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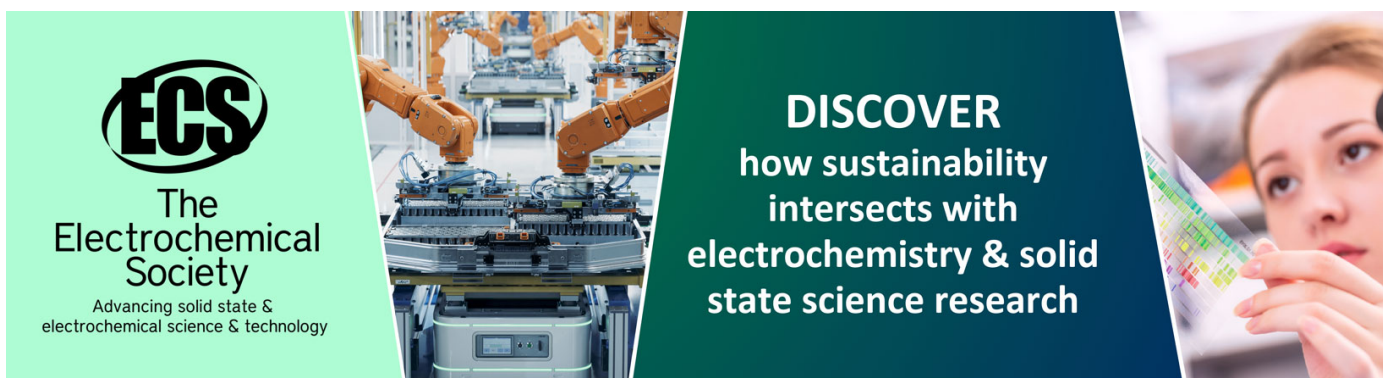
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Research on the Significant Effect of Nozzle's Structure on Air Outlet Speed Based on Numerical Simulation

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Abstract. Aiming at the problems of short spray distance and poor atomization effect in pesticide spraying. In addition, in order to enhance the initial velocity of the droplets and the secondary atomization of the droplets, a new air-driven combined electrostatic nozzle based on the Venturi effect is designed in this paper. And a method for accelerating and atomizing mist droplets using the Venturi effect is proposed. Combined with the distribution of airflow from the venturi, the acceleration and atomization effects of the nozzle were verified and analyzed. Using the factor design test method, three structural parameters, namely the distance A from the nozzle outlet to the venturi mouth, the retracting radius B of the venturi mouth, and the extension distance C of the venturi mouth were tested, and the following conclusions were drawn. At the 1% significance level, the single factors A, B, and C have significant effects on the average velocity of the venturi throat. The interaction of two factors, AB, AC, and BC, had no significant effect on the average velocity of the venturi throat. The interaction of three factors ABC has a significant effect on the average velocity of the venturi throat.

1. Introduction

At present, pesticide control is the most common method in the prevention and control of crop diseases and insect pests, especially in the prevention and control of large-scale pests and diseases, chemical pesticides have outstanding effects [1, 2]. Therefore, chemical pesticide control still occupies a dominant position in the field of plant protection [3, 4].

To solve these problems, many people have conducted a lot of research. In the spraying of pesticides on crops, technologies such as air-blast sprayers, boom sprayers and induction electrostatic sprayers are used [5]. However, due to the large difference in the distance between the canopy height and the spray head, the air-blast sprayer has the phenomenon of uneven application of crops at different heights and the non-spraying of higher plants [6, 7]. Due to the poor spray penetration of the boom sprayer, there is the problem of uneven application of pesticides inside and outside the crops, resulting in a waste of resources. Due to insufficient charging and low initial velocity, the electrostatic sprayer deposits most



of the droplets on the target close to the nozzle, which not only affects the spraying effect, but also pollutes the environment [8]. Many studies have focused on improving the movement state of the droplets during the spraying process to improve the adhesion rate, or improving the nozzle structure and atomization method to improve the atomization effect, but there are relatively few studies by changing the initial state of the droplets [9, 10].

In response to the above problems, this paper provides an electrostatic nozzle based on the Venturi effect, which uses the Venturi effect combined with two charging methods of inductive charging and corona charging, so that the droplets can obtain a higher initial velocity on the basis of full charging. In addition, the droplet deposition efficiency is improved, the droplet drift and dispersion are reduced, and the ecological environment is improved. Moreover, the wind force can make the droplets obtain sufficient initial velocity during the directional movement under the Venturi effect, so that the distance of the droplets is greatly Promote.

2. Nozzle structure and principle

The structure of the nozzle is shown in Figure 1. The nozzle is used to transport pesticide and spray it at the nozzle to complete the initial atomization of the liquid. The wind reaches the throat through the air supply channel. The gas and the droplets sprayed from the nozzle are combined in the Venturi effect area. At this time, the atomized droplets obtain a certain initial velocity. The mist droplets are fully charged under the action of the electrostatically atomizing component. Because the same kind of charges repel each other, the mist droplets realize the second atomization.

The mist droplet charging device includes an induction electrode installed inside the conical protective cover, and further includes an electric needle connected to the induction electrode at one end. The electric needle is provided with a plurality of electric needles and is evenly arranged on the induction electrode. The induction electrode and the electric needle are connected with the power source, so that the droplets can be fully charged under the double charging action. As shown in Figure 2.

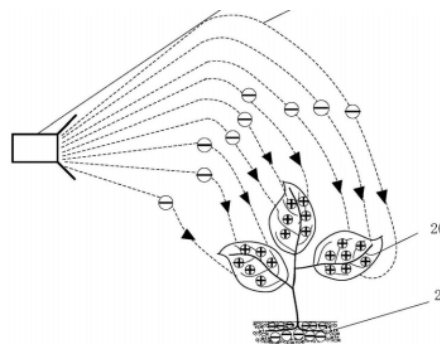
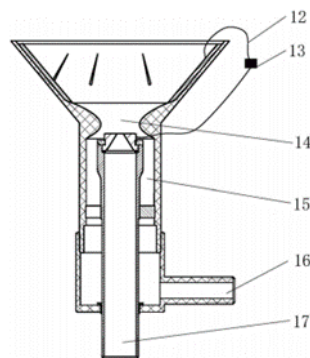


Figure 1. Structure of the nozzle **Figure 2.** The principle of electrostatic application

3. Pre-processing of numerical simulation

Because the geometric model of the nozzle is relatively complex, it is difficult to divide the hexahedral mesh at this time, so ANSYS ICEM CFD software is used to divide the unstructured mesh of the model. Import the three-dimensional model into ANSYS ICEM CFD, define three parts, including one entrance, one exit, and the rest are walls. Define the grid size, set Scale to 1, and Max Element to 1mm. The local encryption processing of the mesh at the venturi throat. The mesh is shown in Figure 3.

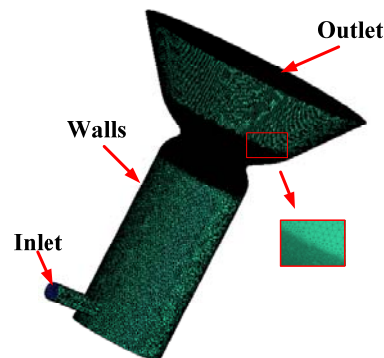


Figure 3. Mesh division

4. Accelerated verification of Venturi effect

According to the acceleration principle of the venturi nozzle, after the droplets are ejected, they should be accelerated by the high-speed airflow. Before the acceleration, the droplets are ejected conically in the nozzle, and the high-speed airflow will affect the original ejection shape of the nozzle. Therefore, the high-speed airflow cannot be near the nozzle, and the best auxiliary acceleration position should be after the droplets are normally ejected at a certain distance and appear conical. As shown in Figure 4. The droplets are ejected normally at the nozzle. When the droplets spread out, they encounter a high-speed airflow, which accelerates the droplets and atomizes them a second time. After this process, the initial velocity of the droplets increases, and the radius of the droplets becomes smaller.

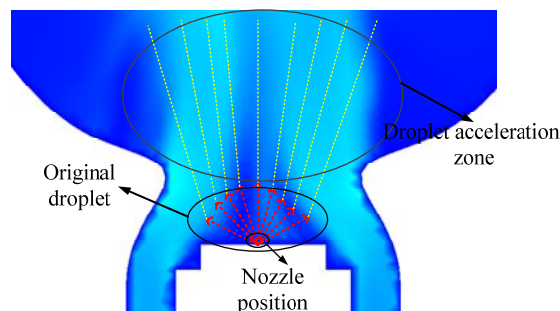


Figure 4. The principle of Venturi effect acceleration

In order to verify that when the ordinary nozzle structure is changed to the venturi throat, the velocity field will change significantly, this paper conducted a comparative test. The ordinary nozzle and the venturi throat nozzle model were established separately. The processing methods of the two models and the conditions of the solution calculation were the same. At the same position along the spray direction of the two models, three straight lines were selected as speed observation lines, and the speed change along this straight line was made into a speed curve, as shown in Figure 5. In Figure 5, curves 1, 2, and 3 are the velocity curves of the venturi throat, and curves 3, 4, and 5 are the velocity curves of the ordinary nozzle. It can be clearly seen that after the venturi throat is added, the overall velocity inside the nozzle is higher than that of the ordinary nozzle. At the throat of Venturi, the speed increases significantly. The increase in speed will facilitate the auxiliary delivery of droplets.

After the analysis in the previous paragraph, it was found that to make the droplets eject normally, the velocity at the venturi should be as small as possible at the center of the nozzle, so as to reduce the impact of the airflow on the original spray. Therefore, this article was verified. The plane where the venturi throat is located is the initial position where the droplets change. Therefore, this paper selects this position as the observation plane and observes the velocity and pressure distribution of the plane. As shown in Figure 6, four straight lines passing the center of the circle are selected along the circular

plane where the venturi throat is located, and the speed change of each straight line is represented by a curve. It is found in the curve that the velocity shows an "M" distribution along the diameter. The closer to the center of the circle, the smaller the velocity and the greater the pressure. And at the position where the original mist droplets are conical mist droplets, the maximum velocity is present, which is conducive to the spraying of mist droplets.

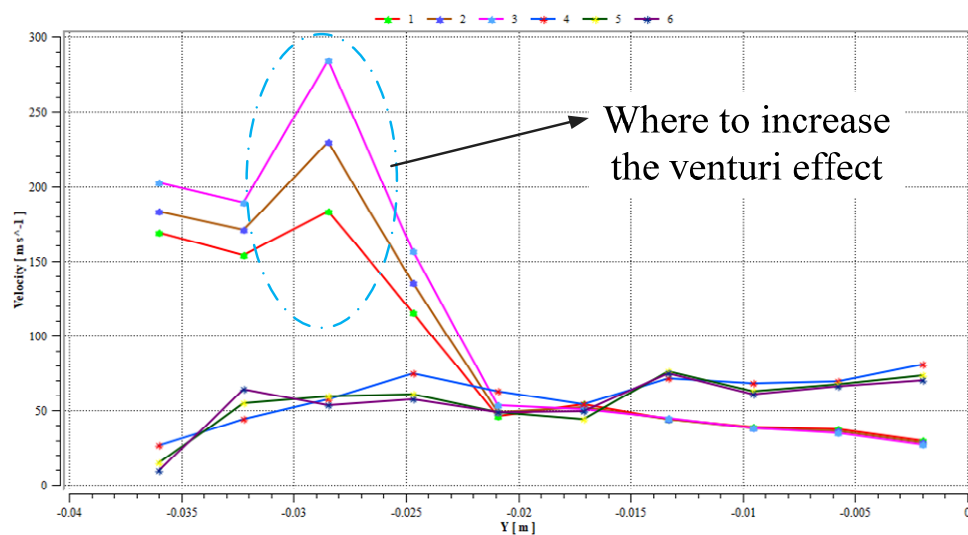


Figure 5. Comparison of speeds

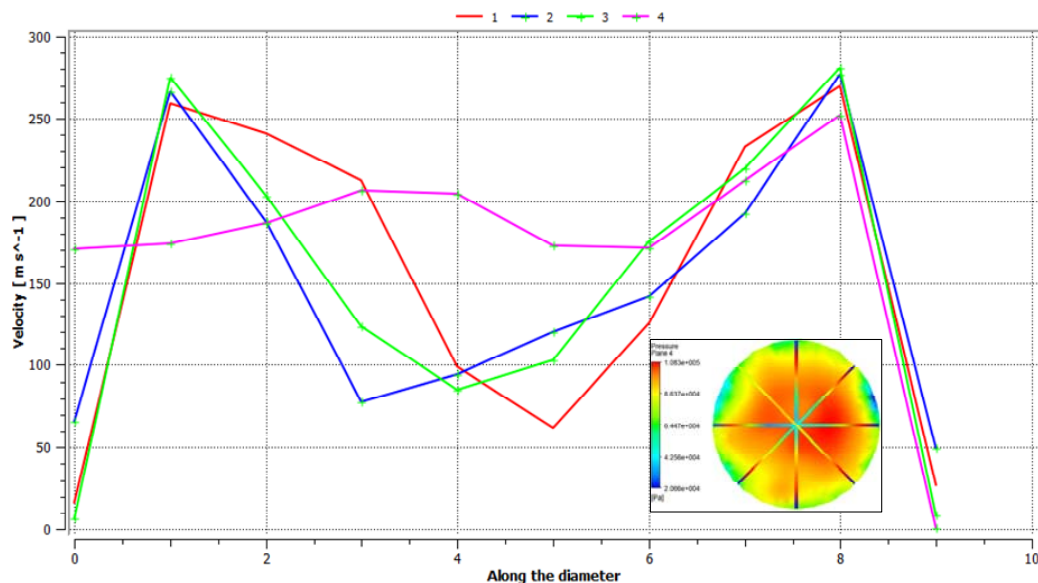


Figure 6. Velocity distribution

5. Design and analysis of 3³ factor design experiment

5.1. Purpose of the experiment

There are many factors that affect the velocity field of the Venturi nozzle. After selecting the way of the air inlet, it is necessary to explore the effect of the structural parameters at the throat of the Venturi on the speed of the outlet. Generally speaking, the higher the speed, the better the effect of auxiliary delivery

of mist droplets. The Venturi throat mainly contains three structural parameters, namely the distance A from the nozzle outlet to the Venturi throat, the retracted radius B of the Venturi throat, and the extension distance C of the Venturi throat, as shown in Figure 7. The effects of these parameters must be studied. In general, the factor design method is the most effective for this type of experiment.

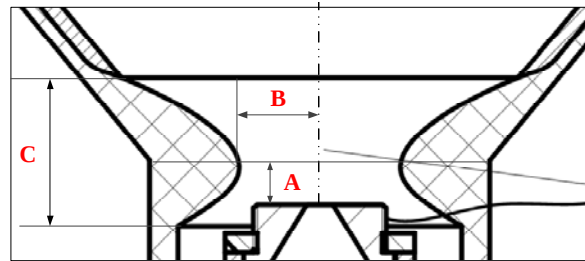


Figure 7. Structure of venturi throat

5.2. Experiment plan

The 3^3 design means that there are 3 factors A, B, and C, and each factor has 3 levels 1, 2, and 3. The specific values of each factor are shown in Table 1. The average speed of the plane where the venturi throat lies is selected as the test index. There are 27 factor-level combinations in this design, and these 27 combinations have 26 degrees of freedom. The main effect of each factor has 2 degrees of freedom, each two-factor interaction has 4 degrees of freedom, and the interaction of 3 factors has 8 degrees of freedom. If the test is repeated n times for each combination, the total degree of freedom is $(n3^3-1)$ and the degree of error is $3^3(n-1)$.

Table 1. Factor level data table

Level \ Factor	0	1	2
A	2	4	6
B	8	10	12
C	7	9	11

5.3. Experiment results and analysis

This is a 3^3 design experiment. Without affecting the analysis, considering the convenience of the calculation, we subtracted 100 from each observation to obtain the average velocity table at the venturi throat, as shown in Table 2.

Table 2. Average velocity table at Venturi throat

	0			1			3			$Y_{..k}$
	0	1	2	0	1	2	0	1	2	
0	24.7	25.1	26.0	22.2	25.9	10.2	21.9	18.8	11.2	186.0
1	45.1	38.2	35.1	25.2	25.3	13.0	23.1	32.9	14.4	252.3
2	36.1	52.2	29.8	37.1	36.4	12.9	28.8	43.5	10.5	287.3
Y_{ij}	105.9	115.5	90.9	84.5	87.6	36.1	73.8	95.2	36.1	$Y_{...}=$
$Y_{i..}$	312.3			208.2			205.1			725.6

The square sum is calculated below, where $a = b = c = 3$, $n = 1$.

$$\begin{cases} S_A = \sum_{i=1}^a \frac{y_{i..}^2}{bcn} - \frac{y_{...}^2}{abcn} \\ S_B = \sum_{j=1}^b \frac{y_{.j.}^2}{acn} - \frac{y_{...}^2}{abcn} \\ S_C = \sum_{k=1}^c \frac{y_{..k}^2}{abn} - \frac{y_{...}^2}{abcn} \end{cases} \quad (1)$$

Where S_A , S_B , and S_C are the sum of squared effects of factors A, B, and C; a, b, and c are the levels of factors A, B, and C; n is the number of trials; and $y_{i..}$, $y_{.j.}$, $y_{..k}$ are the sample mean of factors A, B, C at levels i, j, k; $y_{...}$ is the total sample mean.

$$\begin{cases} S_{AB} = \sum_{i=1}^a \sum_{j=1}^b \frac{y_{ij.}^2}{cn} - \frac{y_{...}^2}{abcn} - S_A - S_B \\ S_{AC} = \sum_{i=1}^a \sum_{k=1}^c \frac{y_{ik.}^2}{bn} - \frac{y_{...}^2}{abcn} - S_A - S_C \\ S_{BC} = \sum_{j=1}^b \sum_{k=1}^c \frac{y_{.jk}^2}{an} - \frac{y_{...}^2}{abcn} - S_B - S_C \end{cases} \quad (2)$$

Where S_{AB} , S_{AC} , and S_{BC} are the sum of squares of the double-acting factors AB, AC, and BC; a, b, and c are the levels of factors A, B, and C; n is the number of trials; $y_{ij.}$, $y_{ik.}$, $y_{.jk}$ are the sample averages of the double-acting factors AB, AC, and BC at the levels ij, ik, and jk; $y_{...}$ is the total sample average.

$$S_{ABC} = \sum_{i=1}^a \sum_{j=1}^b \sum_{k=1}^c \frac{y_{ijk}^2}{n} - \frac{y_{...}^2}{abcn} - S_A - S_B - S_C - S_{AB} - S_{AC} - S_{BC} \quad (3)$$

Where S_{ABC} is the sum of the squares of the ABC effect of the three factors. a, b, and c are the levels of factors A, B, and C. n is the number of trials. y_{ijk} is the sample mean of the three acting factors ABC at level ijk; $y_{...}$ is the total sample mean.

$$S_T = \sum_{i=1}^a \sum_{j=1}^b \sum_{k=1}^c \frac{y_{ijk}^2}{n} - \frac{y_{...}^2}{abcn} \quad (4)$$

Where S_T is the sum of squares of total dispersion.

$$S_E = S_T - S_A - S_B - S_C - S_{AB} - S_{AC} - S_{BC} - S_{ABC} \quad (5)$$

Where S_E is the sum of squared errors.

Bring the relevant data into the above formula and calculate the analysis of variance table after calculation, as shown in Table 3.

Table 3. ANOVA table

Source of variance	sum of square	Degrees of freedom	Mean square	F
Factor A	827.4	2	413.7	13.52
Factor B	1098.7	2	549.3	17.95
Factor C	588.2	2	294.1	9.61
Interaction	156.7	4	39.2	1.28
Interaction AC	122.3	4	30.6	0.99
Interaction BC	299.8	4	74.9	2.45
Interaction ABC	985.3	8	123.2	4.02
Error E	827.3	27	30.6	
Comprehensive F	3251.1	53		

Now take $\alpha = 0.01$. According to the F distribution table, $F_{0.01}(2,27) = 5.49$, $F_{0.01}(4,27) = 4.11$, $F_{0.01}(8,27) = 3.26$. $F_A = 13.52 > F_{0.01}(2,27) = 5.49$, $F_B = 17.95 > F_{0.01}(2,27) = 5.49$, $F_C = 9.61 > F_{0.01}(2,27) = 5.49$, therefore, the single factor A, B and C have significant effects on the average velocity at the venturi throat. $F_{AB} = 1.28 < F_{0.01}(4,27) = 4.11$, $F_{AC} = 0.99 < F_{0.01}(4,27) = 4.11$, $F_{BC} = 2.45 < F_{0.01}(4,27) = 4.11$, therefore, two factors AB, AC, and BC have no significant effect on the average velocity of Venturi throat. $F_{ABC} = 4.02 > F_{0.01}(8,27) = 3.26$, therefore, the effect of ABC on the average velocity of the venturi throat at three factors is significant.

6. Conclusion

In order to enhance the initial velocity of the droplets and the secondary atomization of the droplets, this paper designed a new type of air-driven combined electrostatic nozzle based on the Venturi effect. Using the factor design test method, three structural parameters, including the distance A from the nozzle outlet to the venturi throat, the retracting radius B of the venturi throat, and the extension distance C of the venturi throat were tested, and the following conclusions were drawn. The single factors A, B, and C have a significant effect on the average velocity of the venturi throat at the 1% significance level. Two-factor interactions AB, AC, and BC had no significant effect on the average velocity of the venturi at the 1% significance level. Three-factor interaction ABC has a significant effect on the average velocity of the venturi at the 1% significance level.

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