

EXPERIMENTAL STUDY ON AGGLOMERATION OF SMOKE PARTICLE IN ELECTRIC FIELD

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ABSTRACT: The agglomeration phenomenon of the charged smoke particle has been investigated by the electric-fluid mechanics and transport theory of external force field and depending on several simplifying assumptions the theoretical expression for the agglomeration rate of the smoke particles has been developed. In a model of electrostatic precipitator the agglomeration mechanism of charged particles has been studied further. It is shown that the agglomeration of the charged smoke particles are affected by charge distribution on the surface of particles, particle size and charge polar of particle, particle charges and so on. No matter single polar corona or bipolar corona the agglomeration of smoke particles will take place but the agglomeration occurring between particles with negative charges and particle with positive charges will be limited within a certain scope.

FOREWORD

The agglomeration of smoke particle is the process of the collision and impaction of the smaller finer particles to adhere to larger particles. This important phenomenon taking place among particles leads to decreasing in number of particles and increasing in effective diameter of the particles. Normally ESP (Electrostatic Precipitation) has a high collection efficiency to smoke particle, but to submicron particles, it isn't satisfied, because of the size of the submicron particles being too small to get enough charges.

The classical theory of ESP indicates explicitly that the charges on smoke particle are related to particle size, electric field strength and so on. As is shown by the following Eq. (1), it is the numeration of saturated charge of particle by ion bombardment of particles that is predominant way of particles charging in ESP. [3]

$$q_s = 4\pi\epsilon_0 \left(1 + 2\frac{\epsilon - 1}{\epsilon + 2}\right) a^2 E_0 \quad \dots\dots\dots(1)$$

where q_s is the saturation charges on the particle surface, ϵ is the relative permittivity of particle, a is the particle radius, E_0 is the electric field strength without interfere, ϵ_0 is permittivity of vacuum?

Obviously, the size of particle is one of main factors. Therefore, making finer smoke particle be larger in electric field is an important way of improving the efficiency of ESP. In fact, particle agglomeration is also ease to vibrate particles down integrally from collecting plate falling into the hopper smoothly. It reduces re-entrance of deposits and helps to collect smoke particles too. Investigating the agglomeration mechanism of charged particle in electric field will redound to perfect the present theory of ESP and instruct the practice.

THE AGGLOMERATION OF THE CHARGED SMOKE PARTICLE IN ELECTRIC FIELD

Usually the smoke particles inside ESP are expected to get enough charges. To the charged particle, the interactive potential between particles can be expressed as [1]

$$W(r) = \frac{q_1 q_2}{4\pi\epsilon r} \quad \dots\dots\dots(2)$$

where q_1 and q_2 respectively are the charges of two interactive particle, r is the intervals of two particles.

Assuming a smoke particle with radius r_1 is fixed at the origin of the coordinate system, the space is full of the limitless medium of single disperse and suspend particles with radius r_2 . Charged particles with radius r_2 spread to the particle with radius r_1 . According to the

transporting theory ^[2] of particle in the outer force field, the rate that the particle with radius r_2 spreads to the surface of particle with radius r_1 is

$$J(r) = -D_2 \frac{\partial n}{\partial r} + vn \quad \dots\dots\dots(3)$$

where $n \mathbf{E} / f$ is the migration velocity of smoke particle, F is Coulomb force, f is friction coefficient, D_2 is the diffusion coefficient of the particle with radius r_2 , n is the density of particle with radius r_2 at the moment of t . Therefore, under the steady state, the number of particle with radius r_2 spreading to the particle with radius r_1 within unit time will be

$$N_{12} = -4\pi r^2 J(r) = 4\pi r^2 D_2 \frac{dn}{dr} - 4\pi r^2 \frac{F(r)}{f} n$$

$\because F = \frac{-dW(r)}{dr}$, $D_2 = kT/f$, where k is Boltzmann coefficient, T is the absolute

temperature, so

$$N_{12} = 4\pi r^2 D_2 \frac{dn}{dr} + \frac{4\pi D_2 r^2}{kT} \frac{dW(r)}{dr} n = 4\pi r^2 D_2 \left(\frac{dn}{dr} + \frac{n}{kT} \frac{dW(r)}{dr} \right)$$

or
$$\frac{dn}{dr} + \frac{1}{kT} \frac{dW(r)}{dr} n = \frac{N_{12}}{4\pi r^2 D_2} \quad \dots\dots\dots(4)$$

The Eq.(4) is a linear differential Eq.(1) with one step, solve it:

$$n = n_\infty \exp\left[-\frac{W(r)}{kT}\right] + \frac{N_{12} \exp[-W(r)/kT]}{4\pi D_2} \int_{-\infty}^r \frac{\exp[W(x)/kT]}{x^2} dx \quad \dots\dots\dots(5)$$

if $r = r_1 + r_2, n = 0$, then

$$N_{12} = \frac{4\pi D_2 n_\infty (r_1 + r_2)}{(r_1 + r_2) \int_{r_1+r_2}^{\infty} \{\exp[W(x)/kT]/x^2\} dx} \quad \dots\dots\dots(6)$$

$$\because (r_1 + r_2) \int_{r_1+r_2}^{\infty} \{\exp[W(x)/kT]/x^2\} dx =$$

$$-\frac{1}{q_1 q_2 / 4p\epsilon k T (r_1 + r_2)} \left[1 - \exp\left(\frac{q_1 q_2}{4p\epsilon k T (r_1 + r_2)}\right) \right] = \frac{1}{H} [e^H - 1] \quad \dots\dots\dots(7)$$

where $H = q_1 q_2 / 4p\epsilon k T (r_1 + r_2)$ is a zero-dimensional parameter, and it means the ratio of static potential energy to the heat energy when two particles contact each other. Inserting Eq. (7) into Eq. (6),

$$N_{12} = \frac{4pD_2 n_\infty (r_1 + r_2)}{\frac{1}{H} [e^H - 1]} \quad \dots\dots\dots(8)$$

analyzing the express (8) as follows:

If q_1 and q_2 with the different symbol, then $H < 0$ and $[e^H - 1]/H < 1$ obtained from the extensive formula of $(e^H - 1)$, it shows that the agglomeration rate of particle will increase under this situation.

If q_1 and q_2 with the same symbol, then $H > 0$ and $[e^H - 1]/H > 1$ obtained from the extensive formula of $(e^H - 1)$, it shows that the agglomeration rate of particle will decrease because of repulsion. If $q_1 = q_2 = 0$, then $H = 0$ and $[e^H - 1]/H = 1$, it is the situation that impacted particles have no charges.

However, the following experimental result shows that no matter smoke particles with the positive or negative electric charges impact each other, the agglomeration effect is obviously much better than the neutral particles, especially the agglomerative effect with opposite polarity is better than the one with same polarity.

EXPERIMENT AND ANALYZE

In order to investigate the agglomeration of smoke particle in electric field, an experimental model of ESP with bipolar corona has been designed as described in Fig.1. The major parts of the set consist of a bipolar corona field (positive and negative) and a single polar corona (negative). The smoke for test is produced by the burning of the mosquito smudge and the initial smoke particle size is about 0.1-0.3 μm . With the increasing of particle density and time, the average granularity of smoke particle will be larger. The smoke particles enter the positive and negative corona field through the flue and gradual-expand pipe. Two rectification nets are specially installed in gradual-expanded pipe for ensuring uniform distribution of smoke particle in bipolar corona field. When smoke particles pass through the passage of positive and negative corona area, they take positive and negative charge respectively. Because the bipolar corona field is only for charging smoke particle not for

collecting them, the length of the corona area is designed a little shorter appropriately.

Considering the positive and negative corona having the different V-I characteristic curves, it is the precondition to ensure the same corona current through the collecting plate while confirming the form of corona electrode and applied voltage for positive and negative corona respectively. The charged particles enter the mixture agglomerative district when they get out of the bipolar corona field. In this area, smoke particles driving by Coulomb force will impact each other and agglomerate to larger particles. It can be observed through microscope and it is irregular conglomeration. The agglomerated particles move into the single negative corona field and be charged again. They obtain much more charges obviously, and the collecting efficiency of particles has been improved. The experimental results are as follows:

i) Particles size increasing through single corona (positive or negative) charging

For example, the dispersed degree of particle with diameter less than 0.24 μm drop from original 80% (without charged) to 55%, while it rise from original 20% to 45% when the particle size distribution greater than 0.4 μm . The particle agglomerative form show mostly chain structure. It can be analyzed as follows:

Firstly, if smoke particles get positive or negative charges, it is theoretically disadvantageous to the particle agglomeration because of the repulsion among particles. However, the prerequisite of deriving Eq. (7) is that particle take on the form of ball, single disperse system and the size of a particle is much larger than the average free tenor of gas particle. While the actual smoke particles all belong to the high disperse system, their forms are not orbicular sphere perfectly, and the particles have a good insulation. Under the same charging condition, the charge quantum on particles is different. Even the charge quantum is the same, the charge distribution on the surface of particles might not be the same. Because of particle with different form, the charges on particle surface cannot be transmitted evenly to the whole surface of particle. It leads to non-uniform charge distribution on the surface of particles. Therefore, different charge quantum and distribution cause the agglomeration of particles.

Secondly, smoke particles with different sizes get different charge quantum. The mirror-image force in electric field has exceeded the function of repulsion of particles with the same polarity charges, and it generally takes on the agglomerate of particle.

Thirdly, the smoke particles are polarized into dipole under the function of electric field. The opposite polarity charges will be induced when the particles with the same polarity charges approach closely, and particles will agglomerate because the gravitation among particles is greater than the repulsion. No matter in non-uniform or uniform electric field, the dipole effect of the particle will force the particle move along the power line. In a short period of time, a lot of particles agglomerate along the electric field direction and form the smoke conglomeration with chain structure^[4].

ii) The collision of charged particle by bipolar corona making the size of smoke particle increase obviously

For example, the dispersed degree of particle with diameter less than 0.4 μm drops to 25%, while it rises to 75% when the particle size distribution greater than 0.4 μm . The form of particle agglomerating shows mostly conglomeration structure. The main mechanism of the agglomeration of particle is the result of the particles with opposite polarity charges attracts each other by Coulomb force. Because there is the strong attraction among particles with opposite polarity charges, the probability of particles colliding is increased sharply and the particles close each other, which impel the agglomeration of particle. Meanwhile, the polarized charge plays a positive role to the agglomeration of particle too. Certainly, there is also an acting range produced by the particles with opposite charges known as effective attraction scope. Outside this scope, the Coulomb force doesn't work. It is known that the electric field at a distance X from a smoke particle charges q_1 is:

$$E = \frac{q_1}{4\pi\epsilon_0 x^2} \quad \dots\dots\dots(9)$$

The force produced by this electric field acts on the another smoke particle with charges q_2 is

$$F = \frac{q_1 q_2}{4\pi\epsilon_0 x^2} \quad \dots\dots\dots(10)$$

If these two particles carry opposite polarity charges and assume the particle with negative charges is immobile, then the particle with positive charges will be attracted by the former and does the accelerated motion towards it. The potential energy at the distance X from the immobile particle is:

$$\int_x^\infty \frac{q_1 q_2}{4\pi\epsilon_0 x^2} dx = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

Because the average kinetic energy of the gas atom is $3kT/2$, and if the kinetic energy of the motion particle exceeds the potential energy of the resting particle, the former would not be affected by the latter. Therefore, an effective scope can be gotten around the resting particle (supposing the radius of this range is r_0). Let the kinetic energy of the smoke particle equal to the potential energy at that point, i.e.

$$\frac{3}{2}kT = \frac{q_1 q_2}{4\pi\epsilon_0 r} \quad ? \quad r = \frac{q_1 q_2}{6\pi\epsilon_0 kT} = r_0$$

Assuming the average distance among particles with opposite polarity charges is R_0 , then only when $R_0 > r_0$, the particles with positive and negative charges will impact and agglomerate each other.

CONCLUSIONS

i) The agglomeration of the charged smoke particles in electric field are affected by charge distribution on the surface of particles, particle size and charge polar of particle, particle with neutral charges and so on.

ii) No matter single or bipolar corona the smoke particle size will increase obviously, but the latter is more obvious. The agglomeration of particle caused by single polar corona shows mostly the chain structure, but the agglomeration of bipolar particle shows the conglomeration structure.

iii) The agglomeration occurring among particles with negative and positive charges will be limited within a certain range.

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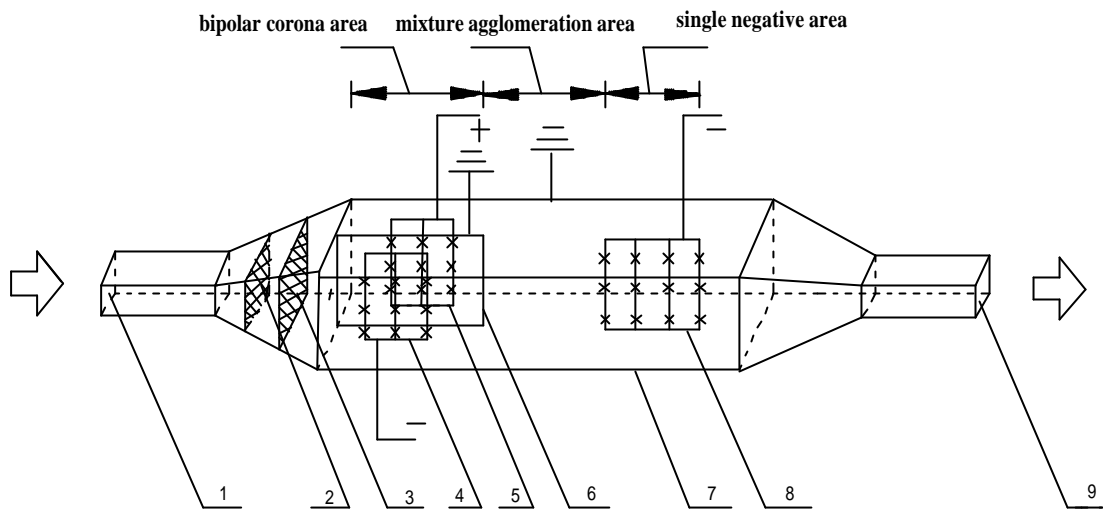


Figure. 1: The ESP model for agglomerating and charging smoke particle

1 smoke entrance ; 2 rectification net 1; 3 rectification net 2; 4 negative corona electrode 1; 5 positive corona electrode; 6 ground plate; 7 experimental model shell; 8 negative corona electrode 2; 9 exit (to fan)