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The performance optimization experiment of a wet high-frequency vibrating grid

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ABSTRACT
Dust preventing is of great significant in mine safety production. The wet high-frequency vibrating grid is one of the most efficient dedusting systems. Therefore, optimizing the dedusting parameters of wet high-frequency vibrating grids is meaningful in controlling dust. Two of the most important parts of wet high-frequency vibrating grids are the spray dedusting system and the vibrating grid filtration system. This study optimized these two systems respectively to obtain the influence of various factors on the two systems by using the method of orthogonal experiment and then chose the two factors which have the greatest impact on comprehensive optimization. The results can be used in mine dedusting practice to reduce the incidence of pneumoconiosis and improve work efficiency.
KEYWORDS: Vibrating wire grid; dust removal mechanism; orthogonal experiment; performance optimization

1. INTRODUCTION

Underground dust is wide spread and lasts for a long time, therefore, dust suppression by spraying has always been the main measure to control mine dust. A variety of forms are in practice, such as wind-water spraying, magnetized water dust suppression, pre-charged water spray dust suppression, high-pressure spraying, etc. (Liu et al., 2011; Wang, 2010; Dong, 2014). Traditional dedusting methods can be divided into dry dedusting and wet dedusting. Mine dust is always damp, therefore the bag filter and electrostatic precipitator can't be used normally. Wet dust collectors used in mines mainly include the venturi scrubber, cyclone dust collector, foam dust catcher, impact dust collector, self-swash dust catcher, and dust removal fan. These dust collectors have simple structures, convenient maintenance, and reliable operation (Song, 2010; Chen, 2013; Li et al., 2011). However, as the underground conditions are complex and changeable, some new equipment and technology has not been generalized effectively (Shi, 2005).

The wet high-frequency vibrating grid is one of the most efficient dedusting systems. Optimizing the dedusting parameters of the wet high-frequency vibrating grid is meaningful in controlling dust. This study first did deep research on the dedusting mechanism of the wet high-frequency vibrating grid and then optimized the vibrating grid system and the spray system of the grid by an orthogonal experiment. Afterwards the wet high-frequency vibrating grid system was synthetically optimized.

2. DEDUSTING MECHANISM OF WET HIGH-FREQUENCY VIBRATING GRID

The wet high-frequency vibrating grid includes spray dedusting and vibration fiber grid dedusting. When the dust-laden air flows through the sprayer, some dust is crashed, intercepted, condensed, and settled. Spray dedusting mainly uses inertial impaction, interception, and Brownian diffusion and other short-range dust catching mechanisms. Vibrating grid dedusting is uses sonic vibration. By the acoustics principle, the particles in the sound field will vibrate under the effect of sound waves. The small particles have high vibration velocity and large particles have low vibration velocity, which make different sizes of particles agglomeration power forward, so that the larger particles will get closer to the small particles and collide, combine into larger particles, making it easier to be trapped. Supplemented by spraying dedusting, this method can achieve high efficiency of reducing the respirable dust concentration. The acoustic agglomeration effect of the vibrating grid is also related to its amplitude, where the greater the amplitude, the higher the collection efficiency. The amplitude is related to the wind speed flow where the higher the wind speed, the greater the amplitude of the vibrating grid, the sound condensation effect is more significant, and the dedusting effect is better. However, at, extremely high wind speeds, damage will be caused to the vibrating grid.

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3. OPTIMIZATION EXPERIMENT RESEARCH ON WET HIGH-FREQUENCY VIBRATING GRID DEDUSTING PARAMETERS

3.1 Experimental procedure and principle

1) Measure the dust mass flow through before and after the wet high-frequency vibrating grid

Put the filter membrane into the culture dish with tweezers moistened with alcohol, and weigh them in the one over ten-thousand analytical balance after drying them in the drying oven, record the initial data. Start the two dust samplers before and after the grid to obtain the filters with dust before and after dedusting. Place the filters into the culture dish originally used to weigh and record the data. Subtract the initial mass from the total mass of dust filters and culture dish to obtain the dust mass before and after dedusting. Refer to the following formulas:

$$M_{before} = M_1 - M_O \tag{1}$$

$$M_{after} = M_2 - M_O \tag{2}$$

M_{before} is the dust mass before dedusting. M_1 is the total mass of filters and culture dish before dedusting. M_0 is the initial mass of filters and culture dish. M_{after} is the dust mass after dedusting. M_2 is the total mass of filters and culture dish after dedusting.

2) Determination of dedusting efficiency

Side-sampling is applied in this experiment. Place two dust samplers before and after the grid in the simulating roadway. Start two dust samplers at the same time, set the flow rate to 20 L/min and the sampling time to two minutes. Take out the membrane filter according to the above method to weigh the filter and calculate the dedusting efficiency according to the following formula:

$$\eta = \frac{1000\cdot(M_{后} - M_{前})}{Lt} \tag{3}$$

η is the dust concentration of sample point, mg/m^3 ; M_{before} is the dust mass before dedusting, mg; M_{after} is the dust mass after dedusting, mg; L is the sampling flow rate, L/min; t is the sampling time, min.

3) Determination and calculation of dedusting resistance

The experiment indicates the dedusting resistance with pressure loss, and set the airflow of inlet pipe and outlet pipe to be equal, then the average total pressure difference between the airflow of inlet and outlet pipe can be obtained by the average static pressure difference. The two sections of the static pressure difference can be measured with a pitot tube and compensation micro-manometer and calculated as:

$$\Delta P = P_1 - P_2 \tag{4}$$

ΔP is the pressure loss, Pa; P_1 is the pressure at the inlet section, Pa; P_2 is the pressure at the inlet section, Pa.

3.2 Design and production of wet high frequency vibrating grid dedusting experiment system

1) Production of vibrating grid board

Set the iron grid board frame internal and external size as 35 cm × 35 cm, 27 cm × 27 cm according to the simulation roadway size. Wrapped the Nylon lines equally spaced around the two sides of the vibrating grid frame and make the fibers remain extremely tight. The produced vibrating grid is shown in Figure 1:

Figure 1: Vibrating grid.

2) Spray system connection

The nozzle parameters of the spray system are as follows: the diameter is 1.5 mm, rated pressure is 4 Mpa, diffusion angle is 70°, and the measuring device used a LZS – 15 flow meter.

The devices were connected by 25 mm high pressure rubber hose, and the metal ring pipe connectors were used to connect the connection parts. The spray system connection order is shown in figure 2.

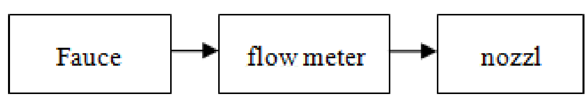

Figure 2: Spray system connection order.

3) Assembly of dust generation system

Dust generation system is made up of a fan and dust injection parts. In order to simulate the wind speed in the actual roadway (3-5 m/s), choosing the BPT12-13 pipeline ventilation fan as the generation device, its air volume Q = 150 m^3/h, and wind speed is about 4.2 m/s.

The experimental design is shown in Figure 3:

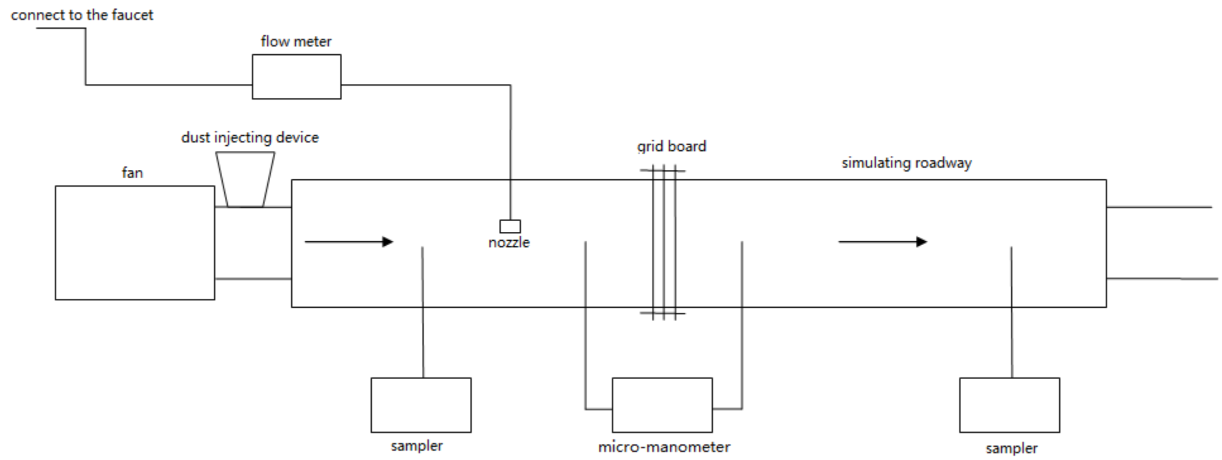

Figure 3: Experimental device design.

3.3 Vibrating grid dedusting orthogonal experiment

To obtain the most efficient parameter combination of the fiber grid dedusting system, select the collection efficiency as assessment indicator. Maintaining water quantity as 1.33 L/min, spray distance as 15 cm, carrying on the orthogonal experiment under this condition, the experimental results are shown in Table 1. Analyze the variance on the above data, the results are shown in Table 2.

Table 1: Vibrating grid dedusting orthogonal experimental results.

Line	1	2	3	Experimental Condition	Experimental Result
Factor	Grid Board number	Fiber Diameter	Parallel Number		
1	1	1	1	A1B1C1	89.1
2	1	2	2	A1B2C2	92.5
3	1	3	3	A1B3C3	94.6
4	2	1	2	A2B1C2	92.3
5	2	2	3	A2B2C3	94.4
6	2	3	1	A2B3C1	96.8
7	3	1	3	A3B1C3	95.9
8	3	2	1	A3B2C1	98.0
9	3	3	2	A3B3C2	99.2
Mean Value 1	92.067	92.433	94.900		
Mean Value 2	94.500	94.967	95.33		
Mean Value 3	98.367	97.533	94.967		
Range	6.300	5.100	0.700		

Table 2: Vibrating grid dedusting efficiency variance analysis

Factor	Square of Deviance	Degree of Freedom	F Ratio	F Critical-value	Significance
Grid Board Number	60.562	2	1441.952	19.000	*
Fiber Diameter	29.016	2	928.952	19.000	*
Parallel Number	0.736	2	17.524	19.000	
Error	0.04	2			

Draw pictures on grid board number, fiber diameter, and parallel number. The abscissa is the actual level and ordinate is the average dedusting efficiency, as shown in Figure 4.

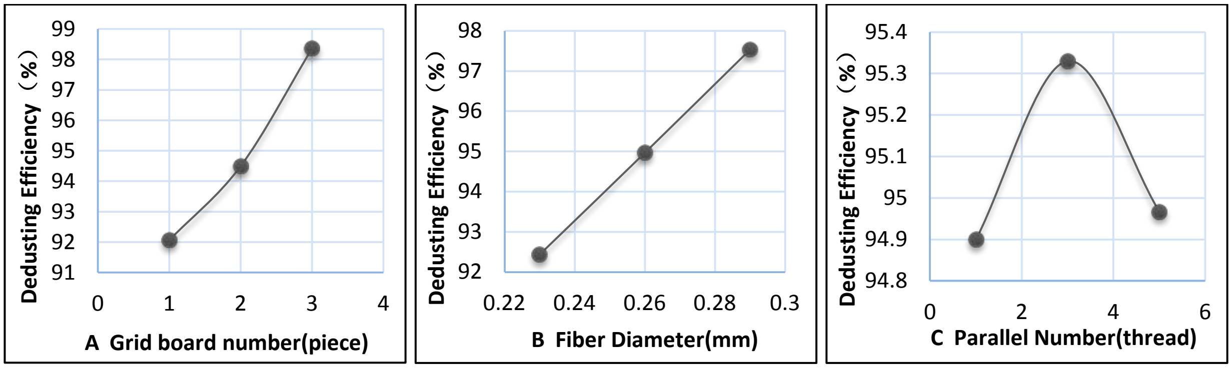

Figure 4 : Factors affecting dedusting efficiency analysis of orthogonal experiment.

The significant analysis shows that the factors affecting the dedusting effect order are as follows: grid board number, fiber diameter, and parallel number. Therefore, select grid board number and fiber diameter as two factors for the integrated optimization orthogonal experiment factors.

The optimal level is the highest total level of the three factors' optimal level. It can be obtained from Table 1 that the optimal combination is when the grid board number is 3, the fiber diameter is 0.29 mm, the parallel number is 2 (A3B3C2), and the dedusting efficiency is 81.2%.

3.4 Spray dedusting orthogonal experiment

To obtain the most efficient parameter combination of the spray dedusting system, select the collection efficiency as the assessment indicator. Maintain the grid board number as 2, fiber diameter as 0.26 mm, and carry on the orthogonal experiment under these conditions. The experimental results are shown in Table 3.Analyze the variance of the data. The results are shown in Table 4.

Table 3: Spray dedusting orthogonal experimental results.

Line	1	2	3	Experimental Condition	Experimental Result
Factor	Spray Water Volume	Spray Distance	Nozzle Angle		
1	1	1	1	A1B1C1	90.0
2	1	2	2	A1B2C2	93.1
3	1	3	3	A1B3C3	91.9
4	2	1	2	A2B1C2	93.2
5	2	2	3	A2B2C3	95.4
6	2	3	1	A2B3C1	93.0
7	3	1	3	A3B1C3	97.9
8	3	2	1	A3B2C1	99.7
9	3	3	2	A3B3C2	98.3
Mean Value 1	91.667	93.700	94.233		
Mean Value 2	93.867	96.067	94.867		
Mean Value 3	98.633	94.400	95.067		
Range	6.966	2.367	0.834		

Table 4: Spray dedusting efficiency variance analysis.

Factor	Square of Deviance	Degree of Freedom	F Ratio	F Critical-value	Significance
Spray Water Volume	76.096	2	352.296	19.000	*
Spray Distance	8.869	2	41.060	19.000	*
Nozzle Angle	1.136	2	5.259	19.000	
Error	0.22	2			

Draw graphs of the spray water volume, spray distance, and nozzle angle. The abscissa is the actual level and ordinate is the average dedusting efficiency, as shown in Figure 5.

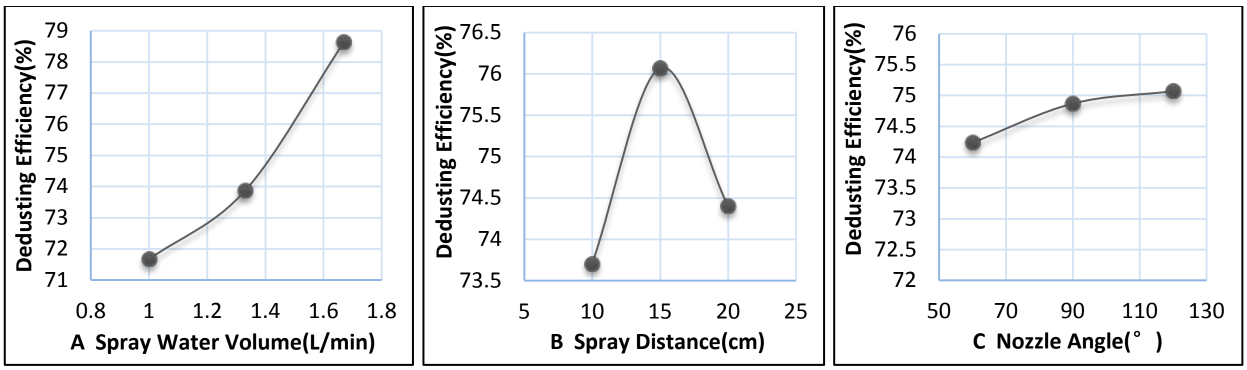

Figure 5: Factors affecting dedusting efficiency analysis of orthogonal experiment.

The significant analysis shows that the factors affecting the dedusting effect order is as following: spray water volume, spray distance, and nozzle angle. Therefore, select spray water volume and spray distance as two factors for the integrated optimization orthogonal experiment factors.

The optimal level is the highest total level of the three factors' optimal level. It can be obtained from Table 3 that the optimal combination is that the spray water volume as 1.67 L/min, the spray distance as 15 cm, the nozzle angle as 60° (A3B2C1), and the dedusting efficiency is 79.7%.

3.5 Wet high frequency vibrating grid dedusting-parameter optimization experiment

According to the two orthogonal experiments above, choose four factors for comprehensive optimization experiments, namely, grid board number, fiber diameter, spray water volume, and spray distance. Select dedusting efficiency and dedusting resistance as evaluation indicators.

1) Dedusting efficiency orthogonal experimental result analysis

The dedusting efficiency orthogonal experimental results are shown in Table 5. Analyze the variance of the data. The results are shown in Table 6.

Table 5: Dedusting efficiency orthogonal experimental result.

Line	1	2	3	4	Experimental Condition	Experimental Result
Factor	Fiber Diameter	Spray Water Volume	Grid Board Number	Spray Distance		
1	1	1	1	1	A1B1C1D1	88.8
2	1	2	2	2	A1B2C2D2	93.9
3	1	3	3	3	A1B3C3D3	98
4	2	1	2	3	A2B1C2D3	92.1
5	2	2	3	1	A2B2C3D1	95.5
6	2	3	1	2	A2B3C1D2	95.2
7	3	1	3	2	A3B1C3D2	93.3
8	3	2	1	3	A3B2C1D3	93.1
9	3	3	2	1	A3B3C2D1	97.3

Mean Value1	93.567	91.400	92.367	93.867		
Mean Value2	94.267	94.167	94.433	94.133		
Mean Value3	94.567	96.833	95.600	94.400		
range	1.000	5.433	3.233	0.533		

Table 6: Dedusting efficiency variance analysis.

Factor	Square of Deviance	Degree of Freedom	F Ratio	F Critical-value	Significance
Fiber Diameter	1.580	2	3.700	19.000	
Spray Water Volume	44.287	2	103.717	19.000	*
Grid Board Number	16.087	2	37.674	19.000	*
Spray Distance	0.427	2	1.000	19.000	
Error	0.43	2			

Draw graphs of fiber diameter, spray water volume, grid board number, and spray distance. The abscissa is the actual level and ordinate is the average dedusting efficiency, as shown in Figure 6.

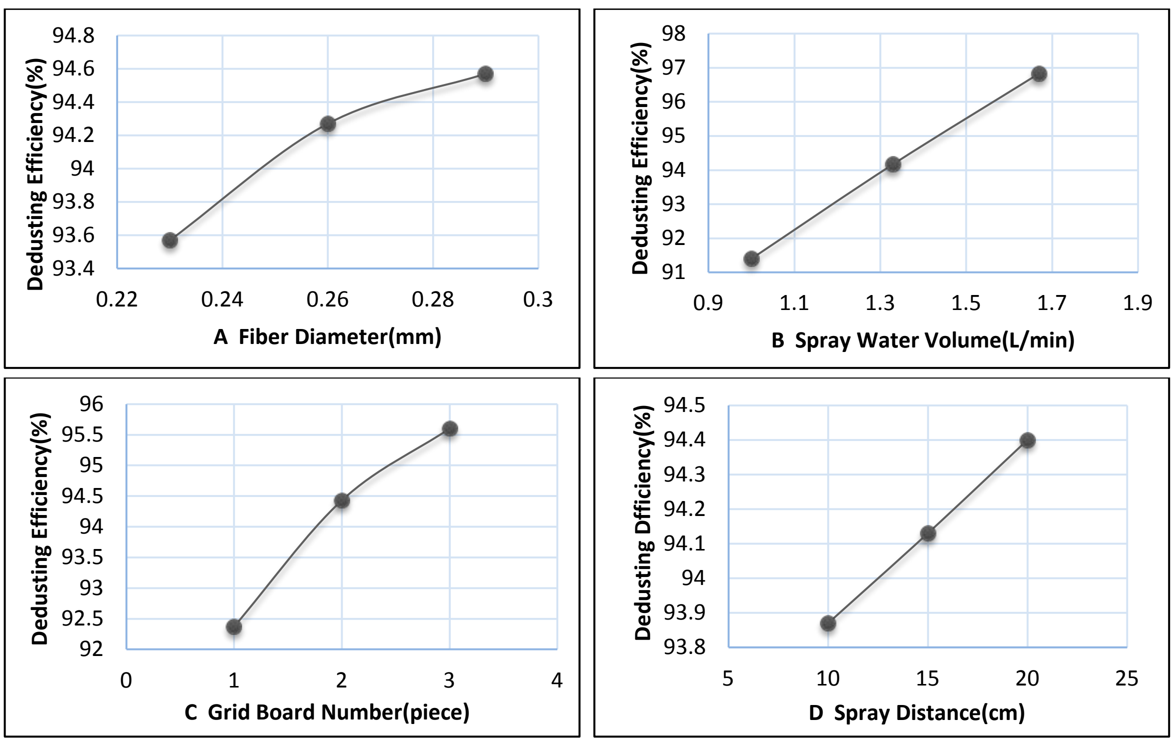

Figure 6: Factors affecting dedusting efficiency analysis of orthogonal experiment.

The significant analysis shows that the factors affecting the dedusting effect order are as follows: spray water volume, grid board number, fiber diameter, and spray distance.

2) Dedusting resistance orthogonal experimental result analysis

The dedusting resistance orthogonal experimental results are shown in Table 7. Analyze the variance of the data. The results are shown in Table 8.

Table 7: Dedusting resistance orthogonal experimental results.

Line	1	2	3	4		
Factor	Fiber Diameter	Spray Water Volume	Grid Board Number	Spray Distance	Experimental Condition	Experimental Result
1	1	1	1	1	A1B1C1D1	33.15
2	1	2	2	2	A1B2C2D2	60.37
3	1	3	3	3	A1B3C3D3	83.83
4	2	1	2	3	A2B1C2D3	56.63
5	2	2	3	1	A2B2C3D1	81.66
6	2	3	1	2	A2B3C1D2	48.02
7	3	1	3	2	A3B1C3D2	79.81
8	3	2	1	3	A3B2C1D3	44.87
9	3	3	2	1	A3B3C2D1	69.26
Mean Value1	59.117	56.530	42.013	61.357		
Mean Value2	62.103	62.300	62.087	62.733		
Mean Value3	64.647	67.037	81.767	61.777		
Range	5.530	10.507	39.754	1.376		

Table 8: Dedusting resistance variance analysis.

Factor	Square of Deviance	Degree of Freedom	F Ratio	F Critical-value	Significance
Fiber Diameter	45.970	2	15.390	19.000	
Spray Water Volume	166.119	2	55.614	19.000	*
Grid Board Number	2370.569	2	793.629	19.000	*
Spray Distance	2.978	2	1.000	19.000	
Error	2.99	2			

Draw graphs of fiber diameter, spray water volume, grid board number, and spray distance. The abscissa is the actual level and ordinate is the average dedusting resistance, as shown in Figure 7.

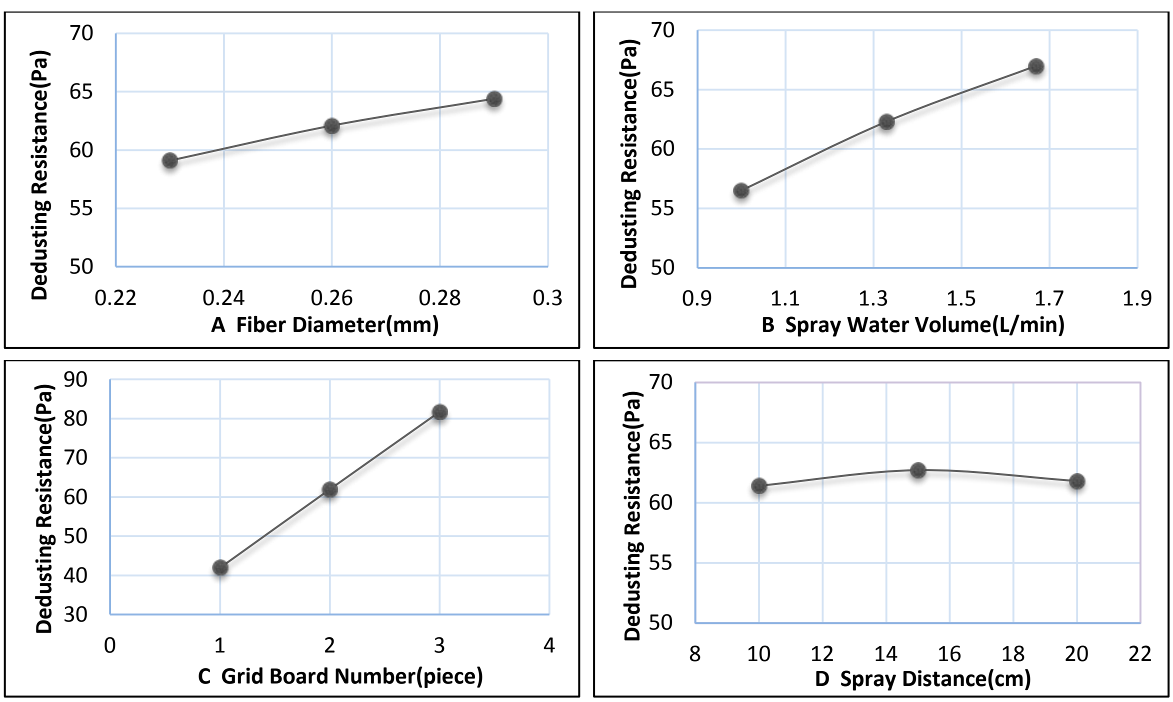

Figure 7: Factors affecting dedusting resistance analysis of the orthogonal experiment.

The significant analysis shows that the factors affecting the dedusting effect order are as follows: grid board number, spray water volume, fiber diameter, and spray distance.

3) Determine the optimal level combination

The optimal level is the highest total level of the four factors' optimal level. It can be obtained from Tables 5 and 7 that the optimal combination is when the fiber diameter is 0.23 mm, spray water volume is 1.67 L/min, grid board number is 3 and spray distance is 20 cm (A1B3C3D3), the dedusting efficiency is 78.0%, and the dedusting resistance is 83.83 Pa.

It can be seen from Figures 6 and 7 that the combination of A3B3C2D1 might be called the best combination. Its dedusting efficiency is 77.3% and dedusting resistance is 69.26 Pa. Compared with combination A1B3C3D3, combination A3B3C2D1 has lower dedusting efficiency, but its dedusting resistance is also smaller, thus it can be obtained that the wet high frequency vibrating grid dedusting optimal combination of parameters is that the vibrating grid fiber diameter is 0.29 mm, the spray water volume is 1.67 L/min, the grid board number is 2, and the spray distance is 10 cm, namely A3B3C2D1.

4. CONCLUSION

In the orthogonal experiment of the vibrating grid, the influence factors on the dedusting effect are ranked as follows: grid board number, fiber diameter, and parallel number. Therefore, we select grid board number and fiber diameter as the integrated optimization orthogonal experiment factors. Firstly, grid board should be used more in the system in consideration with dedusting resistance, economic costs and other factors. Secondly, fine fiber diameter is supposed to be avoided according to the material and costs.

In the orthogonal experiment of spray dedusting, the influence factors on the dedusting effect are ranked as follows: spraying rate, the distance of spray, and the angle of nozzle. We select the first two factors as the integrated optimization orthogonal experiment factors. Firstly, spraying rate is supposed to be increased in consideration of dedusting resistance and costs. Secondly, at a distance of 15 cm between the spray and grid board the performance is best. In practice, the actual distance can be magnified.

We obtain four factors used by a comprehensive optimization experiment through previous experiments. Their dust removal effect rankings are as follows: grid board number, fiber diameter, spraying rate, and the distance of spray. By analyzing the combination of parameters, we conclude that the optimal combination of wet high-frequency vibrating grid parameter values are: 0.29 mm (vibrating wire grid fiber diameter), 1.67 L/min (spraying rate), 2 (grid board number), and 10 cm (distance of spray).

5. ACKNOWLEDGEMENT

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