Study on Dust Migration Law and Spray Dust Suppression Technology in Fully Mechanized Mining Face

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Abstract: To effectively solve the problem of high dust concentration during coal cutting and frame shifting in fully mechanized mining faces, based on the theory of gas–solid two-phase flow, a geometric model of a fully mechanized mining face was established by using COMSOL numerical simulation software. Simulations were performed for the movement characteristics of wind flow and the law of dust diffusion. Results show that the air flow at the junction of the working face, the air inlet, the hydraulic support moving area, and the vicinity of the shearer has accelerated movement, and the maximum wind speed zone of about 3 m/s can be formed. Under the influence of wind flow, dust particles above 35 um settle faster, while dust particles below 35 um are very vulnerable to the influence of wind flow, and the settling speed is slower. Using a custom experimental platform, the atomization characteristics and wind resistance of a pressure fan nozzle, a supersonic nozzle, and an ultrasonic nozzle were tested, and the nozzle that was suitable for the scheme was selected and applied in the field. Comparing the dust concentration before and after the application of the dust removal scheme at the sampling point, results show that the dust removal efficiency of the proposed scheme exceeds 85%, and the treatment effect is good.

Keywords: fully mechanized mining face; numerical simulation; wind characteristics; dust spread; atomization characteristics; wind resistance

1. Introduction

In recent years, with the rapid development of China’s industrial sector, the level of coal mining technology has been markedly improved, and the output of raw coal and coal consumption have increased rapidly. High-intensity coal mining produces serious dust-pollution problems, and the dust generated at a fully mechanized mining face accounts for 45% to 80% of the total mine dust generation [1,2]. In the absence of any effective control measures, the dust concentration on the working face far exceeds the upper limit of the national coal mine safety regulations. High concentrations of dust have a negative impact on the environment and seriously threaten the physical and mental health of workers [3,4]. The national occupational disease report released by the National Health and Family Planning Commission shows that pneumoconiosis accounts for a high proportion of new occupational diseases. From 2005 to 2020, the number of pneumoconiosis cases increased from 8783 to 14,367. High-concentration dust also increases the possibility of explosion [5,6]; thus, it is urgent to solve the problem of dust pollution in fully mechanized mining faces.

Many scholars have conducted in-depth research of dust removal methods for fully mechanized mining faces while considering that water injection in coal seams [7,8] may reduce coal quality. A pre-charged electrostatic precipitator [9] has certain requirements.
on the specific resistance of the dust to be processed and has strict requirements on manufacturing and installation accuracy. The cost of foam dust removal [10] and energy loss of Venturi tube dust removal [11] are too high; thus, spray dust removal remains the primary treatment method used with fully mechanized mining faces [12,13]. Huitian Peng et al. [14] designed a new type of air-assisted centralized spray dust removal device for hydraulic supports. Gang Zhou et al. [15] obtained the airflow and dust movement law by means of numerical simulation software and designed a negative pressure spray dust collector on this basis. Yao Xie et al. [16,17] obtained the diffusion law of the droplet field with different spray parameters by establishing the air droplet coupling model of the fully mechanized face. Guobao Zhang et al. [18,19] analyzed the influence of airflow on the distribution of dust particles and droplet particles and put forward multi-stage atomization dust reduction technology for a fully mechanized coal mining face on the basis of single-stage atomization dust suppression system. Shibbo Yang et al. [20,21] obtained the nozzle radius, spray pressure, nozzle installation angle, and other parameters in the wet dusting scheme by combining an orthogonal experiment, numerical simulation, and field test. The existing research results do not sufficiently consider the layout of the nozzle at the shearer, the nozzle optimization process, or the wind resistance performance of the nozzle.

In this study, a geometric model of a fully mechanized mining face was established according to the field working conditions. The COMSOL simulation software was used to obtain the air flow movement characteristics and the migration law of dust particles. Based on the simulation results, an atomization and dust reduction scheme was proposed. Through the self-built experimental platform test, the atomization characteristics and wind resistance of different nozzles were compared, and the appropriate nozzles were selected and applied in the field.

2. Numerical Simulation

In this study, the fully mechanized mining face of the Sandaogou Coal Mine was selected, of which 5-2 coal is the primary mineable coal seam throughout the area. The average thickness of this coal seam is 4.97 m. Dust pollution during the fully mechanized mining operation is particularly serious. The dust primarily comes from the process of shearer cutting and frame shifting, and excessive dust concentration has an impact on the operation of underground workers. To propose an efficient and reasonable dust control scheme, this work involved an in-depth study of the wind flow field and dust particle migration law of a fully mechanized mining face through COMSOL simulation software [22,23].

2.1. Mathematical Model

In this study, gas is defined as a continuous medium, and the $k\varepsilon$ turbulence model in single-phase flow was selected for simulation [24]. The specific equations are as follows:

Turbulent kinetic energy $k$ transport equation:

$$\rho (u \cdot \nabla) k = \nabla \cdot \left( \left( \mu + \frac{\mu_T}{\sigma_k} \right) \nabla k \right) + P_k - \rho \varepsilon$$  \hspace{1cm} (1)

Turbulent kinetic energy dissipation rate $\varepsilon$ equation:

$$\rho (u \cdot \nabla) \varepsilon = \nabla \cdot \left( \left( \mu + \frac{\mu_T}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + C_{\varepsilon 1} \frac{\varepsilon}{k} P_k - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k}$$  \hspace{1cm} (2)

$$\varepsilon = \varepsilon_p$$  \hspace{1cm} (3)

$$\mu_T = \rho C_p \frac{k^2}{\varepsilon}$$  \hspace{1cm} (4)

$$P_k = \mu_T \nabla u : (\nabla u + (\nabla u)^T)$$  \hspace{1cm} (5)
where $\rho$: gas density, kg/m$^3$; $k$: turbulent kinetic energy, m$^2$/s$^2$; $\varepsilon$: turbulent kinetic energy dissipation rate, m$^2$/s$^2$; $P_c$: turbulent kinetic energy generation term caused by average velocity gradient; $\mu$: turbulent viscosity coefficient, Pa s; $C_p$, $C_g$, $C_v$: empirical constants; $C_p = 0.09$, $C_g = 1.44$, $C_v = 1.92$; $\mu$: molecular viscosity coefficient of fluid, Pa s; $u$: continuous phase velocity, m/s; $\sigma$, $\sigma_g$, $\sigma_v$ are the $k$ equations, respectively; and the turbulent Prandtl number of the $\varepsilon$ equation, $\sigma=1.0, \sigma_g=1.3$.

Considering dust particles as discrete phases, the simulation of dust particles is based on the particle force in the Lagrangian coordinate system to solve the particle motion trajectory [25]. The particle motion balance equation can be expressed in the Cartesian coordinate system as:

$$\frac{du_p}{dt} = F_D(u - u_p) + g_x(p_p - p) / \rho_p + F$$  \hspace{1cm} \text{(6)}$$

$$F_D = \frac{18\mu C_p Re}{\rho_p D_p^2}$$  \hspace{1cm} \text{(7)}$$

where $F_D = (u - u_p)$: the drag force per unit mass of dust particles, N; $u_p$: particle velocity, m/s; $\rho_p$: particle density, kg/m$^3$; $g_x$: gravitational acceleration in the x-axis direction, m/s$^2$; $t$: time, s; $F$: other external forces, N; $C_p$: drag coefficient, $D_p$: particle diameter, m, $Re$: relative Reynolds number.

2.2. Geometric Model and Meshing

According to the real size of the fully mechanized mining face in the Sandaogou Coal Mine, a geometric model was established, as shown in Figure 1. The overall structure of the geometric model is U-shaped, primarily composed of an air inlet road, return air road, shearer, hydraulic support, etc. The working space of the fully mechanized face is $246 \times 5.2 \times 3.5$ m (length $\times$ width $\times$ height), the size of the inlet and return air lanes on both sides is the same, and the length $\times$ width $\times$ height is $15 \times 5 \times 3.5$ m. The shearer is approximated in the simulation. Simplified as a cuboid, its length $\times$ width $\times$ height dimensions are $6 \times 1.2 \times 1.1$ m, the radius of the drum is 1 m, and the length of the rocker arm is 2 m. There are 140 hydraulic supports, with a spacing of 1.75 m. The entire fully mechanized mining face is divided into the unremoved-frame area and the frame-removal-completed area, and the unremoved-frame area includes the coal mining area and the unmined area.

![Figure 1. Geometric model.](image)

Grid generation is an important part of numerical simulation. Grid division should consider effects on the accuracy of simulation results and calculation efficiency: Too many grid cells increase the computational cost, and too few lead to inaccurate simulation results. Typically, the mesh is refined in the area where the fluid property changes at a fast rate, and the mesh can be coarsened in the area where the change rate is slow. In this study, the number of tetrahedrons was 754,673, the number of triangles was 120,114, and
most average element quality exceeded 0.3 [26]. The specific mesh division is shown in Figure 2.

![Grid at the air inlet](image1)

![Grid at workspace](image2)

![Shearer grid](image3)

![Grid at return air alley](image4)

**Figure 2.** Partial meshing of the geometric model.

2.3. Boundary Conditions and Parameter Settings

The boundary conditions were set according to the real situation on site, and the specific parameters are shown in Table 1.

**Table 1.** Boundary conditions and parameter settings.

<table>
<thead>
<tr>
<th>Project</th>
<th>Parameter Name</th>
<th>Parameter Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary conditions</td>
<td>entry boundary</td>
<td>VELOCITY-INLET</td>
</tr>
<tr>
<td></td>
<td>export border</td>
<td>Pressure-outlet</td>
</tr>
<tr>
<td></td>
<td>turbulent flow model</td>
<td>Standard k-ε model</td>
</tr>
<tr>
<td></td>
<td>wall condition</td>
<td>no slip</td>
</tr>
<tr>
<td>Turbulence parameters</td>
<td>temperature/K</td>
<td>293.15</td>
</tr>
<tr>
<td></td>
<td>diffusion coefficient of gas molecules/(m²·s⁻¹)</td>
<td>$2 \times 10^{-5}$</td>
</tr>
<tr>
<td></td>
<td>dynamic viscosity/Pa·s</td>
<td>$1.79 \times 10^{-5}$</td>
</tr>
<tr>
<td></td>
<td>air density/(kg·m⁻³)</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>inlet velocity/(m·s⁻¹)</td>
<td>1.0</td>
</tr>
<tr>
<td>Dust source parameters</td>
<td>dust particle density/(g·cm⁻³)</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>average particle mass/kg</td>
<td>$5 \times 10^{-11}$</td>
</tr>
<tr>
<td></td>
<td>dust production method</td>
<td>Surface</td>
</tr>
<tr>
<td></td>
<td>number of entry particles</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>
3. Numerical Simulation Results and Analysis

The simulation was performed according to the boundary conditions and parameters described above. First, the wind flow field was solved. After the iteration curve converged, the dust particles were solved. By analyzing the wind flow field and the simulation results of dust particles, the migration law of dust particles in a fully mechanized mining face was obtained.

3.1. Distribution Characteristics of the Wind Flow Field

Figure 3 is the streamline diagram of the wind flow field. To describe the movement state of the wind flow more clearly, three sections are set along the height of the working face, $Z = 0.6$ m (near the bottom plate), $Z = 1.6$ m (the height of the breathing zone), and $Z = 3$ m (near the top plate). The distribution of streamlines at different heights is shown in Figure 4.

![Figure 3. Streamline diagram of the wind flow field.](image)

The airflow flows in from the air inlet channel and out from the return air channel. The speed at the air inlet is relatively stable and basically maintained at 1 m/s. When entering the working face from the air inlet, due to the reduction in the cross section of the working space, the wind flow completes the first acceleration movement, and the local wind flow at the corner shown in Figure 4a reaches 2 m/s. Most of the wind flow in the working face moves in the gap between the coal wall and the pillar and forms a wind speed zone of 2–2.5 m/s. In addition, as shown in Figure 4 b,c, when the wind flow rushes to the working face, another wind speed band is formed between the hydraulic support struts, the height of the working face increases, and the wind speed also increases.

When the wind flow flows from the rack-moving completion area to the non-rack-moving area, the cross-sectional area changes due to the rack-moving process, and the wind flow accelerates for the second time when it flows through this area. Compared with the speed change range between the hydraulic support struts, the change in speed is higher outside the hydraulic strut, where the wind speed increases to 2.5 m/s instantaneously.

When the wind flows through the shearer, the volume of the space blocked by the machine decreases, and the speed increases again. Concurrently, the wind flow moves laterally, and most of it flows to the area between the shearer and the hydraulic prop, resulting in a local velocity exceeding 2 m/s. A small amount of the wind flow also flows along the coal wall to the downwind side of the shearer. After the wind flow passes through the shearer, due to the increase in the cross-sectional area of the roadway, the streamline moves more towards the coal wall, and the speed decreases within a short range of 5 to 6 m from the shearer to its downwind side. In general, under the influence of multiple acceleration conditions in the roadway, the final speed of the wind flow is maintained at approximately 3 m/s, which is three times the speed of the inlet airway, resulting in a high wind speed zone that continues to the return airway. At the return air
alley, the wind hits the wall, creating turbulence; eddy currents also appeared in the upper right corner and the lower left corner of the return air alley.

![Streamline diagram of the wind flow field at different heights](image)

**Figure 4.** Streamline diagram of the wind flow field at different heights. (a) $z = 0.6$ m near the bottom plate; (b) $z = 1.6$ m breathing belt height; (c) $z = 3$ m near the top plate.

3.2. **Distribution Characteristics of the Dust Particle Field**

The dust in the fully mechanized mining face primarily comes from the frame shifting process and the shearer coal cutting process. In addition, according to the site conditions, a small amount of dust falls from the top of some supports in the unmoved frame area. In this study, no air inlet was set to carry dust; thus, there was no dust in the frame-removal-completed area. Because the coal is mined downwind, the dust particles are moved from the dust source to the downwind side of the shearer driven by the wind flow until they flow out of the return air lane. In order to ensure consistency with the characteristics of on-site dust particles, the particle size of dust particles in the study was concentrated within 100um, of which 95% were less than 50 um, 81% less than 30 um, 56% less than 20 um, and 30% less than 10 um. The step size used in this study is 1 s, and the diffusion results and velocity sections of dust particles in the unmoved area at 10, 20, 30, and 40 s are shown in Figure 5.

First, a certain amount of dust is generated in the dislocation area of the rack, but there is less dust on the side of the goaf when the rack is moved. Combined with the wind flow field, the instantaneous wind speed in this study is high, the particles are yet to settle, and the particles suspended in the air driven by the wind move towards the shearer. Second, most of the dust generated by the cutting action of the front drum of the shearer migrates to the rear drum, which is superimposed with the dust generated by the coal cutting of the rear drum itself, resulting in many dust particles appearing at the rear drum. The sectional view of particle velocity in Figure 5 shows that the particles on the coal wall side move faster than the particles between the hydraulic support struts, which is consistent with the state of the wind flow field. The particles in the fast-moving area spread more widely, and under the effect of the pressure difference, the particles in the coal wall area spread to the vicinity of the sidewalk, which seriously endangers the physical and mental health of the staff.

At 10 s, the dust spreads from the shearer to a position approximately 10 m downwind. The particle migration speed at different positions in this interval is different, and at 20 s, it spreads to half of the unmoved area. After some time passes, the diffusion range of dust particles gradually increases, and the dust spreads to the return air alley after 40 s. Six meters downwind of the shearer to the return air lane, the particle movement is relatively stable because the air flow near the coal wall is relatively uniform and thus forms a dust belt with a speed of 3 m/s. Thus, when analyzing and designing the dust
removal scheme, the hydraulic support and the vicinity of the shearer body should be regarded as the key areas for dust control.

Figure 5. Diffusion results of dust particles at different times.

Figure 6 shows the particle size distribution diagram of dust particles. Different colors represent different particle sizes. From the partially enlarged front view on the right side, the reddish particles that are larger than 35 μm are in the middle and lower parts and are eventually deposited onto the bottom plate. Particles smaller than 35μm are very vulnerable to wind flow and float in the air. After a period of time, some particles settle slowly, indicating that the larger the particle size, the faster the particle settles.

Figure 6. Particle size distribution.

4. Experimental Study on Atomization Characteristics and Wind Resistance of Nozzles

The atomization characteristics and wind resistance of nozzles have an important effect on wet dust suppression. To select the best nozzle suitable for the fully mechanized mining face of Sandaogou and maximize the dust removal effect of the spray, the atomization characteristics and wind resistance of three types of nozzles (a pressure fan nozzle, an ultrasonic nozzle, and a supersonic nozzle) were compared and analyzed using a custom experimental platform. The nozzle with the best effect of combining spray and dust particles and strong wind resistance was then selected for further investigation.
4.1. Experiment of Atomization Characteristics

4.1.1. Construction of the Experimental System

Figure 7 shows the custom experimental platform used for testing nozzle atomization characteristics in this study. The experimental platform is primarily composed of a laser particle size analyzer, PVC pipe, tripod, air compressor, and nozzle. In this experiment, the diameter of the droplet was measured using a laser particle size analyzer. The instrument consists of a transmitter unit and a receiver unit. This instrument uses the principle of information optics and emits a laser with a wavelength of 532 nm. The particle size distribution is analyzed by measuring the scattering spectrum of the particle group. During the experiment, it is necessary to align the center of the transmitter unit and the receiver unit of the instrument, and the distance between the two is approximately 0.5 m. The nozzle is placed in the center of the gap. The position of the nozzle can be changed using a tripod. The nozzle is connected to the air compressor and water source through a PVC pipe. The distance between the nozzle and the laser beam and the air pressure were changed to obtain different experimental data.

![Experimental platform for atomization characteristics.](image)

4.1.2. Evaluation Index of Nozzle Spray Particle Size

To date, domestic and foreign scholars have proposed particle size evaluation methods based on characteristic droplet size and average droplet size, which are widely accepted. The characteristic droplet size includes D₅₀ and D₉₀ [27–29], which represent the corresponding particle size when the cumulative particle size distribution percentage reaches 50% and 90%, respectively. D₅₀ is also called the median diameter, and this particle size index is also used in many fields, such as pesticides, insecticides, and medicine. In addition, the average droplet size of Dₛ (surface area average diameter) and Dᵥ (volume average diameter) [30,31] can describe the degree of droplet fragmentation. This study primarily analyses the characteristic droplet size.

4.1.3. Experimental Scheme and Data Analysis

After the instrument was set up, the laser particle size analyzer was turned on and allowed to warm up for 10–15 min, and a background measurement was performed first. After the background measurement was performed 10 times, the energy spectrum test was started. During the experiment, we ensured that the same water drawing height was maintained; thus, we moved the tripod to different distances between the nozzle and the laser beam (1, 2, and 3 m). The control valve was adjusted at these distances, and the measured air pressure was 0.2, 0.3, 0.4, and 0.5 MPa, corresponding to particle size values. The experimental results are shown in Figure 8.
The comparative analysis of the experimental data shows that the particle sizes of \( D_{50} \) and \( D_{90} \) are inversely proportional to the air pressure and proportional to the distance and
that $D_{50}$ is strongly affected by the air pressure and the distance. Under the same air pressure and distance conditions, the particle size of the supersonic nozzle is always smaller than that of the other two nozzles. The maximum $D_{50}$ of the supersonic nozzle is 45 $\mu$m, and $D_{50}$ remains less than 80 $\mu$m. In contrast, the maximum $D_{50}$ of the other two nozzles exceeds 100 $\mu$m. The smaller the droplet size value, the more fully broken, the greater the probability of collision and capture between droplets and coal dust, the more fully the droplets with high kinetic energy combine with dust particles, and the better the dust reduction effect [32,33].

4.2. Wind Resistance Test

The atomization characteristic experiment compares the spray of $D_{50}$ and $D_{90}$ particle sizes from a microscopic perspective to compare nozzle performances. The next wind resistance experiment compares the spray deflection degree from a macroscopic perspective to compare the nozzle performance.

4.2.1. Construction of the Experimental System

The experimental instruments used in this test include nozzles, fans, air compressors, PVC pipes, pressure valves, nozzle brackets, etc. Fans were used to provide transverse wind. The experimental instruments are shown in Figure 9.

![Figure 9. Primary experimental instruments for the wind resistance experiment.](image)

4.2.2. Experimental Results and Analysis

Simulation results show that the maximum wind speed in the roadway is approximately 3m/s; thus, this experiment compares the deflection degree of different nozzle sprays at the maximum wind speed. First, the initial position of the nozzle, the lateral wind speed, pressure, and other variables are the same, and the wind flow direction is from right to left. The spray state of the three nozzles under the influence of the lateral wind is shown in Figure 10. In comparison, the spray formed by the supersonic nozzle begins to deflect markedly when the spray distance is 2.3 m, and the spray is completely blown to the side of the laser. The spray formed by the ultrasonic nozzle is markedly deflected when the spray distance is 2.1 m, while the pressure type spray formed by the fan nozzle begins to deflect markedly at a spray distance of 1.8 m. The experiment intuitively shows that the supersonic nozzle has the best wind resistance, and the wind resistance performance of the pressure fan spray is worse than that of the ultrasonic spray, which is worse than that of the supersonic spray.

The supersonic nozzle not only performs well in atomization characteristics and wind resistance but also has low price and high cost performance compared with the other two nozzles. Under working conditions, the gas consumption of the supersonic nozzle is
about 4.5 m³/h, and the water consumption is 128 mL/min, which is far lower than the other two nozzles, greatly saving resources. In conclusion, we determined that the supersonic nozzle is the best nozzle for the proposed dust removal scheme.

Figure 10. Spray state of different nozzles under the influence of lateral wind.

5. Field Application

Firstly, the positions of 5, 10, 15, 20, 25, and 30 m on the downwind side of the shearer were measured by the tape. The above positions and the position of the return airway were marked. The wind speed of the height of the breathing zone at the above measuring point was measured by the wind speed measuring instrument, and the measurement results were recorded and compared with the simulation results. The results show that the speed of the two is almost the same, indicating that the simulation is correct. The on-site wet dust removal scheme selects supersonic nozzles, adjusts the nozzle position and injection angle according to the scheme, and controls the air pressure between 0.4 and 0.5 MPa. In this scheme, a multichannel fog curtain is set between the hydraulic supports, and the adjacent fog curtains are separated from the distance of six hydraulic supports. Each fog curtain is composed of three nozzles, and the interval between the adjacent nozzles is 0.5 m. The three nozzles are on the same horizontal line, and the spray direction of the nozzle is 20° to the vertical direction to avoid the influence of the spray direct injection sidewalk on the walking of the staff. There are five nozzles that are evenly arranged in the front and rear of the middle box of the shearer, and the injection direction is at an angle of 45° with the vertical direction. During operation, the front and rear drums cut coal, and the nozzles begin to operate. The fog droplets combine with dust particles at the source. The fog droplets cover the drum to a certain extent to reduce the dust concentration. Figures 11 and 12 show the effect of spray treatment between the hydraulic supports and the effect of spray treatment at the shearer, respectively. The fog screen can cover the section well without affecting the passage of pedestrians on the sidewalk.

To more clearly describe the dust removal achieved by the proposed scheme, the height of the breathing zone was considered to be the sampling height, and the position of the moving frame; middle part of shearer; the 10, 20, and 30 m on the downwind side of the shearer; and the return air lane were selected as sampling points. The AKFC-92A dust concentration measuring instrument shown in Figure 13 was used to measure the dust concentration of the sampling points before and after the application of the dust reduction scheme. The sampling time was set to 10 min, and the sampling flow rate was adjusted to 20L/min. First, the filter membrane was weighed, and the initial weight was recorded. By measuring the weight change of the filter membrane before and after sampling, the mass of dust in the unit volume of air was calculated. Each sampling point was measured three times, and the average value was calculated. The final calculation results are shown in Table 2. The dust
concentration at the sampling point is high (far above the national standard) before treatment. After treatment, the dust concentration is markedly reduced, and the dust reduction efficiency reaches more than 85%, indicating that the scheme can effectively control the dust and plays an important role in dust removal and dust suppression. The results of this study should be implemented in other coal mines and could be extended into the field of non-mine dust removal with good application potential.

Figure 11. Real treatment effects of inter-rack spraying.

Figure 12. Effect of spray treatment at the shearer.

Figure 13. Dust concentration measuring instrument.
Table 2. Dust concentration before and after treatment at different sampling points.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Dust Concentration before Treatment/(mg/m³)</th>
<th>Dust Mass Concentration after Treatment/(mg/m³)</th>
<th>Dust Removal Efficiency/%</th>
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</thead>
<tbody>
<tr>
<td>Transfer position</td>
<td>Total Dust</td>
<td>245</td>
<td>17.6</td>
<td>92.82</td>
</tr>
<tr>
<td></td>
<td>Respirable Dust</td>
<td>125</td>
<td>11.7</td>
<td>90.64</td>
</tr>
<tr>
<td>Middle part of shearer</td>
<td>Total Dust</td>
<td>163</td>
<td>9.8</td>
<td>93.99</td>
</tr>
<tr>
<td></td>
<td>Respirable Dust</td>
<td>85</td>
<td>7.4</td>
<td>91.29</td>
</tr>
<tr>
<td>10 m from the downwind side of the shearer</td>
<td>Total Dust</td>
<td>288</td>
<td>25.4</td>
<td>91.18</td>
</tr>
<tr>
<td></td>
<td>Respirable Dust</td>
<td>142</td>
<td>16.9</td>
<td>88.1</td>
</tr>
<tr>
<td>20 m from the downwind side of the shearer</td>
<td>Total Dust</td>
<td>214</td>
<td>16.8</td>
<td>92.15</td>
</tr>
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<td></td>
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<td>117</td>
<td>12.3</td>
<td>89.49</td>
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<tr>
<td>30 m from the downwind side of the shearer</td>
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<tr>
<td></td>
<td>Respirable Dust</td>
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<tr>
<td>Return laneway</td>
<td>Total Dust</td>
<td>55</td>
<td>3.9</td>
<td>92.91</td>
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<td></td>
<td>Respirable Dust</td>
<td>42</td>
<td>2.3</td>
<td>94.52</td>
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</table>

6. Conclusions

In this study, the movement characteristics of air flow and the migration trajectory of dust particles were revealed by means of numerical simulation software, which provides a theoretical basis for the on-site plan layout. At the same time, the accuracy of simulation was verified by on-site data testing. The atomization characteristics and wind resistance of the nozzle were tested by the self-built experimental platform, and the best nozzle was selected. The proposed dust control scheme achieved good results in on-site application and played an important role in dust suppression and dust control. Based on the results of this study, the following primary conclusions can be drawn:

(1) A high wind speed zone exists on the inner side and the outer side of the hydraulic prop of the roadway. The wind speed is higher in the area near the coal wall on the outer side. When the air flows from the air inlet road to the return air road, it flows into the working face, the frame transfer area, and the shearer. The air experiences several acceleration movements, and finally, the speed from the 6 m downwind side of the shearer to the return air roadway tends to be stable, and a wind speed band of approximately 3 m/s is formed near the coal wall side.

(2) A large amount of dust is generated during coal cutting and frame shifting of the shearer. This dust moves from the dust source to the return air lane along the wind flow. Under the influence of the wind flow, a particle belt of approximately 3 m/s is formed on the downwind side of the shearer. Particles that are larger than 35 um settle quickly, while particles that are smaller than 35 um settle slowly.
(3) The atomization characteristics and wind resistance of three types of nozzles (ultrasonic, pressure fan, and supersonic) were tested with a custom experimental platform. Results show that under the same pressure and distance variation conditions, the particle size of the supersonic nozzle is the smallest, and the droplet breaking effect is the best of the studied nozzles. Concurrently, the supersonic nozzle has good wind resistance, and the spray is not easily blown away by the wind flow, which meets the requirements of the fully mechanized mining face on site.

(4) According to the dust migration law during operation and considering the working conditions in the field, we designed a wet dust removal scheme that achieved good results in dust suppression and dust control in a real application. Fog droplets can cover the section and coal mining area. Compared with the change in dust concentration before and after treatment, the dust reduction efficiency reached more than 85%.

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