Research and application of dust control technology based on long pressure and short pumping system in mechanized tunneling face of coal roadway

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Abstract. In order to solve the problem of dust pollution in mechanized tunneling face, master the best matching relationship between the long and forced ventilation and the dusting and short dust removal parameters in the working face, reducing the dust concentration of working flour to the maximum degree. This paper takes the high-yield dust comprehensive mining face of Wangjialing coal mine as the research background, by establishing CFD model, the effect of dust control on different axial and radial air out ratio of working face is compared, and the parameters range of effective dust control is obtained, and the actual application of the field is verified and analyzed in order to get the best matching parameters of the control dust removal process. The results show that, after increasing the dust control of the wall winder, a fresh air flow transparent wall along the wall of the tunnel is formed in the tail of the roadheader, the dust can be controlled in the area of the front of the work. When the ratio of the axial and radial air out is 1:3, the dust is controlled in the smaller area near working face, the dust control effect is the best. The total and respirable dust concentration of the driver's position and the 5m position at the tail of the driving machine can be reduced to less than 26.1 mg/m³ and 12.7 mg/m³. The dust control efficiency is above 80%, the overall dust efficiency is up to 94%, the dust reduction effect is obvious, and reduces the occupational hazards of workers.

1. Introduction
Dust is one of the six disasters in coal mine production, and it cause pneumoconiosis occupational disease. During the 12th Five-Year Plan period, China's coal mines achieved the goal of improving production safety, but the upward trend of occupational hazards in coal mines has not been effectively curbed [1-3]. The number of workers exposed to occupational hazards in coal mining enterprises is large and the dust exposure rate is high. Pneumoconiosis cases caused by coal mine dust hazards have been on the rise all the time [4-5]. At present, China's mines have entered the era of mechanized production in an all-round way, with high output on one side, high footage speed and serious dust hazard, especially in fully mechanized mining face, because of its narrow working space and limited five sides, the operators have been in a high concentration of dust hazard and the dust hazard is very serious [6-9]. In view of dust prevention in fully mechanized mining face, long pressure and short pumping ventilation control dust collector system is the most effective measure to solve the dust hazard, but after many mines
adopt this system, the dust hazard is still serious [10-11]. The key problem that restricts the long-pressure and short-suction ventilation dust control system is how to solve the coordination relationship between long-pressure dust control and short-suction dust control. On the premise of ensuring safe production, scientific and reasonable selection of dust control technical parameters and matching models of dust control equipment will enable the dust control equipment to play its maximum use efficiency in the best dust control area, improve the dust extraction and purification capacity of dust control equipment, and comprehensively improve the dust control effect of fully mechanized mining face. In view of the deficiencies in the research on dust control and dust reduction technology in the fully mechanized mining face, this paper based on the 20106 fully mechanized mining face in Wangjialing Coal Mine, carries out research on the long-pressure ventilation and dust control theory and the matching process of short-pumping and dust removal technical parameters, which provides theoretical guidance for the selection of the technical parameters of dust control and dust removal technology in the long-pressure short-pumping system in the fully mechanized mining face under such conditions, improves the efficiency and dust removal efficiency of the system, reduces dust hazards in the fully mechanized mining face, protects the occupational health of operators and eliminates dust explosion hazards.

2. Engineering survey
Wangjialing mine 2 # coal seam average thickness is 5.8 m, the dip angle is 2~4 degrees, the 20106 fully mechanized mining face heading along the floor of the coal seam, and used EBZ-220 cantilever roadheader to cut and drop coal, 91000 pairs of flexible air cylinders are used and supplied 550 m³/min, and absolute gas emission is 0.27 m³/min. The coal seam is dry and fragile, the wettability is poor, the tunneling section is large (S=5.0×3.6m=18m), the tunneling speed is fast. These factors lead to high dust production intensity (the original total dust concentration is 2744 mg/m³, and the respirable dust is 619 mg/m³), which is difficult to control and requires high dust control system technology.

In order to control the dust, the face is equipped with low-pressure external spraying of the roadheader, and a KCS-550D wet dust collector is installed at the tail of the roadheader bridge, with a handling air volume of 450 m³/min, moving with the cantilever roadheader, and connected with the dust hood of the working face through a negative pressure dust extraction air cylinder to form a short dust extraction system. At the same time, a wall-attached air duct was installed at the outlet of the air supply duct to control dust. The axial outlet distance was 10m away from the face and the radial outlet distance was 15m away from the face. The radial outlet is free, not controlled, resulting in the unreasonable distribution of the axial outlet distance and the outlet air volume and the failure to control dust effectively, the dust collector can't rapidly pumping high-concentration dust. The total and respirable dust concentration was still as high as 1224.8 mg/m³ and 312.6 mg/m³. The pollution was still serious, far exceeding the "Coal Mine Safety Regulations" management standard. Therefore, it is urgent to conduct scientific research on the matching technology of controlled dust removal process parameters.

Aiming at the above problems, based on the field conditions, this paper uses numerical simulation method to find the approximate range of the radial air outlet ratio of the attached wall duct shaft, and then compares and verifies the best dust control matching parameters through the field test method.

3. Establishment of numerical model

3.1. Solution process
In this paper, discrete model (DPM) is used to simulate the movement of dust in the gas field, and Euler-Lagrange model is used to describe the gas flow field and the movement of particles. When solving the discrete phase problem, the SIMPLE algorithm is first used to calculate the flow field velocity and other parameters of the continuous phase. Secondly, a discrete phase jet source is created to determine the position, size, particle size and initial velocity of the jet source. Then, the particles in the particle swarm are integrated in the Lagrange coordinates. In the random orbit model, the random method is used to consider the influence of instantaneous turbulent velocity on the particle orbit [12-15].
3.2. Establishment of CFD Model
According to the actual situation in the field, the dust movement law and the change of airflow field in the head-on 50m range of the working face are modeled. The model structure size parameters are shown in Table 1 below. The CFD model is shown in figure 1.

| Serial number | Name                  | Physical dimension | Placement position                  |
|---------------|-----------------------|--------------------|-------------------------------------|
| 1             | Simulated roadway     | 50m×5.0m×3.6m      | -                                   |
| 2             | Air supply duct       | Φ1.0m×30m          | Connect the dust control device     |
| 3             | Dust control ram      | Φ1.0m×4m           | 15m away from the face              |
| 4             | Rectifier duct        | Φ1.0m×6m           | 10m away from the face              |
| 5             | Boring machine        | 9.0m×3.5m×1.8m     | The cutting is attached to face     |
| 6             | Dust collector        | 3.0m×1.2m×1.2m     | 20m away from the face              |
| 7             | Dust extractor        | Φ0.6m×17m          | Connect dust collector and hood     |
| 8             | Suction hood          | 1.0m×1.5m×0.3m     | 3m away from the head               |

Figure 1. CFD model

3.3. Setting of boundary conditions
Regarding the boundary conditions of numerical simulation, the turbulence model is set as a standard k-ε two-way model. Open the discrete phase model and close the energy equation.

| Serial number | Parameter name            | Parameter setting          |
|---------------|---------------------------|----------------------------|
| 1             | Injection type            | Surface                    |
| 2             | Release from surfaces     | Injet                      |
| 3             | Material                  | Coal-hv                    |
| 4             | Diameter distribution     | Rosin-rammler              |
| 5             | Min. diameter /μm         | 1e-06                      |
| 6             | Max. diameter /μm         | 4.5e-04                    |
| 7             | Mean diameter /μm         | 2.5e-05                    |
| 8             | Spread parameter          | 1.2                        |
| 9             | Total flow rate /kg·s⁻¹   | 0.025                      |
| 10            | Turbulent dispersion      | Stochastic tracking        |
| 11            | Number of tries           | 20                         |
| 12            | Time scale constant       | 0.15                       |

Set the inlet boundary type as speed inlet, match the supply air volume (550 m³/min), and the outlet boundary type as free outlet. All wall surfaces are solid boundary conditions without slippage, and the pressure provided by the fan in the extraction type air duct is set to ensure that the treated air volume is
450 m³/min, and the fan surface is set as the dust capture surface. DPM model parameter settings are shown in table 2.

4. Analysis of Numerical Simulation Results

4.1. Distribution Law of Air Flow Field and Dust in No Dust Control

When unused dust control, no wind flowing out from the radial outlet, All air flows out of the radial outlet, the driver of roadheader is 5m away from the face and the height of its breathing zone is about 2.3m. when z=2.3m, the wind speed and dust distribution are studied, as shown in figure 2.

![Airflow field and Dust field](image)

**Figure 2.** Air flow field and concentration distribution without dust control

Under the condition of no dust control device, the long-pressure ventilation airflow directly rushes to the coal wall of the working face, the high-speed airflow moves to the right side of the roadway under the obstruction of the coal wall, and at the same time, a large amount of dust is carried out and diffused to the right side of the head-on to gather. However, the dust hood of the dust collector system sucks away a lot of fresh air, resulting in reduction in the use efficiency of the dust collector system and limited dust removal effect of the dust collector system. In the overlapping section between dust control device and dust collector, a great deal of dust is gathered here due to the decrease of wind speed in the tunnel. When the dust gradually diffuses to the tail of dust catcher, the dust will be diluted and its concentration will decrease due to the increase of wind speed in the cross section.

4.2. Flow field - dust distribution rule when there is dust control

When used dust control, the radial air outlet will be opened, and both axial and radial air will exit simultaneously. After the diversion and dust control is increased, the dust is attached by the radial wind, and a transparent wind wall rotating along the coal wall of the roadway section is formed under the suction action of the dust collector to control the dust in the coal wall area, effectively preventing the dust from diffusing backward, meanwhile, the operators are in fresh wind flow, avoiding dust hazards. In order to obtain the key parameters of the optimal axial radial air outlet ratio, selected four air outlet ratio conditions for comparative study, and for details, see the table 3.

![Table 3](image)

**Table 3.** Air distribution in simulation

| Air output ratio | Air output (m³/min) | Exit area(m²) | Exit wind speed(m/s) |
|------------------|---------------------|--------------|----------------------|
|                  | Axial | Radial | Axial | Radia | Axial | Radia |
| 1:2              | 183   | 367    | 0.5   | 0.5   | 6.1   | 12.2  |
| 1:3              | 137.5 | 412.5  | 0.5   | 0.5   | 4.6   | 13.75 |
| 1:4              | 110   | 440    | 0.5   | 0.5   | 3.7   | 14.6  |
| 1:5              | 92    | 458    | 0.5   | 0.5   | 3.0   | 15.3  |

According to the numerical simulation, the height position of the driver's breathing zone with z = 2.3m is taken to analyze the change of airflow field, as shown in figure 3. According to the analysis of wind flow field under four dust control parameters, when the radial wind output ratio of important official is less than 1:3, the wind speed in some areas is low, and with the further reduction of the wind output ratio, the area with low wind speed gradually expands, which is not conducive to safe production and will cause local gas accumulation. In the overlap section of long pressure and short pumping, with the decrease of the air output ratio, the radial air output increases, the
area with low wind speed in the overlap section gradually decreases, and the wind speed also tends to be more uniform, which has a positive impact on the wind speed requirements in the overlap section. Compared with safety, the impact of head-on gas accumulation should be taken into account and parameters should be selected reasonably. According to the current distribution of wind speed field, when the ratio of axial radial wind output is 1:2 and 1:3, the probability of head-on gas accumulation is relatively small, and the accumulation position is biased toward the head-on return air side. The gas concentration warning device installed here can give early warning and should be selected first.

![Wind field in different axial direction](image1)

**Figure 3.** Wind field in different axial direction

After the dust control device is added, the dust is controlled in the front area of the working face, and the dust is controlled in the range of about 4 m in front of the working face when the air outlet ratio in the axial direction is 1:3, 1:4 and 1:5. When the air outlet ratio is 1:2, although the dust can be controlled within a certain range before and after the roadheader, the dust concentration area is large, the driver is completely surrounded by high-concentration dust, and the radial air outlet does not press the axial air outlet dust back to the head of the working face, so the dust control effect is not good. The dust control effect of different air outlet ratios is shown in figure 4.

![Comparison of dust control effects of different axial and radial wind outlet](image2)

**Figure 4.** Comparison of dust control effects of different axial and radial wind outlet

![Comparison of dust control effect in different positions of coal roadway](image3)

**Figure 5.** Comparison of dust control effect in different positions of coal roadway
By extracting the driver's position and the dust concentration value inside the dust extraction duct, the best dust control parameters are obtained through comparative analysis, and the comparison of dust control effects is shown in figure 5.

Through comparison, it is found that the dust control effect is good when the air outlet ratio is 1:3 and 1:4, especially when the air outlet ratio is 1:3, the dust concentration in the driver's position can be reduced to 12.8 mg/m³ from 1596.43 mg/m³ without dust control, and the control effect is the best. At the same time, the instantaneous concentration inside the dust extraction duct is the highest when the air outlet ratio is 1:3, increasing from 1446.78 mg/m³ to 5934.28 mg/m³ when there is no dust control, indicating that the dust collector system can exert the maximum dust extraction and purification capacity under this parameter, and increasing the dust control can improve the dust extraction and purification capacity of the dust collector system by more than 75.6%, greatly improving the use efficiency of the dust collector system.

Through comprehensive analysis of head-on wind speed, safety impact, dust control range and dust extraction concentration, the dust control effect is the best when the radial air outlet ratio of dust control parameter axis is 1:3.

5. Analysis of Field Application Effect
In order to verify the effectiveness of the numerical simulation of the optimal dust control parameters, a comparative test was carried out in Wangjialing 20106 fully mechanized excavation face to verify the effectiveness of the dust control parameters through visual qualitative and quantitative analysis of the dust control effect.

5.1. Visual effect analysis
Before dust control was adopted, visibility was low in the area of about 30 m in front of the whole work, and it was difficult for drivers of fully mechanized coal diggers to see the coal wall, requiring one person to direct the coal cutting operation. After dust control parameters were optimized, visibility in the work area was greatly improved, and head-on visibility could be clearly seen. Head-on dust production was quickly removed and purified by the dust collector, and the working environment was improved. At the same time, compared with the case where no dust control was adopted, the dust adhesion of the filter membrane was significantly reduced within the same dust measurement time after the parameter optimization, indicating that the dust concentration in the air of the working face was effectively controlled, verifying the effectiveness of the dust control parameter, and the comparison of the dust adhesion of the filter membrane before and after optimization is shown in figure 6.

![Figure 6. Comparison of dust test membrane physical map on the driver's position](image)

5.2. Field measurement analysis
After the completion of on-site process matching, dust control tests were carried out on the spot under the conditions of axial radial air outlet ratio of 1:2, 1:3 and 1:4, and dust control effects were compared by continuous 8h measurement at the driver's position using CCZ-20 sampler. The field test results are summarized in Table 4.

| Air output ratio | Time weighted average concentration (mg/m³) | Remarks |
|-----------------|----------------------------------|--------|
|                 | Total dust                        | Respiratory dust |                  |
| 1:2             | 98.5                             | 25.3    | The dust collector system is in normal use |
| 1:3             | 26.1                             | 12.7    |                  |
| 1:4             | 63.0                             | 18.5    |                  |
The field test shows that the axial and radial outlet areas of the dust control device can be adjusted to achieve the axial air outlet ratio. The dust control effect is obviously improved under the three dust control parameters, but the dust control effect is most obvious when the air outlet ratio is 1:3. The total dust concentration can be controlled at 26.1 mg/m³, the respirable dust is reduced to 12.7 mg/m³, and the dust concentration is greatly reduced. The dust control and dust removal are most effective under this parameter, and the maximum use efficiency of the dust control system is exerted. After the comparison of field tests, when the ratio of shaft radial air outlet is 1:3, the control effects of the driver and the tail 5m position are tested respectively, and the results are shown in Table 5.

### Table 5. Dust concentration test in 20106 workface

| Sampling location | Dust Type | Time weighted average dust concentration (mg/m³) | Dust reduction efficiency |
|-------------------|-----------|-----------------------------------------------|--------------------------|
|                   |           | Original | Only collector | Only control dust | control dust and collector | Collection | Control | Total |
| Driver's position | Total     | 2744     | 1224.8        | 216.2            | 26.1                      | 55.4%      | 82.3%   | 97.9% |
| 5m away from tail | Respirable| 619      | 312.6         | 59.8             | 12.7                      | 49.5%      | 80.8%   | 95.9% |
|                   | Total     | 916      | 489.7         | 88.6             | 23.5                      | 46.5%      | 81.9%   | 95.2% |
|                   | Respirable| 232      | 128.3         | 22.4             | 8.8                       | 44.7%      | 82.5%   | 93.1% |

After the optimization of the axial and radial distribution dust control parameters, the total dust concentration at the driver's position and the heading machine's tail 5m decreased from 1224.8 mg/m³ and 489.7 mg/m³ to 26.1 mg/m³ and 23.5 mg/m³, respectively, with the dust control efficiency above 80% and the total dust control efficiency above 95%. The concentration of respirable dust dropped to 12.7 mg/m³ and 8.8 mg/m³ respectively, and the dust-settling efficiency of respirable dust reached more than 93% with remarkable treatment effect. The dust concentration of the whole working face is close to the management standard limit, indicating that this set of technology can effectively solve the dust hazard of the fully mechanized mining face.

This paper only studies the matching parameters of pressure air diversion dust control and short pumping dust removal. Although the effect is close to the management value, it is still not up to the standard. If the spraying parameters outside tunneling are optimized and a certain proportion of wetting agent is added, the dust removal effect can be further improved and is expected to reach below the management value, the next study is needed.

6. Conclusion

Through comparison, the numerical simulation results show that it is affected by the radial air outlet attachment effect and forms a transparent air wall rotating along the coal wall of the roadway section under the suction effect of dust collector by using dust control device, controlling the dust in the front area of the working face, it can improve the efficiency of dust collector system, effectively preventing the dust from diffusing backward, while the operators are in fresh air flow, avoiding dust hazards.

Through comprehensive analysis wind speed, safety impact, dust control range and dust extraction concentration of four different axial radial air outlet ratios, when the axial and radial air outlet ratio of the dust control parameter is 1:3, the dust control effect is the best, the dust concentration can be controlled within 26.1 mg/m³, and the dust concentration in the dust extraction system is the highest. The dust control system can improve the dust extraction and purification capacity of the dust collector by more than 75.6 %, increasing the use efficiency of the dust collector system.

Through the field application test, it shows that the visibility of the working face has been greatly improved, and the use effect of the system continues to be stable, and the working environment has been improved. The best dust control parameter is 1:3, and the total and respirable dust concentration at the driver's position and 5m at the end of the roadheader can be reduced to within 26.1 mg/m³ and 12.7 mg/m³, respectively, the dust control efficiency is over 80%, the overall dust removal efficiency increased to more than 93%, and the dust control effect is obvious.
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