Study on the Relationship of Electrode and Charge Characteristic in Electrostatic Spraying

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Abstract. In this paper, the full factor jet charged spray test was carried out by using the installation position and the annular electrode of different diameters. The influence of the charging voltage, the diameter of the electrode ring and the installation position on the charge of the droplet was analyzed in detail. The characteristics and mechanism of the droplet were theoretically analyzed. The test results show that there is a linear relationship between the charge and the diameter and installation location of the electrode ring. Through further analysis, the empirical formula of the relationship between charge coefficient and electrode parameters and location is built. This formula can be used to calculate and predict the charge capacity of induction electrode. It also could provide a scientific basis for electrode parameters and reasonable design of electrostatic sprinkler.

Introduction
In recent years, electrostatic spray as a new plant protection technology is mature in application because it can improve the deposition of droplets on the plant as well as can reduce waste and pollution [1-3]. The primary method to charge the droplet is the induction charge, and most of the electrode structures used is ring electrodes. The droplet charge electricity is influenced complicatedly by the diameter of the ring electrode and the installation position and charge voltage, droplet size and dielectric constant. At present, the theoretical research on the mechanism of induction charge is more [4-9], and the experimental research and equipment development of the charge on the electrode parameters are less [10-14]. At the same time, there is no report that the effect of electrode parameters on the charge is directly used to calculate and predict the charge, and used to design the electrode structure in the practical application [15-17].

This paper focuses on the linear relationship between the electrode ring structure parameters and the charge effect of jet spray. Based on the experimental research, the empirical formula for calculating the charge capacity of the ring electrode is established, which is used for the calculation of induced charge, guiding the design of electrode and electrostatic nozzle structure.

Constructive Data of Charge Load Test
The test device used is shown in figure 1. The inductive charged spray test device is mainly composed of three parts: spray system for making liquid atomizing pressure, high voltage power supply [13] with variable voltage, and data acquisition system for measuring charge load and quality.
Pressure is pumped from the liquid pump to the electrostatic spray system. Working pressure is adjusted and stabilized by regulating valve to control medicine spraying from the nozzle in forming a uniform refinement of the droplet through air impact rupture. High voltage which is adjustable within 0~30kv is generated by HVDC. The electrode arranged at ahead of the nozzle of the spray system is connected with negative power electrode. When the electric field produced by the electrode acts on the conical mist ejected through the nozzle, the nebulized droplet is charged. Charged droplets in front of the nozzle are collected by net receiving device. The micro current is measured by precision ammeter. The total mass of the droplet population and the time of the test experience are collected and measured by the foggy sample bailer, which is used to calculate the droplet charge mass ratio.

The charge characteristics of the droplets are expressed by the ratio of the charge of the droplets to the total mass of the droplets (the ratio of charge to the mass). The net target method is used to measure the charge current and the total liquid mass of the droplet group. The net target is measured with the mesh target method, and the distance between the mesh target and the nozzle is 200mm.

In order to investigate the influence of the diameter and installation position of the electrode on the droplet, the electrode size and installation position are changed in the test. The experimental design is as follows:

Five sizes of electrode diameter respectively are 50mm, 60mm, 70mm, 80mm, 90mm, which are made of stainless steel wire with a diameter of 0.8mm.

Installation position: the electrode is installed in front of the nozzle, and the distance between the electrode and the nozzle is divided into 5 sizes respectively as 0mm, 5mm, 10mm, 15mm, 20mm.

Nozzle: hollow cone nozzle which the flow rate is 4.92mL/s and spray nozzle angle is 90 degrees. The droplet sprayed from the nozzle forms a cone. The farther the electrode installation is from the nozzle, the closer it is to the conical surface of the fog. The smaller the diameter of the electrode is, the closer it is to the fog cone. The electrode used in the test is located outside the conical surface of the fog, and the electrode is near the fog conical surface with the diameter of 50mm. The contact charge is easily formed by making the electrode approached to the fogging cone.

Jet pressure: the test pressure is 0.2MPa.

Electrode voltage: the charge voltage is changed from 5kV to 15kV steplessly.

Results and Analysis

Single Factor Fitting Model

The influencing factors of the charged test shows that there is a significant linearity between the charge of an induced charged jet spray and the charge voltage of the electrode. The relationship between the diameter of the electrode ring and the location of the electrode is clear. The charge of large diameter is small and the charge of small diameter is bigger. The charge increases with the installation positions. The near equal interval distribution and equal interval design of the charge curve are observed. There is a linear relationship between the charge and mass ratio of the droplet.
and the diameter of the electrode ring, the arrangement of electrodes, and the charging voltage. The formula is expressed as:

\[
\begin{align*}
\lambda &= K \nu \\
K &= K_d + K_i + K_0
\end{align*}
\]

(1)

or

\[
\begin{align*}
K &= K_d + K_{il} = K_i + K_{0d} \\
K_i &= k_i l \\
K_d &= k_d d
\end{align*}
\]

(2)

Where \( \lambda \) is the charge mass ratio; \( K \) is the charge coefficient determined by the diameter of the electrode ring and the location of the installation; \( K_d, K_i, K_0 \) is the charge coefficient respectively corresponding to the diameter of the electrode ring, the position of the installation and the reference point; \( k_i \) is the influence coefficient of installation position; \( l \) is the distance from the electrode to the nozzle, that is, the installation distance; \( k_d \) is the influence coefficient of electrode ring diameter; \( d \) is the diameter of electrode ring; \( \nu \) is the voltage of electrode ring; \( K_{0d} \) is the fitting coefficient relative to the installation position of the electrode ring; \( K_{0d} \) is the fitting coefficient relative to the diameter of the electrode ring.

The value \( K \) can be obtained from direct fitting by using the test data of the charge mass ratio to the voltage variation. It is the deviation of each test fitting, which includes electrode diameter and installation location changes. While \( k_i \) and \( k_d \) show the relationship between the change of diameter and the change of position in each test, the diameter and position variables need to be introduced in the slope value \( K \) of the first fitting curves for further analysis.

In the obtained charge coefficient \( K \), the variable \( d \) of the electrode ring diameter and the variable \( l \) of the installation position are introduced respectively. The single factor linear regression is carried out in (2). The results of processing analysis are shown in Figure 2 and Figure 3. Analysis and test show that the minimum correlation coefficient is 0.9406, which the linear analysis processing of data is suitable. The corresponding diameter influence coefficient \( k_d \) and position influence coefficient \( k_i \) are expressed by averaging value (expressed as av in Figure 2 and in Figure 3) as following as: \( k_d = -0.0002, k_i = 0.0005 \).

The symbols of the first term coefficient \( k_d \) and \( k_i \) reflect the variation of the charge mass ratio with the change of the diameter of the electrode ring and the arrangement mode of the electrode. The values of the two coefficients indicate the change rate of the charge mass ratio with the diameter of the electrode ring and its arrangement. The coefficient \( K \) includes the influence of two factors, such as the diameter and location of the electrode. From the single factor, another factor is concentrated in the constant term. The information expressed by the constant term is more complex, which includes another factor and the invariant value.
Multifactor Model

By using the previous single factor analysis results, a multifactor quantitative analysis model with the change of the charge mass ratio with the diameter of the electrode ring and the position of the electrode installation can be further established. According to (1) and combining with (2), the linear regression analysis of two elements is carried out, for the general case, the coefficient $K$ can be written as,

$$K = K_d + K_l + K_0 = K_0 + k_d d + k_l l$$

(3)

If it is fitted by using the minimum diameter $d_0$ of the electrode ring as the reference point, the coefficient $K$ can be written as,

$$K = K_d + K_l + K_0 = K_0 + k_d (d - d_0) + k_l l$$

(4)

Generally, in order to simplify the analysis, the point of unidirectional monotonic change is often chosen as a reference point. The reference point can be selected at the working point with 0mm size of the installation position and 50 mm size of diameter of the electrode ring. The fitting method can be applied (4) directly, or fitted by the results of the position coefficient $k_l$ and the ring diameter coefficient $k_d$ obtained in the single factor analysis. The regression equation of the variation of the charge coefficient with the diameter and position of the electrode is obtained as,

$$K = 0.0396 - 0.0002 d + 0.0005 l$$

(5)

The equation (5) shows that the coefficient of charge increases linearly with the increase of installation location, and decreases linearly with the increase of the diameter of the electrode ring. The location factor is almost twice the influence of the diameter factor. In fact, for the 90 degree hollow conical spray nozzle, the longitudinal displacement and the diameter change are equal theoretically, but due to the uneven distribution of the electric field of ring electrodes, the difference of coefficients is caused. At the same time, (5) shows the smaller the distance between the electrode and the spray produced by the spray is, the greater the charge is.

Checkout of Fitting Curve

The test of empirical model (in (5)) can be done under new test conditions, or it can be compared with the measured value by using the charge coefficient $K$ get from the multi factor model. The comparison between the calculated value and the measured value shows that the overall error is 4% and the single point maximum error is 10%. The empirical formula obtained can meet the requirements of engineering test and design.
Under the induction charging mode, the closer the distance between the electrode and the fog conical surface is, the better the effect of the induction charge is. At the same distance, the farther away from the nozzle electrode, induction charging effect is better. That is, the cone forming region is its good effect, the relationship can be applied to the solid cone nozzle and fan nozzle. The larger the fog cone area is, the larger the droplet size and the larger the surface area are and the better the charging performance is. The influence of droplet size and dielectric properties on the charge characteristics needs further research.

Conclusions

From the experimental study and analysis of the influence of the diameter of the electrode ring and the position of the electrode installation on the charge, the following conclusions are obtained.

There is a linear relationship between the charge and the location and diameter of the electrode. The empirical formula of the charging coefficient (seen from (5)) obtained from the test can be used as a reference for the calculation and prediction of the charge in the design of the electrostatic spray nozzle, so as to provide a basis for the design of the electrostatic sprinkler.

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References


