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Numerical Simulation of Combination Form of External Spray Nozzle for Roadheader

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ABSTRACT. *In order to study the influence of the combination of external spray nozzles on droplet size in the atomization superposed area, according to different nozzle combinations, spray pressure and jet axial distance, the droplet size of the atomization superposition area was simulated by FLUENT software under the combination of single nozzles and 4 nozzles according to the combination of different nozzles, and the optimal nozzle combinations were selected according to the dust trap theory. The changing trend of droplet size in atomization superposed area was analyzed by combination of nozzle, spray pressure and jet axial distance. The results showed that the spray combination had an obvious effect on improving the atomization effect. The spray pressure was inversely proportional to the droplet size of the atomization superposed area. With the increase of the axial distance, droplet size decreased first and then increased, but the minimum value was different. When the spray pressure is near 2MPa, the droplet size is close to the theoretical value in the atomization superposed area of the three nozzle combination. The experimental study of the atomization superposition area of the nozzle combination form has important guiding significance for the treatment of the underground dust.*

KEYWORDS: *Roadheader, Nozzle combination, Droplet size, Numerical simulation*

1. Introduction

In recent years, with the rapid development of industry and the improvement of people's living standards, coal, as the basic energy in China, still plays an important role in social production. Scholars predict that this phenomenon will not change in the next 30 years. In order to meet the people's demand for coal, many researchers and scholars work hard on the efficiency of coal mining. With the increase of coal mining volume, the mechanical power is also increased, which makes the working face environment worse and worse. The dust control also brings serious hidden danger to the underground safety.When the dust concentration is too high, it will not only cause harm to the miner's body, but also accelerate the damage of underground equipment[1],visibility will also be greatly reduced, so dust control has become the

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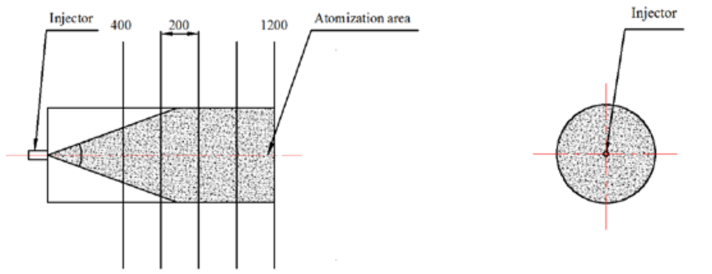
top priority of mine safety.In order to solve this problem and improve the efficiency of dust deposition, this paper proposes a new type of nozzle combination dust reduction method, which is of great significance to the treatment of underground working environment. In recent years, nozzle assembly has been widely used in fire protection, oil drilling, agricultural irrigation and other important fields, but no one has paid attention to it in mining machinery,in the process of oil exploitation, Li Zhaomin tested the jet velocity field of streamlined combined nozzle with experimental method[2], analyzed the axial velocity and radial velocity of the velocity field of the combined nozzle, and obtained the internal law of the velocity in the mixing section of the flow field.Xu Yi found that the disadvantages of ultra-high pressure jet rock breaking drilling[3], using different nozzle combinations to improve the nozzle, greatly improving the drilling speed, and subsequently, the drilling cost has been further reduced, and according to different nozzle combinations, the method of numerical simulation is used to analyze the downhole flow field.Liu Zhichao proposed that the arrangement of nozzles had different effects on the pressure drop of gas in the pipeline transportation process[4], which was further verified. In the process of computer simulation, the relationship between the arrangement of nozzles and pressure drop was obtained, and the combined arrangement of nozzles had an important relationship with the transportation of low concentration gas.Therefore, this paper will use the experimental research method to study the combination form of double nozzles, and deeply explore the size and distribution range of the particles with different axial spacing when the nozzle combination form changes in different pressure, which will lay a good foundation for the underground environment treatment.

2. Numerical Simulation

2.1 The Establishment of Geometric Model

In this paper, the atomization flow field under different nozzle combinations is the focus of the study. Therefore, the main research is the change of droplet size in the outflow field, and the numerical simulation of atomization effect under different nozzle combinations.



(a)Nozzle structure (b)Schematic diagram of guide core

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Fig.1 Injection Diagram

Aiming at the key point of the research, the combined geometry model of nozzle is established and meshed. The schematic diagram of nozzle combination is shown in Figure 3-1 (a). The main consideration of nozzle combination type atomization is the change of fog particles in the fog drop superposition area of atomization flow field. After checking the relevant Atlas of roadheader, the distance between the two nozzles is about 100 mm. Therefore, the center distance of nozzle combination type is set to 100 Mm. In the process of numerical simulation, the three-dimensional finite element model of atomization flow field is a cylinder with a diameter of 500 mm and a height of 1200 mm. The nozzle is placed on the end face. The center of the figure formed by each nozzle and the center of the end face circle are the same point and the nozzle spacing is 100 mm.

In order to make the atomization area more regular and convenient to measure the distribution range of droplet size in the atomization superposition area,the combination of nozzles adopts regular polygon layout[5],the layout is shown in Figure 2.

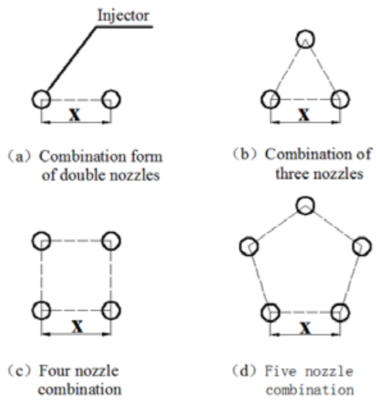

Fig.2 Layout of Nozzle

The 3D model is established by using the 3D mapping software CATIA, and the 3D model is imported into ICEM for mesh generation. The mesh type is tetrahedral mesh, and the finite element model is shown in Figure 3-1 (b).

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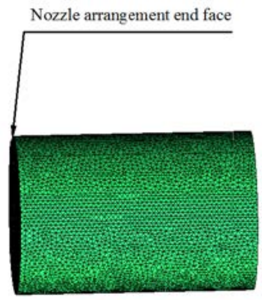

Fig.3 Finite Element Model

2.2 Mathematical Model

(1) Gas phase control equation

In the rectangular coordinate system, the general equation of the gas phase control equation is[6]

$$\frac{\partial(\rho\phi)}{\partial t}+div(\rho u\phi)=div(\Gamma grad\phi)+S \qquad (1)$$

In the formula ϕ --General variable,It can represent u, v, T and other solving variables;

Γ --Generalized diffusion coefficient;

S --Generalized source term.

(2) Droplet motion equation

For the gas-liquid two-phase flow, considering all kinds of forces on the droplet, the equation of droplet motion can be obtained by Newton's second law[7]

$$\frac{\mathrm{d}U_{\mathrm{P}}}{\mathrm{d}t}=F_{\mathrm{D}}\left(U-U_{\mathrm{P}}\right)+\frac{g\left(\rho_{\mathrm{P}}-\rho\right)}{\rho_{\mathrm{P}}}+F \qquad (2)$$

$$F_{\mathrm{D}}=\frac{18\mu}{\rho_{\mathrm{P}}d^{2}{}_{\mathrm{P}}}\frac{C_{\mathrm{drag}}\,\mathrm{Re}}{24} \qquad (3)$$

In the formula UP --Droplet velocity,m/s;

ρp--Droplet density,kg/m3;

Re--Relative motion Reynolds number,Reynolds number

$\mathrm{Re} = d_p \rho \left(u - u_p\right) / \mu$;

Cdrag--Drag coefficient.

(3) Turbulence model

The choice of turbulence model depends on the size of Reynolds number, which is the physical quantity to measure the flow characteristics of fluid. In this study, Re is more than 4000, which is turbulent state, so turbulence model is selected[8].

2.3 Boundary Condition Setting

The boundary condition of the inlet is nozzle nozzle, and the outlet of the nozzle is set as pressure inlet. Because the nozzle is free jet, the outlet is full outlet boundary, the wall is set as wall, and the type is escape. It is assumed that the wall is approximately isothermal and has no slippage. The numerical simulation uses a three-dimensional single precision simulator to solve the convection field in a coupled way. The pressure rotating atomizer model is selected as the atomizer model and water as the dispersion phase.

3. Results and Analysis

Based on the theory of spray Dustfall and the theory of dust collection, the optimum droplet size is not 30~120 μm when the dust of 2~12 μm is collected.The three-dimensional simulation of the atomization flow field of different nozzle combination forms under different pressures is carried out in a coupling way. At the end of the iterative calculation, the particle size at different positions of the nozzle superposition area in the atomization area under the nozzle combination form is extracted. After the extraction, the unit of the droplet size is converted into μm, and the unit of the axial distance is converted into mm.In order to make the expression more convenient, the axial distance of spray nozzle is expressed as a, B, C, D and e respectively, which is 400 mm, 600 mm, 800 mm, 1000 mm and 1200 mm.

3.1 Analysis of Atomization Particle Size Characteristics of Single Nozzle

(a)1 MPa (b)2 MPa (b)3 MPa

Fig.4 Cloud Chart of Droplet Size Distribution of Single Nozzle

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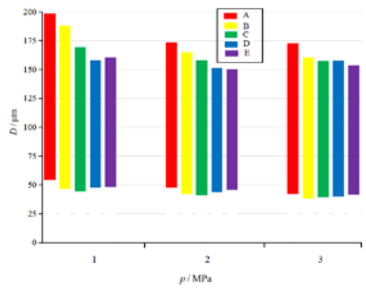
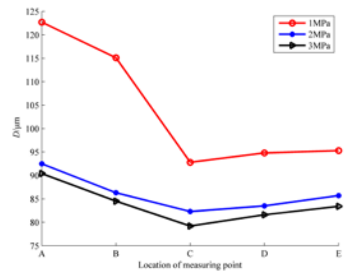
From Figure 4, we can see that with the increase of spray pressure, the droplet size in the atomized area increases gradually. The droplet size of the front droplet increases with the increase of the distance between the spray axis and the spray nozzle. The droplet size increases with the increase of the axial distance. The droplets were polymerized into larger size droplets.



(a)Droplet size distribution range of single nozzle



(b)Average particle size curve of single nozzle

Fig.5 Particle Size Distribution of Single Nozzle

From Figure 5 (a), it can be seen that droplet size of single nozzle is smaller than that of 1MPa when the spray pressure is 2~3 MPa, and the droplet size distribution is 38~198 μm. Based on the theory of dust collection, it can be seen that the droplet size of single nozzle is generally larger than the optimal range of droplet size. In order to make the atomization effect more uniform, the influence of nozzle combination on the atomization effect is proposed. From Figure 5 (b), it can be seen that there is a negative correlation between the spray pressure of single nozzle and droplet size. Under the same spray pressure, droplet size decreases first and then increases with the increase of jet axial distance, and the minimum droplet size point appears at C point.

3.2 Analysis of Particle Size Characteristics of Combined Atomization of Nozzles

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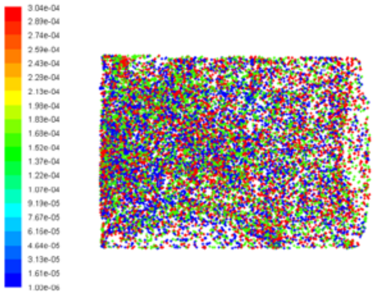
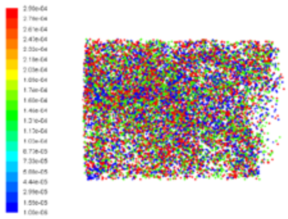
In order to analyze the effect of nozzle combination on droplet size in atomization superposition area, the droplet size characteristics of atomization superposition region under different spray pressure and different axial distance between 4 different nozzle combinations were analyzed.

(4) Combination of two nozzles

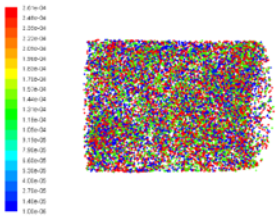
The cloud figure of droplet size distribution in the combined form of double nozzles is shown in Figure 6. Compared with the single nozzle, the number of particles in the combined form of double nozzles is significantly increased, and the water consumption is increased. For more intuitive analysis, the combined form of double nozzles is extracted numerically, and the droplet size distribution in the combined form of double nozzles is drawn, as shown in Figure 7.



(a)1 MPa



(b)2 MPa



(b)3 MPa

Fig.6 Cloud Chart of Droplet Size Distribution in Combination of Two Nozzles

It can be seen from Figure 7 (a) that compared with the droplet size of single nozzle, the droplet size in the superposition area of double nozzle combination atomization is significantly reduced, which shows that the nozzle combination has a significant effect on the improvement of atomization effect, and the droplet size distribution range is 37-159 m. From Figure 7 (b), it can be seen that droplet size decreases with the increase of spray pressure when the measuring points are the

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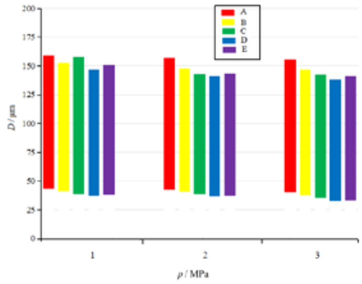
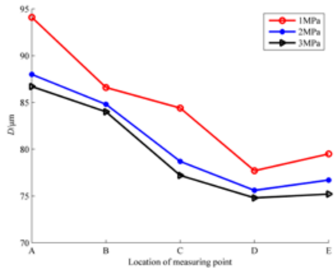
same. Under the same spray pressure, the droplet size decreases first and then increases with the increase of the axial distance, and reaches the minimum at D.



(a)Droplet size distribution range of double nozzles



(b)Average particle size of double nozzles

Fig.7 Particle Size Distribution of Double Nozzle Combination

(5)Combination of three nozzles

The cloud figure of droplet size distribution in the combination of three nozzles is shown in Figure 8. It can be seen from the diagram that droplet size decreases with the increase of spray pressure. When the spray pressure is 1 MPa, the droplet size distribution near the wall is larger. When the spray pressure is 2 MPa, the droplet size distribution is distributed near the wall of the cylinder. Due to the influence of airflow in free space, the droplet size will generate Brown motion in the free space and condense into larger droplets with the surrounding droplets. When the spray pressure is 3 MPa, the droplet size distribution in the front of the nozzle is atomized without covering area, and the droplet size is smaller in the rear part of the atomization area.

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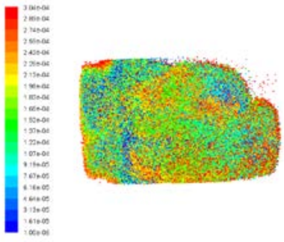
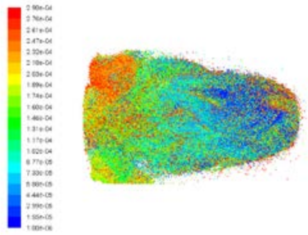
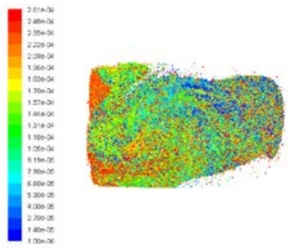




(a)1 MPa (b)2 MPa



(b)3 MPa

Fig.8 Cloud Chart of Droplet Size Distribution in Combination of Three Nozzles

It can be seen from Figure 9 (a) that the distribution range of droplet size in the atomization superposition area under the combination of three nozzles is 31-139 μm. compared with the combination of two nozzles, the droplet size also shows a significant decrease trend, indicating that the combination of three nozzles is better than the combination of two nozzles. From Figure 9 (b), it can be seen that droplet size decreases with the increase of spray pressure. With the increase of the axial distance, droplet size decreases first and then increases, and the smallest droplet size appears near D point. It can be explained that with the increase of spray pressure, the initial velocity of droplets increases, and droplet size collisions become more intense in atomization superposed area. The stronger the ability of fog droplets to break surface tension into smaller droplets is. With the increase of the axial distance of the spray, the kinetic energy of the droplets will gradually decrease, reaching the minimum near point D. therefore, the ability to overcome the surface tension after point D will be lower, and the small droplets will agglomerate into larger size droplets to move in the atomization area.

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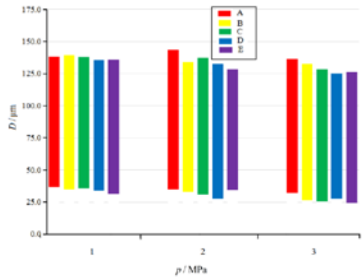
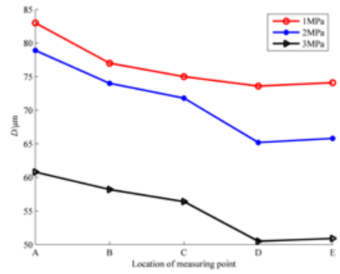


(a) Droplet size distribution range of three nozzles

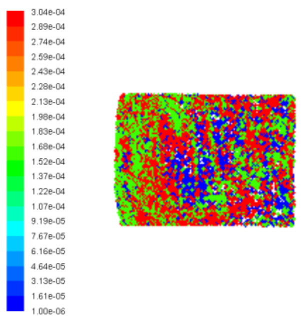


(b) Average droplet size of three nozzles

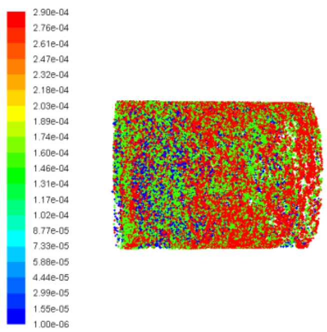
Fig.9 Droplet Size Distribution of Three Nozzle Combination

(7)Four nozzle combination

Under different spray pressure conditions, the droplet size distribution cloud map of the four nozzle combination form is shown in Figure 10, and the numerical simulation of the four nozzle is numerically extracted, as shown in Figure 11.



(a)1 MPa



(b)2 MPa

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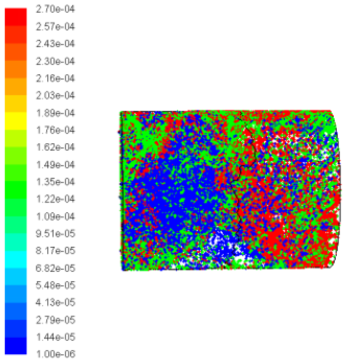
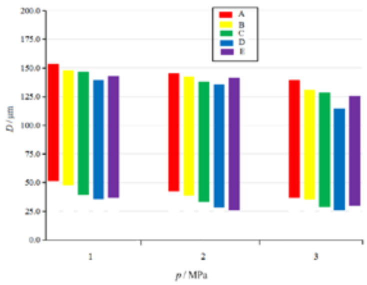


(b)3 MPa

Fig.10 Cloud Chart of Droplet Size Distribution of Four Nozzle Combination

It can be seen from Figure 11 (a) that the distribution range of droplet size in the atomization superposition area is 25-153 μm under the combination of four nozzles. Compared with the combination of three nozzles, the droplet size of the combination of four nozzles has a significant increase trend again. Combined with the dust collection theory, it shows that the atomization effect of the combination of four nozzles has a trend of decreasing. It can be seen from Figure 11 (b) that the change rule of droplet size in the superposition area of four nozzle combination and three nozzle combination is similar, and the minimum droplet size point appears at point D.



(a)Distribution range of droplet size of four nozzles

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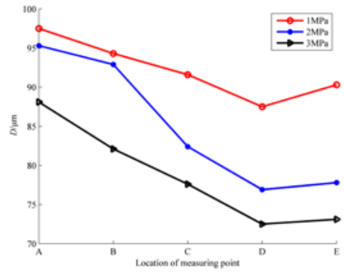
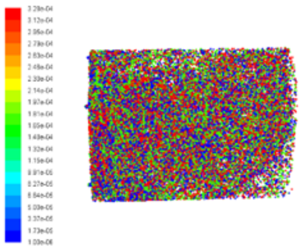


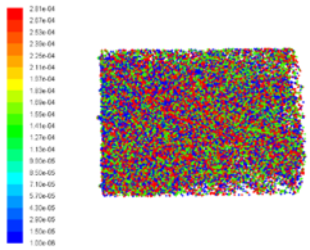
(b)Average droplet size of four nozzles

Fig.11 Particle Size Distribution of Four Nozzle Combination

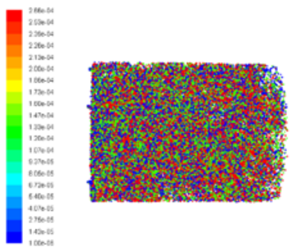
(1)Five nozzle combination

Under different spray pressure conditions, the droplet size distribution of five nozzle combinations is shown in Figure 12.





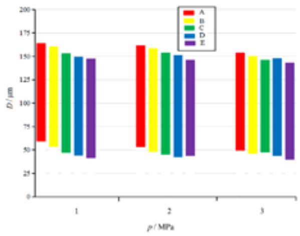
(a)1 MPa (b)2 MPa



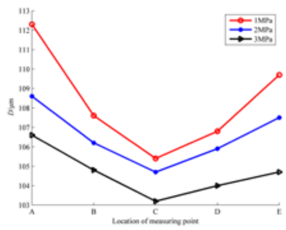
(b)3 MPa

Fig.12 Cloud Chart of Droplet Size Distribution in Combination of Five Nozzles

It can be seen from Figure 13 (a) that under the combination of five nozzles, compared with other combinations of nozzles, the droplet size increases significantly. Therefore, it can be concluded that with the increase of the number of nozzles, the water consumption of the combination of five nozzles also increases. As the number of droplets in the atomization space increases sharply, the collision acceleration kinetic energy between the droplets decreases. Due to the influence of surface tension, small droplets converge and synthesize Larger droplet size. It can be seen from Figure 13 (b) that the pattern of five nozzle combination is similar to that of four nozzle, but the minimum point appears near the C measuring point, and moves forward compared with other nozzle combination. It can be concluded that the probability of collision between the droplets with five nozzle combination is also greatly increased, which makes the velocity of the droplets attenuate rapidly, and the droplets with lower velocity can not collide with each other to produce more fine droplets. After point C, the droplet size shows an upward trend.



(a) Droplet size distribution range of five nozzles



(b) Average droplet size of five nozzles

Fig.13 Distribution of Droplet Size in Combination of Five Nozzles

To sum up, according to the actual working conditions, combined with the theory of spray and dust suppression and the theory of dust collecting, spray atomization effect is best when the spray pressure 2 MPa is near the three nozzle combination form, and the efficiency of combining dust and droplets is the highest.

4. Conclusion

(1)when the nozzle combination is the same as the jet axial distance, there is a negative correlation between spray pressure and droplet size in the atomization superposed area. When the nozzle combination form and spray pressure are constant, the droplet size decreases first and then increases with the increase of the axial distance.

(2)The combination of nozzles has obvious effect on improving the atomization effect in atomizing area. When the spray pressure of three nozzle combination is 2MPa, the droplet size of atomization superposition zone is the closest to theoretical value, and the theoretical efficiency of spray dust fall is the highest.

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