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# Study on Mode and Mechanism of Electrostatic Spray Charged

**Z. Y. Chen†‡*, Z. J. Gao†‡, & C. F. Wu†‡**

†Faculty of Resource and Environmental Engineering, Jiangxi University of Science and Technology, Ganzhou, 341000, China

‡Jiangxi Key Laboratory of Mining & Metallurgy Environmental Pollution Control, Ganzhou, 341000, China,

*Email: welczy@163.com

ABSTRACT: The electrically charged water-drop trapping tiny dust is one effective method. The multitudinous electrically charged water-drop achieve to catch the dust body in the use dust removal space, which reduces the distance of between the dust with catching dust，coagulates charged particles, enhances the electrostatic force function, thus elevates greatly the dust removal efficiency in this paper. In the dust removal process by electrostatic spray, there are three kinds of charged methods, which are contact spray charging, induction charging of water-drop and corona charging of spray. Water charged of spray corona is produced by high voltage electrode tip corona discharge， which make the droplets charged ions. When the direct current high voltage by discharge electrode is applied, the high field strength around the discharge electrode in air is produced large numbers of electrons and ions. While the water mist is through the space, the water spray is charged and attached by both electric field effect and diffusion of charged ions.

KEYWORDS: Water spray; Corona charge; Fine dust; Charge-mass ratio.

This paper also describes respectively three charged spray methods of principle, structure, characteristics and elements, as well as of calculation formula of charging effect, so that it is provided guidance to improve the dust removal efficiency of fine dust.

Charged with water mist and dust removal technology has an attractive prospect in the purification of fine dust. The dust removal technology by electrostatics droplets is developed on the basis of overcoming the defects of both the electrostatic dust removal and the wet dust [1,2]. Charged droplets in mist and micron and submicron dust can be combined to form the larger dust particles, which make the Coulomb forces between the particles to achieve remarkably synergistic effects of dust particle agglomeration and to be removed [3,4]. So as to make the water mist of charged, there are mainly three methods which are contact electrically charged, induction electrically charged, corona electrically charged [5]. Theoretical research on mist charge and the limit value of ratio of charge-mass, which plays a guiding role of charged fog technology, designs and tests related to the manufacture in electrostatic spray nozzles in this paper.

## 1 ELECTRICALLY CHARGED METHOD OF CONTACT SPRAY

### 1.1 Electrically Charged Quantity of Contact Spray

Based on contact charging method, as shown in figure 1, the calculation formula of contact spray electrically charged quantity is as follows [6]:

$$q_z = KCU \quad (1)$$

Wherein , C —electric capacity of single water droplet， C; U—spray nozzle to ground potential,V ; K— correction factor , based on the structure and environmental factors of mist nozzle , K = 0.01-0.001.

The capacitance of single particle spherical droplets of is calculated as follows:

$$C = \frac{4\pi\varepsilon_0 s}{(\frac{4s}{d_z} - 3) + \sqrt{(\frac{4s}{d_z} + 1)^2 + 8}} \quad (2)$$

Wherein: $\varepsilon_0$—the air dielectric constant ; s —the distance of single spherical particle from ground ; $d_z$— droplet diameter.

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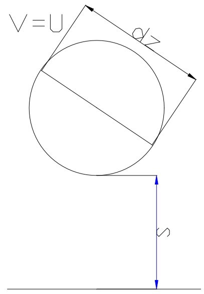


**Figure 1**. Distance of single spherical particle from ground.

When the type (1) is substituted to the type (2), the carrying capacity of spray based on directness electrically charged is confirmed as follows:

$$q_z = \frac{4\pi\varepsilon_0 sUK}{(\frac{4s}{d_z} - 3) + \sqrt{(\frac{4s}{d_z} + 1)^2 + 8}} . \tag{3}$$

**1.2 Spray Electricity Current**

Supposing the capacity of spurt mist current is $Q_z$, and the droplet number from spout in the unit time is N, then the spray electricity current is determined as follows:

$$I_z = q_z N = q_z \frac{Q_z \rho_z}{m} = \frac{24\pi\varepsilon_0 s\omega KQ_z}{d_z^3[(\frac{4s}{d_z} - 3) + \sqrt{(\frac{4s}{d_z} + 1)^2 + 8}]} . \tag{4}$$

**1.3 Charge-mass Ratio of Spray ($\beta_z$)**

The electrically charged quantity of water-drop and the Charge-mass ratio of spray are not same as that based on the different electrically charged method. The charge-mass ratio of spray is calculated as type (5), by contact spray electrically charging method from type (3).

$$\beta_z = \frac{q_z}{m} = \frac{24\pi\varepsilon_0 s\omega K}{d_z^3 \rho_z[(\frac{4s}{d_z} - 3) + \sqrt{(\frac{4s}{d_z} + 1)^2 + 8}]} . \tag{5}$$

Because of s >> $d_z$, (namely $d_z$ is micron-level), when the $d_z$ increases, the value of $\beta_z$ will decrease, and vice versa, when the $d_z$ increases decreases, the value of $\beta_z$ will increase.

The stable charge quantity can be produced greatly by method of contact charge, but it is difficult insulation, especially for high voltage. Because water is used for dust removing liquid, which is containing impurities and ion, has certain conductivity. In addition, the insulation resistance of equipment falls further， since after spraying the air humidity increases, causes the device to damp, electrical insulation to decline, coupled with the dust adhered on the device. So, the design and application of insulation should be given full consideration in contact spray electrically charging.

## 2 INDUCTION CHARGING SPRAY

According to the principle of electrostatic induction 7,8], the spray charged polarity is opposite to discharge electrode polarity by induction charging method. The principle of spray induction charge is shown in Figure 2. Because a certain distance in front of sprayer is applied negative direct current high voltage induction coil, there existed a strong electric field between the rings and sprays. Follow the electric induction principle, the very thick dipole layer is formed in contact of both water (liquid) and nebulizer. When the liquid spouts into the mist from the nebulizer, the portable mist raises the quantity of positive charge, as the same time the negative charge of dipole layer returns the earthed pole from the water supply system, so as to achieve a spray induction charging which is a continuous process of inductive charging.

The advantage of induction charging is that the power consumption is minimal, simple power supply, low voltage, good insulation, while the disadvantage is that the charge-mass ratio of spray is relatively small.

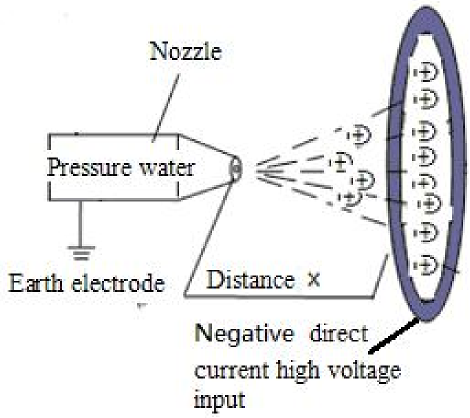


**Figure 2.** rinciple of spray induction charging.

2.1 Induced Electric Current of Atomization Spray by Induction Charging Method

The induced charge density of liquid surface can be obtained by Gauss's law [9]:

$$J_g = \varepsilon_0 E \,. \tag{6}$$

Wherein: $J_g$—induced charge density of liquid surface , C / $m^2$; $\varepsilon_0$—air dielectric constant.

Then the electric current of atomization spray by induction charging method is calculated as follows:

$$I = 2\pi r J_g u = \frac{2J_g Q}{r} = \frac{2\varepsilon_0 E Q}{r} \,. \tag{7}$$

Wherein: u—flow rate from nozzle outlet, m / s; r—radius of nozzle outlet, m; Q—water flow, $m^3$ / s.

The charged amount of ring mathematical formula is as follows:

$$q_g = 8\pi\varepsilon_0 R U \,. \tag{8}$$

Wherein: $q_g$—charged amount, C; R—an induction loop radius, m; U—applied voltage , V.

The charged quantity of spherical water droplet is computed. Assuming that the charged quantity of spherical water droplet from the nozzle comes from induction charging of the water droplets projection equal area of the water surface, in order that the charged quantity of spherical water droplet can be determined by the following expression:

$$q_0 = \tfrac{1}{4}\pi d^2 \varepsilon J_g \,. \tag{9}$$

Wherein: d—droplet diameter, m; ε—dielectric constant of a drop of water.

Supposing the distance of between the nozzle mouth and the charged ring is x, the electric field intensity is calculated as follows:

$$E = \frac{1}{4\pi} \frac{qR}{(x^2 + R^2)^{\frac{3}{2}}} = \frac{2RUx}{(x^2 + R^2)^{\frac{3}{2}}} \,. \tag{10}$$

The type (8) is substituted to the type (7), the induced current is as follows:

$$I = \frac{4\varepsilon_0 QRUx}{r(x^2 + R^2)^{\frac{3}{2}}} \,. \tag{11}$$

2.2 Charge-mass Ratio of Spray by Induction Charging Method

This type (11) on both sides of x is differentiated, based on making $\frac{\partial I}{\partial x} = 0$ , so that the x is as follows:

$$x = \frac{R}{\sqrt{2}} . \tag{12}$$

It can be seen that, when the diameter of the ring is constant, the induced current of spray body has an optimum value of x.

The charge-mass ratio of spray induction charging can be determined by the following expression:

$$\frac{q}{m} = \frac{I}{\rho Q} = \frac{4\varepsilon_0 RUx}{\rho r(x^2 + R^2)^{\frac{3}{2}}} . \tag{13}$$

Wherein: q/m—charge-mass ratio, C / kg; ρ—water density , kg / $m^3$.

2.3 Electrically Charged Quantity by Induction Charging Method

The type (10) and type (6) are substituted to the type (9), the electrically charged quantity of induction charging spray is calculated as follows:

$$q_0 = \frac{\pi\varepsilon_0 \varepsilon d^2 RUx}{2(x^2 + R^2)^{\frac{3}{2}}} . \tag{14}$$

There is a sufficient amount of spray of positive charge by induction charging, which is effectively purified the dusty airflow based on Coulomb force under the action of force. The charge-mass ratio of spray need be greater, in order to ensure that water mist has a larger charge levels. Namely try to improve the water current in the case of spray volume not changing too large.

3 CORONA CHARGE OF SPRAY

3.1 Saturated Electric Quantity by Corona Charge of Spray

The corona charged is forms the ion through the corona discharge [10], but these ions with particle encounter are accelerated by outside electric field, thus which causes them electrically charged method, as shown in Figure 3.

Taking into account that a radius, dielectric constant epsilon (epsilon > epsilon 0) dielectric ball is placed the uniform electric field, the electric potential of the point P in the space can be calculated.

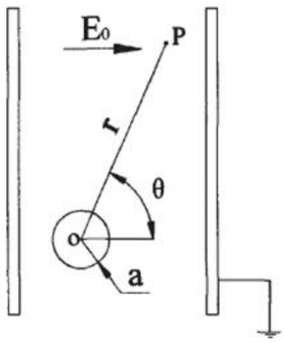


**Figure 3**. Dielectric sphere in an uniform electric field.

The electric potential of the point P should sum of the electric potential which forms for polarized electric charge dipole moment m and of the electric potential which produces with outside electric field $E_0$.Supposing the electric potential of the point P is as ϕ, then the formula is as follows:

$$\phi = \frac{m\cos\theta}{4\pi\varepsilon_0 r^2} - E_0 r\cos\theta . \tag{15}$$

If the electric field strength inside the ball is set $E_i$, the electric potential of the point i inside the ball$\Phi_i = -E_i\cos(\theta)$, and the value of θ , should have $\Phi = \Phi_i$, regardless in the sphere department, therefore the formula is shown as follows:

$$\frac{m\cos\theta}{4\pi\varepsilon_0 r^2} - E_0 a = -E_i a \ . \tag{16}$$

The ball surface should meet with the successive conditions of electric potential.

$$\varepsilon_0(\frac{d\phi}{dr}) = \varepsilon(\frac{d\phi_i}{dr}) \ . \tag{17}$$

Then the type (18) is obtained.

$$\frac{m}{4\pi\varepsilon_0} \bullet \frac{2\varepsilon_0}{a^3} + \varepsilon_0 E_0 = -\varepsilon E_i \ . \tag{18}$$

The m is obtained by type (16) and type (18) eliminating $E_i$.

$$m = (\varepsilon - \varepsilon_0) 4\pi\varepsilon_0 a E_0 \Big/ (\varepsilon + 3\varepsilon_0) \ . \tag{19}$$

So, the electric potential inside the ball Φ is calculated as follows:

$$\phi = \frac{\varepsilon - \varepsilon_0}{\varepsilon + 2\varepsilon_0} a^3 E_0 \frac{\cos(\theta)}{r^2} - E_0 r \cos(\theta) \ . \tag{20}$$

Thus, the electric field $E_i$ of the point P of initially uncharged electric fields is generated as follows:

$$E(r,\theta) = -\frac{d\theta}{dr} = E_0 \cos\theta + 2(\frac{\varepsilon - \varepsilon_0}{\varepsilon + 2\varepsilon_0}) E_0 \cos\theta \frac{a^3}{r^3} \ . \tag{21}$$

If the electric field is E(r，θ)＝0 at position P(a，л), as shown in Figure 4, it indicates that the charged amount is limit value. When the electric field of charged particles is bigger than the external electric field, corona charge will be unable to continue. As the same time in type (21) the r＝a and θ＝л are supposed, the saturated electrically charged quantity $q_{max}$ is obtained as follows:

$$q_{\max} = 4\pi\varepsilon_0 a^2 E_0 \frac{3\varepsilon}{\varepsilon + 2\varepsilon_0} = 4\pi\varepsilon_0 a^2 E_0 p \ . \tag{22}$$

Wherein: $p = \frac{3\varepsilon}{\varepsilon + 2\varepsilon_0}$.

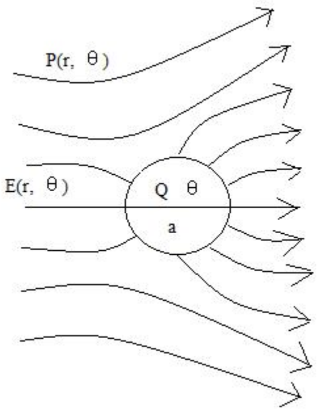


**Figure 4**. Charged dielectric sphere in uniform electric field.

3.2 Charged Quantity based on Corona Charge of Spray

The migration velocity of particle is μ, if it is through the electrically charged space, in which the ion density is $N_0$, and supposing that the electric-charge density of granule surface is σ when it is the time t, then the current continuity equation of application of particle surface is calculated as follows:

$$\frac{\partial \sigma}{\partial t} = -eN_0 \mu E(a,\pi). \tag{23}$$

In type(21), supposing r＝a， θ＝л， q＝4лa$^2$σ, $E(a,\pi) =$ [illegible] $= pE_0$ can be obtained , and the E (a, л) being substituted to type( 23 ), the formula can be obtained as follows:

$$\frac{\partial \sigma}{\partial t} = -eN_0 pE_0 - \frac{eN_0 \mu}{\varepsilon_0} \sigma. \tag{24}$$

In the initial conditions, it is t = 0, σ= 0, the type (24) can be resolved as follows:

$$\sigma = 4\pi\varepsilon_0 a^2 E_0 p[1 - \exp(-\frac{eN_0 \mu}{\varepsilon_0} t)]. \tag{25}$$

According to this kind of electronics corona electrically charged mechanism, spray quantity formula of corona charged is derived as follows:

$$q = q_{\max} \frac{t/\tau}{1 + t/\tau}. \tag{26}$$

Among them, the charge time constant τ is calculated as follows:

$$\tau = \frac{4\varepsilon_0}{\mu \sigma_i} = \frac{4\varepsilon_0 E}{i}. \tag{27}$$

From the above it can be seen that when a particle enters high-voltage electrostatic field, as time increasing, the particle is fully charged, and the charged quantity of particle ultimately achieve in saturated charge of $q_{max}$ as type (22) shown. The method of electronics corona charged commonly used in the static electricity dust removal, the static electricity spraying, the static electricity sprays and so on the aspects.

## 4 CONCLUSIONS

(1) Contact electrically charged is applied in the external voltage directly with the water or the spray nozzle docking, which causes the mist blowout, the water-drop surface attaching the ion. In this case, the electrically charged ion polarity are same that of the external voltage, the water drop electrically charged sets is also decided by the external voltage. But the insulation of contact spray charging is difficulty, its application is restricted.

(2) When there is some conductivity of water mist and the voltage electrode approaching the distance, based on induction charging spray, the mist surface produces with the electrode polarity opposite electric charge, the mist induces electrically charged has the voltage to be low. So, spray induction charging method is seldom used in air purification.

(3) Water charged of spray corona is produced by high voltage electrode tip corona discharge， which make the droplets charged ions. When the direct current high voltage by discharge electrode is applied, the high field strength around the discharge electrode in air is produced large numbers of electrons and ions. While the water mist is through the space, the water spray is charged and attached by both electric field effect and diffusion of charged ions. This method of electrically corona charged is broad to apply in the paint spray paint, mainly in the gas purification technology domain.

## DECLARATION

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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