technology of Forced Ventilation Diversion to Control and Reduce Dust in Comprehensive Excavation Face

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Abstract. In order to solve the problem of dust pollution in the comprehensive excavation face, the matching relationship between the long forced ventilation and the short dust removal sucking was grasped, and reasonable control dust removal process parameters were obtained. In this paper, the 31 # coal return air roadway in Hongliulin Coal Mine is taken as the research object. By establishing the working face physical model and adopting the numerical simulation method, the different axial diameter outward air ratio is compared and analyzed. Combined with the field measurement, it is verified to obtain the optimal range of dust axial diameter outward air ratio. The application results show that a swirl air curtain is formed along the sidewall of the roadway after the adoption of the attached air duct, and a dust control air curtain pointing to the head is gradually formed after entering the section of the roadheader. When the axial diameter outward wind ratio is 1:2~1:3, the breathing dust at the driver's position can be controlled within 17 mg/m³, and the dust removal efficiency can be increased to more than 93%, which greatly improves the working environment and ensures the occupational health and safety of workers.

1. Introduction
Coal is China’s main energy source [1]. In order to ensure the continuous and safe supply of coal, a large number of high-yield and high-efficiency mines have emerged in recent years. The main features are: high degree of mechanization, high single-sided output, and fast roadway excavation [2]. Rapid excavation has caused serious dust pollution during face production. For this reason, mixed ventilation and dust removal techniques are often used for treatment [3, 4], which has achieved certain results, but it is not ideal. The main reason is that although the dust removal efficiency of the dust removal fan has increased to more than 90%, the dust collection efficiency of the dust removal system is low, which affects the improvement of the dust reduction efficiency of the working face. On the premise of not affecting the safety of the working face, how to solve the matching of wind control dust and short-extraction dust removal, and obtain reasonable dust control and removal process parameters, has become the key to efficiency improvement. In this paper, 31 # coal return air roadway in Hongliulin Coal Mine is taken as the research object. Through numerical simulation and field experiment, the research on dust diffusion control technology is carried out by dividing the air supply into axial and radial air outlet, so as to provide reference for dust control in working face under similar conditions.
2. Overview of working face
The average thickness of the 3-1 coal seam in Hongliulin Coal Mine is 2.71 m, and the dip angle of the coal seam is 1 ~ 3°. Ebz-200h integrated excavating machine is used to drive along the roof of the coal seam, and DSJ-800 belt conveyor is used to transport coal. The designed length of roadway is 2527.5 m, the width of roadway section is 6 m and the height is 3.5 m. The working face adopts the air supply duct with a diameter of 8000 mm, and the air supply volume is 460 m³/min. The maximum gas emission of working face is 0.1 m³/min, and the explosive index of coal dust is 44.87%.

According to the actual measurement data, when the Working face is in normal production, the original total dust concentration at the driver's position is as high as 970 mg/m³, and the respirable dust concentration is as high as 245 mg/m³. In order to control the dust on the working face, a dust collector is arranged on the working face with a suction volume of 450 m³/min and a load carrier is adopted to realize the synchronous advance and fall of the dust collector and the roadheader. The supply air duct is provided with a wall-attached air duct. The end of the supply air duct is 6 m away from the head. Due to the lack of control over the radial air outlet of the air duct, the total dust concentration at the driver's place is still as high as 294 mg/m³ and the respirable dust concentration is as high as 97 mg/m³ during production, far exceeding the relevant requirements of "Coal Mine Safety Regulations".

In this paper, aiming at the above problems, the physical model of the working face was first established, the reasonable ratio of axial and radial air outlet was determined by numerical simulation method, so as to achieve the process parameters for controlling dust diffusion, and the rationality of the parameters was verified by field experiments.

3. Numerical simulation

3.1. Solution process
In this paper, SIMPLE algorithm was first used to calculate the flow field velocity and other parameters of the air flow, then discrete phase injection source was created, and parameters such as the location and particle size of the discrete phase injection source were determined, and the movement of dust in the air flow field was calculated by the discrete phase model [5-9].

3.2. The establishment and meshing of physical model
According to the equipment layout of the 3-1 coal return roadway, the equipment irrelevant to the study is omitted, and the physical model with equal proportion of the working face is established. The size and position relationship of the main components in the model are shown in Table 1 and Figure 1.

| Serial number | Part Name | size              | Positional relationship                   |
|---------------|-----------|-------------------|------------------------------------------|
| 1             | Roadway   | 50m×6m×3.5 m      | The center of the air duct is 0.6 m from the roof and 0.7 m from the left side |
| 2             | air supply duct | φ800 mm     |                                           |
| 3             | Wall-attached air duct | φ800 mm×4 m |                                           |
| 4             | The outlet of Wall-attached air duct | φ500 mm | The Angle to the horizontal is 30°, and it slopes upward |
| 5             | Rectifying air duct | φ800 mm | 6 m from Working face |
| 6             | Roadheader | 11 m×3.2 m×1.9 m |                                           |
| 7             | dust collector | 3 m×1.3 m×1.1 m | 29 m from Working face |
| 8             | Air duct for vacuuming | φ600 mm×18.7 m |                                           |
| 9             | Dust collecting plant | 4.2 m×1.0 m×0.5 m |                                           |
3.3. Boundary conditions and parameter settings
According to the specific situation of the comprehensive excavation face and the measured data, the numerical simulation parameters and boundary conditions were determined by combining FLUENT's calculation method and mathematical model as follows: the turbulence model is the standard k-ε two-equation model, the DPM model is turned on, and the energy equation is closed. The air duct outlet is set as the speed inlet, and the air supply is 460 m³/min. The exit of roadway is set as free outflow. The outlet of the dust collector is set as the speed outlet, the air volume is 450 m³/min, and the wall surface of the fan outlet is set as the dust capture surface. The roadway and the wall surface of all components have no slip solid boundary condition. The main parameters of the dust source are shown in Table 2.

Table 2. Dust source parameter table

| Serial number | parameter name       | Parameter setting value     |
|---------------|----------------------|-----------------------------|
| 1             | Jet source type      | surface                     |
| 2             | Release surface      | injet                       |
| 3             | material             | coal-lv                     |
| 4             | Particle size distribution | rosin-rammler             |
| 5             | Mass flow rate/kg.s⁻¹ | 0.01                        |
| 6             | Minimum particle size/m | 1e⁻⁰⁶                    |
| 7             | Maximum particle size/m | 0.0001                   |
| 8             | Median diameter/m    | 1e⁻⁰⁵                       |
| 9             | Dispersion coefficient | 3.5                        |
| 10            | Turbulence model     | stochastic tracking         |

4. Analysis of simulation results

4.1. Distribution law of wind flow field - dust field when there is no separation of wind control dust
The main working face operator is the driver of the comprehensive excavator, whose breathing belt is about 2.3 m high. Therefore, take Y=2.3 m to compare and analyze the wind flow field - dust flow field of different ventilation methods, as shown in Figure 2 and Figure 3.

As can be seen from Figure 2 and Figure 3, after the tunneling face adopts mixed ventilation, some of the air flow back to the working face directly enters the dust removal system, while the other flows...
back along the right side of the roadway. In this part of the air flow, most of the air flow generates eddy currents due to the suction effect of the dust collector, and flows back into the dust removal system again. At this time, the dust concentration in the driver's breathing zone was 1168.7 mg/m³. In the overlapping part of the dust removal system and the air supply duct, dust carried by the return air will accumulate here due to the decrease of wind speed. After the tail of the dust collector, the dust concentration will decrease rapidly due to the dilution effect of the exhaust air of the dust collector.

Figure 2. Vector diagram of wind speed in the breathing zone of drivers with mixed ventilation without controlled dust

Figure 3. Dust flow field distribution diagram of drivers' breathing zone with mixed ventilation

4.2. Distribution law of wind field - dust field when dust is controlled by wind separation

Because the dust removal system has no dust control device, the dust concentration is still high in places such as the driver who is working on the head. At this time, a separate wind control device, such as a wall-attached air duct, is needed to improve the dust collection efficiency of the dust removal system. The wall-attached air duct changes the axial air supply of the long-pressure ventilation into two parts, the axial and the radial air outlet. The axial air outlet dilutes gas, dust, etc., the "pressure action" of the radial air outlet and the "negative pressure suction action" of the dust collector form the "dust control surface", which controls the high concentration dust in the working face range and greatly improves the dust collecting efficiency of the dust removal system.

The effect of wall-attached air duct is closely related to the ratio of the axial and radial air outlet. In order to determine the range of the optimal axial-radial air outlet ratio of the 31 coal return air roadway, and improve the dust collection efficiency of the dust removal system, under the condition of ensuring effective dilution of the gas concentration in the working face, comparative analysis was carried out on wind field and dust field under five conditions of axial-diameter air outlet ratio of 1:1, 1:2, 1:3, 1:4 and 1:5.

| ratio of axial and radial air output | Air volume/(m³.min⁻¹) | Air outlet area/m² | Air outlet wind/m.s⁻¹ |
|------------------------------------|----------------------|-------------------|----------------------|
| 1:1                                | Axial:3.84 Radial:3.84 | Axial:0.50 Radial:0.20 | Axial:7.63 Radial:6.51 |
| 1:2                                | Axial:2.56 Radial:5.11 | Axial:0.50 Radial:0.20 | Axial:5.09 Radial:8.69 |
| 1:3                                | Axial:1.92 Radial:5.75 | Axial:0.50 Radial:0.20 | Axial:3.82 Radial:9.77 |
| 1:4                                | Axial:1.53 Radial:6.14 | Axial:0.50 Radial:0.20 | Axial:3.05 Radial:10.42 |
| 1:5                                | Axial:1.28 Radial:6.39 | Axial:0.50 Radial:0.20 | Axial:2.54 Radial:10.86 |
The distribution of dust flow field in the driver's breathing zone is shown in FIG. 4 with different axial and diameter-outward wind ratios. As can be seen from FIG. 4, the dust distribution range in the driver's breathing zone decreases first, then increases, and then gradually decreases with the decrease of the ratio of axial and radial air output. When the ratio of axial and radial air output is 1:2, the dust control effect is the best, and the dust is controlled within 4.3 m of the head. When the ratio of axial and radial air discharge is 1:3 and 1:5, the dust control effect is second. The ratio of axial and radial air discharge is 1:3, which is slightly better than 1:5. Dust is controlled within 5.9 m and 4.8 m of the head respectively. When the ratio of axial and radial air output is 1:4, the dust control effect is the worst. Dust is filled within the range of 18.2 m at the head and the dust concentration at the driver's position is as high as 263.3 mg/m³.

![Figure 4. Dust flow field distribution in the driver's breathing zone with different radial air outlet ratios](image)

It can be seen from Figure 5 that the above result is mainly due to the fact that the wind flow is divided into axial wind and radial wind. The distance from the axial wind to the front is only 6 m, and the wind speed when the wind reaches the front is still high. After blowing the dust, the air flow turns back to carry the dust to the direction of the roadway opening, and due to the combined action of the "press-in effect" of the radial air outlet and the "negative pressure suction" of the dust collector, the dirty air folds back again after passing the dust suction port, and finally enters the dust suction port. For example, when the axial and radial wind ratio is 1:1, the maximum dust diffusion distance is 11.1 m.

With the increase of the radial air volume, the "press-in effect" of the radial air outlet increases, forming a "dust control air curtain" that evenly points to the working face; as the axial air volume decreases, its "blowing effect" also weakened, the two superimposed effects, the dust is controlled in the working face area. When the ratio of axial and radial outgoing air volume is 1:2, the two forms a balance in the area near the dust suction port, and the high-concentration dust is quickly inhaled into the dust collection system. When the ratio of axial and radial outgoing air volume is 1:3, the balance area gathers near the entrance of the scraper conveyor and the right side. High-concentration dust spreads along the flow path of the scraper conveyor and under the action of the "dust control air curtain". The dust is pressed back to the working face again, and the wind speed of the overlap part between the dust removal system and the air supply duct decreases, and the dust carried by the return air flow diffuses, and when the ratio of axial and radial outgoing air volume is 1:4, the working
environment of the working face is seriously deteriorated. When the ratio of axial and radial outgoing air volume is 1:5, the balance area shifts to the left side of the roadway, and the high-concentration dust is controlled in the upper corner area of the roadway, and the amount of dust diffused through the flow passage of the scraper conveyor is reduced. At the same time, as the axial wind speed decreases, the "blowing effect" is weakened, and the dust discharge speed of the dust suction port also decreases with the reduction of the ratio of axial and radial outgoing air volume.

**Figure 5.** The distribution of dust concentration in the radial direction of different shafts

**Figure 6.** The distribution of wind speed in the breathing zone of the working face driver with different radial air outlet ratios

The different ratio of axial and radial outgoing air volume also has an important effect on the air speed in the working face section and the air speed in the air duct coincidence section. It can be seen from Fig. 6 that as the ratio of axial and radial outgoing air volume decreases, the wind speed in the working face area before the dust suction port gradually decreases. For example, when the ratio of axial and radial outgoing air volume is 1:1, the wind speed in most areas is above 2.5 m/s, and when the ratio of axial and radial outgoing air volume is 1:5, the wind speed in most areas is 0.5~0.75 m/s. The reduction of wind speed will cause gas accumulation in working face and affect the speed of dust emission, which is not conducive to safe production. With the increase of the radial wind, the low wind speed area in the overlapped section of the air ducts is significantly reduced. For example, when the ratio of axial and radial outgoing air volume is 1:3, the wind speed in most areas increases to above 0.5~0.75 m/s.
Therefore, considering the dust control effect and the wind speed of working face comprehensively, the ratio of axial and radial outgoing air volume should be controlled in 1:2~1:3.

5. Analysis of on-site application effect
In order to verify the rationality of the simulation, according to GBZ/T 192.2-2007 "Determination of dust in Workplace Air - Part 2: respirable dust Concentration", CCZ20 individual respirable dust sampler was used to measure the dust concentration at the driver's position in four conditions for 8 h continuously. In these four cases, the ratio of axial and radial outgoing air volume is 1:2, 1:3, 1:4 and no partial wind is adopted. In addition, a comparative analysis is made before and after dust treatment in the flow passage of the scraper conveyor. The results are shown in Table 4.

Table 4. Dust concentration at drivers' locations with different dust control parameters

| Ratio of axial and radial air output | Time weighted average concentration/mg.m⁻³ | Dust reduction efficiency/% |
|-------------------------------------|------------------------------------------|----------------------------|
|                                     | Respirable dust | Respirable dust             |                            |
| Not adopted to take air distribution| 250.7          | 242.3                       |                            |
| 1:2                                 | 18.4           | 16.3                        | 92.66                      | 93.27                      |
| 1:3                                 | 22.2           | 13.6                        | 91.14                      | 94.39                      |
| 1:4                                 | 125.7          | 20.5                        | 49.86                      | 91.54                      |
| Remarks                             | Before treatment | After treatment             | Before treatment            | After treatment             |

According to the analysis in Table 4, after the dust control measures are taken, the concentration of respirable dust in the driver's position is significantly reduced, and the visibility in the driver's field of vision is greatly improved. One person needs to take a mining lamp to assist in lighting before the treatment, but no additional lighting is needed after the treatment. Before the dust treatment in the flow passage of the scraper conveyor, the dust removal rate reaches 92.66%, 91.14% and 49.86% respectively. The dust removal effect is basically consistent with the numerical simulation. After the dust treatment in the flow passage of scraper conveyor, the dust concentration decreases to different degrees, and the dust removal rate increases to 93.27%, 94.39% and 91.54% respectively. Among them, the ratio of axial and radial outgoing air volume is 1:4, and dust reduction is obvious.

6. Conclusion
(1) Before adopting the technical measures of air separation and dust control, mixed ventilation and dust removal system is unable to collect and treat dust quickly, and dust pollution of the whole working face, the utilization ratio of dust collector is relatively low.

(2) After adopting the technical measures of air separation and dust control, with the reduction of the ratio of axial and radial outgoing air volume, the dust control effect tends to increase first, then decrease, and finally increase. The actual dust control ability is continuously improving, but the dust pollution in working face is serious when the ratio of axial and radial outgoing air volume is 1:4 due to the diffusion of dust through the flow path of the scraper conveyor. Considering the dust control effect and the wind speed of working face comprehensively, the ratio of axial and radial outgoing air volume should be controlled in 1:2~1:3.

(3) The actual application on site shows that the numerical simulation result is basically consistent with the actual measurement result when no treatment measures are taken for the flow passage of the scraper conveyor. After the adoption of treatment measures, the dust treatment effect is improved to a certain extent under the condition of different ratios of axial and radial outgoing air volume. The dust treatment effect has been improved most obviously when the ratio of axial and radial outgoing air volume is 1:4. When the ratio of axial and radial outgoing air volume is 1:2~1:3, the respirable dust at
the driver's position can be controlled within 17 mg/m³, the dust reduction efficiency is increased to more than 93%, and the dust reduction effect is obvious.

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