Non-static Collection Process of the Electrostatic Precipitator

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Abstract: In order to describe non-static dust collection in electrostatic precipitator comprehensively and propose a non-static dust collection theory on it, the leading accumulation and release of the dust layer electronic charge on the collection plate was researched according to the electrostatic principle. The calculation equation of the dynamic dust collection electric-field intensity that changes with the dust layer thickness was deduced. Furthermore, the equation of the dynamic velocity of the charged particle could also be obtained. And finally, the non-static electrostatic dust collection theory was proposed. The results indicated that the particle velocity was related to many factors such as particle specific electric resistance, applied voltage and dust layer thickness during electrostatic dust collection process. The collection efficiency decreases with the increasing of the particle specific electric resistance. The collection efficiency can reach a maximum value when an optimal applied voltage is got. Multiple laboratory experiments were completed on many kinds of particles with different specific electric resistance. The experiment results obey to the theoretic results. The non-static dust collection theory could explain contradictive points between the actual electrostatic dust collection process and the traditional electrostatic dust collection theory and provided a scientific theoretical foundation for the design of the electrostatic precipitator and the decision of its operating parameters.

Keywords: electrostatic precipitator; accumulated dust layer on the collection plate; accumulated electronic charges; particle velocity; collection efficiency

1 INTRODUCTION

As high effect dust-cleaning equipment electrostatic precipitator has been widely applied. However comparative to the process of dust-cleaning technique it developed slowly. Traditional theory on static duster neglected influence on static dust collecting of dust deposited on electrode board. It indicated that dust collecting was a stable process. Practical operation which conflicts with traditional theory is relational with the assumption. Influence of dust deposited on electrode board on static dust collection has been a pendent problem in static dust collection industry (Zhao Zhibin, Zhang Guoquan, 1992; Zhang Guoquan, 2000). At present, no relational formulas between dust-surface accumulated charge and working voltage, specific electric resistance and thickness of dust layer has been derived.

In the operation of electrostatic precipitators the thickness and conductance of dust layer on dust-cleaning electrode board certainly will affect conduction and release of inpouring charge. Various amount accumulated charge are formed in dust layer Accumulated charge produce additional electric field, direction of which is contrary to original field. It changes the characteristic of original electric field. In fact the electrostatic precipitator is a non-steady-state process. (HAO Wenge 2004).The study applied basic theory of electrostatics to analyses the inpouring, conduction and release processes of current in dust layer in the course of dust depositing to electrode board. Finally the formula of particle velocity in non-static collection is obtained. The experiments of non-static collection prove preciseness of non-static collection theory. The results could explain many phenomenon that traditional theory conflict with reality, which has guide meaning on design and selection of parameter in electrostatic precipitator.

2 THEORETICAL RESEARCH ON THE NON-STATIC COLLECTION PROCESS

2.1 Accumulation charge of plate sedimentary dust layers

In the process of collecting dust in ESP, charged particles in the electric field run to collecting plate under the power of electric field. A certain thickness dust layer gradually formed on electrode board. Supposing collecting time is t(s), the resistivity of the particles is ρ_d (Ω·m), the charged dust accumulate on the plate layer by the speed of f (m·s^{-1}), the charge density in internal dust is q_d(cm^{-3}), electric field intensity is E_d (V·m^{-1}), thickness of dust layer is X (m). When the dust layer accumulates to the thickness of x(m), the following relationship come into existence (Bao Chong-guang,1993;Blanchard D, Atten P, 2002):

$$-divj_d = \frac{\partial j_d}{\partial x} = \frac{\partial q_d}{\partial t} \quad (1)$$

$$div\varepsilon_d \varepsilon_0 E_d = -\varepsilon_d \varepsilon_0 \frac{\partial E_d}{\partial x} = q_d \quad (2)$$

$$j_d = \frac{E_d}{\rho_d} \quad (3)$$

Supposing that the electric field intensity E_d' in the junction between dust layer and dust collection space is a constant, according to the electric displacement boundary conditions, it can be concluded that $\varepsilon_0 E_0 = \varepsilon_0 \varepsilon_d E_d'$.Then the electric field intensity E_d' in the junction between dust layer and dust collection space is

$$E_d' = \frac{E_0}{\varepsilon_d} \tag{4}$$

E_0—electric field intensity of electric-field (V/m);

ε_d—relative dielectric constant of dust layer;

ε_0—Vacuum permittivity (C/Vm);

j_d—the density of electeic current in the dust (A/m^2).

With the growth of collecting time, the charged particles deposit in collecting board by the force of electric-field. According to Poisson equation the current density of the border can be concluded:

$$j_d' = E_d'/\rho_d \tag{5}$$

for $j_0 / f = q_0$,it can be simplified:

$$q_d' = q_0 - \frac{E_d'}{\rho_d f} \tag{6}$$

By-(6) the current density of the border can be seen a constant. For $q_d' = q_{do}$ According to continuity equation and Ohm's law, the differential equation of dust layer charge density distribution can be established.

$$\frac{\partial q_d}{\partial t} = -\frac{q_d}{\tau_d} \tag{7}$$

x ≤ X in the context of (7) points to a dust density of the internal charge-distribution function:

$$q_d(x) = (\frac{j_0}{f} - \frac{E_0}{\varepsilon_d \rho_d f})\exp[-(X-x)/f\tau_d] \tag{8}$$

By-(8) can be known that when the dust thickness is for X, accumulated charge of dust in per area for the total Q (C/m^2):

$$Q = \int_0^X q_d(x)dx = (j_0 - \frac{E_0}{\varepsilon_d \rho_d})[1-\exp(-X/f\tau_d)]\tau_d \tag{9}$$

j_0—the current density in the dust-collecting space (A/m^2);

τ_d—the constant of the discharge (s), $\tau_d = \rho_d \varepsilon_0 \varepsilon_d$.

2.2 Electric field intensity of electric-field for dust-collecting

According to the ESP characteristics, when the collecting plate is clean (Written by Hyter, Translated by Wang Chenhuan,1984):

$$j = KU(U - U_s) \tag{10}$$

U—operation voltage (V);

U_s—discharge inception voltage (V);

$K = \frac{\varepsilon_0 k}{b^3}$, k—the mobility ratio (m^2/VS);

b—the distance between plates (m).

When the dust in the plate is in a certain thickness:

$$j = K(U - j\rho_d X)(U - j\rho_d X - U_s) \tag{11}$$

By-(11), it can be seen that the drop of the voltage significantly reduced the size of the corona current. Then the collection field intensity reduces significantly. It affects the capability of electrostatic dust collection. By-(11) the change and size of corona current can be calculated under a certain thickness dust layer.

By-(9), it can be seen that plate sedimentary layers of dust accumulation and charge of dust is a value related to dust resistivity. The bigger dust resistivity is, the more accumulated charge is, and the bigger the strength of the anti-electric field is. They have negative infection for the ESP. The size of anti- electric-field generated by the surface accumulated charge can be calculated according to Gauss theorem:

$$E_p = \frac{j\rho_d \varepsilon_d}{2} - \frac{E_0}{2} \tag{12}$$

Composed with original field the real density of field is

$$E_0' = \frac{3}{2}E_0 - \frac{j\rho_d \varepsilon_d}{2} = 3\sqrt{\frac{jb}{\pi\varepsilon_0 k}} - \frac{j\rho_d \varepsilon_d}{2} \tag{13}$$

2.3 Particles velocity of non-static electrostatic dust collection

With reduce of field density, the particles velocity decreases. By-(13), particles velocity can be obtained under different collection time, different particles, different supply voltage (current density)

$$\omega = \frac{\varepsilon_0 \varepsilon_d d_p}{\mu(\varepsilon_d + 2)}(3\sqrt{\frac{jb}{\pi\varepsilon_0 k}} - \frac{j\rho_d \varepsilon_d}{2})^2 \tag{14}$$

ω—particles velocity (m/s);

d_p—diameter of dust particle (m);

μ—Gas viscosity coefficient (Pa/s);

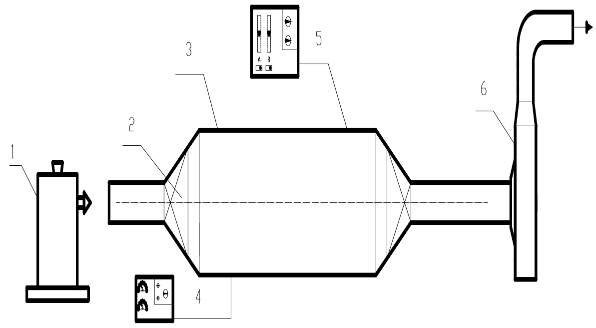
Through the theory above process it can be seen that: in the electrostatic dust collection process, the accumulated charge generated by sedimentary dust layers on base plate of and its voltage drop will reduce the particles velocity. Then the efficiency of dust collecting reduces. To the electrostatic dust collection, there is a best supply voltage, under which voltage efficiency of dust collection is the highest. Under the same voltage the collecting efficiency decline with the drop of particles velocity. When the resistivity of the particles is higher, with the thickening layer of dust, the corona current significantly reduced. Then the particles velocity and collection efficiency reduce.

3 EXPERIMENTAL RESEARCHES ON THE NON-STATIC COLLECTION PROCESS

3.1 Experimental system and method

In order to test the influence of dust layer for static dust collection efficiency, the efficiency is tested under different factors Test model is shown in Fig. 1.

Model uses single-district lines. The length of the collecting plate is 0.7 m; height is 0.3 m, line-spacing of 0.1 m. four lines of Corona are established on access centers. ESP applies high-voltage power supply by CGD DC. Dust in the electric field is according to Membrane-law in mind (GB/T16157). The dusts, such as calcium hydroxide, ashes, aluminum oxide are used in the experiment. At normal temperature the resistivity of the particles were 2×10^9 Ω·cm, 5×10^9 Ω·cm, 4.5×10^{11} Ω·cm, respectively. Experiment tests relationship between working voltage and the collection efficiency, the collection efficiency and the dust thickness, different resistivity of the particles and collection efficiency.



1—Dust Generator; 2—Air distribution plate; 3—The model of ESP; 4—High-voltage power; 5—Sampler; 6—Fan

Fig. 1 Sketch map of experiment device

3.2 Experimental results

3.2.1 Relationship between operating voltage and collecting efficiency

In order to verify the relationship between voltage and collection efficiency, the relationship between voltage and collection efficiency on three different resistivity particles were studied in Fig. 2:

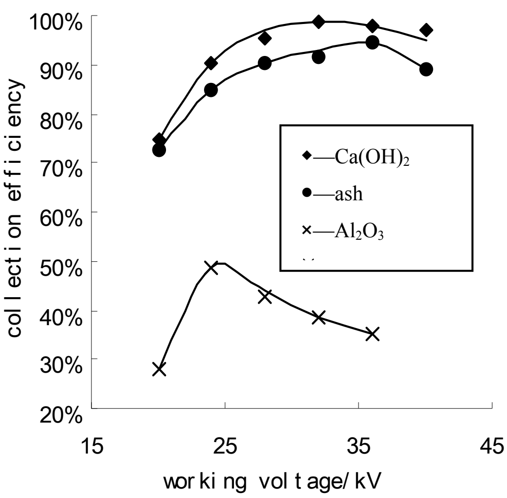


Fig. 2 The relation between collection efficiency and the applied voltage

From the Fig. 2, to different resistivity of the particles, there is a best-voltage power supply; high resistivity dust (aluminum oxide) is most obvious. Mainly reasons is: in process of electrostatic dust collection, the plate sedimentary layer of dust will gradually accumulate a certain amount charge, resulting in anti-electric field. It makes the speed of the charged particles is relative to a corona current, the resistivity of the particles, and other factors. Theoretical analysis and experimental results show that: when the corona current reached a certain value, particles velocity is largest and collection efficiency is the highest.

3.2.2 Relationship between collection efficiency and resistivity

It can be seen from Fig. 3: In the same voltage (30 kV), with the increase of the resistivity, collection efficiency decreased. The reason is that with the increase of the resistivity, accumulated charge in the dust layer increase which makes anti-increasing electric field increase. At the same time the current corona reduces which weakens the intensity of collecting electric field. So collection efficiency is reduced. When the resistivity of the particles is very high (ρ_d) $5\times10^{10}\Omega\cdot$cm), the anti-electric-field could seriously affect the collection process, making collection efficiency drop significantly. This is consistent with experimental results showed in Fig. 3.

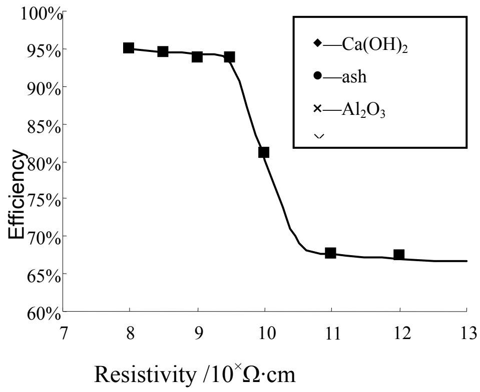


Fig. 3 The relation between the particle resistivity and the collection efficiency

3.2.3 Relationship between t thickness of dust layer and collection efficiency

It can be seen from Fig. 4: at the same voltage (30 kV) and entrance density (0.2 g/m^3) the collection efficiency of high resistivity reduces significantly with the increase of dust thickness. The reason id that dust plate sedimentary layer will produce a certain amount of accumulated charge which may exclude follow-up dust collection. Increase of dust layer will reduce corona current.

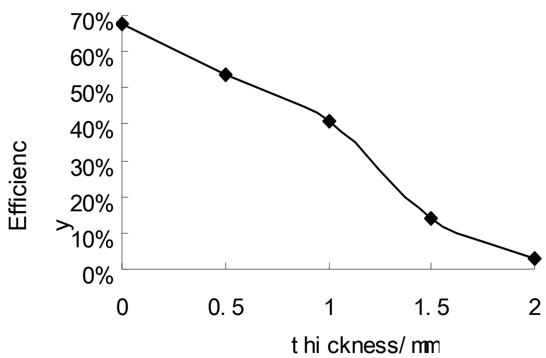


Fig. 4 Relation between thickness of the dust layer and the collection efficiency.

3.3 Comparisons between classification efficiency and f theoretical results

To calculate classification efficiency applies numerical modeling method. Substitution non-static theoretical particle velocity into transport equation of charge particle:

$$v\frac{\partial\rho}{\partial x}+\omega\frac{\partial\rho}{\partial y}-E\frac{\partial^2\rho}{\partial y^2}=0 \tag{15}$$

In order to obtain accurate numerical solution, the boundary condition and turbulence coefficient must be ensured. Because the entrance concentration is homogeneous, the boundary condition on entrance is: $\rho=\rho_0|x=0$. Because the symmetrical characteristic of dust consistency of both sides of corona wire, in the center: $\frac{\partial\rho}{\partial y}=0|y=0$. Supposing laminar boundary layer is δ, length is dx.According to conservation of particles, the following equation can be created (Miller J et al,1998; Robinson M, 1961; Soldati A, 1993):

$$\rho v_1\delta-\left(\rho v_1\delta+v_1\delta\frac{\partial\rho}{\partial x}\mathrm{d}x\right)+\left(\omega\rho\mathrm{d}x-E_y\frac{\partial\rho}{\partial y}\mathrm{d}x\right)-\omega\rho\mathrm{d}x=\frac{\partial\upsilon}{\partial t}\mathrm{d}x\cdot\delta \tag{16}$$

v_1—average speed of Laminar boundary layer, (m/s);

δ —average thickness of the Laminar boundary layer (m);

As dust concentration is a fixed value, then:

$$-v_1\delta\frac{\partial c}{\partial x}=Ey\frac{\partial c}{\partial y}\,|\,y=b \tag{17}$$

Synthesize turbulence mixing coefficient:

$$Ey=\frac{0.382(1+N_{EHD})\ v y^2 c_f^{0.5}}{b[(1+N_{EHD})\mathrm{Re}]^{0.04}} \tag{18}$$

c_f — friction coefficient;

Re—Reynolds number of fluid in field;

N_{EHD} —Current number;

$N_{EHD}=\frac{i}{s\rho k v^2}$,

s—Corona length(m);

ρ_g—gas density(kg·m^{-3}).

Parse (15), exit sectional consistency of different particle diameter are obtained. Then classification efficiency is figured out. Compare calculated result to experimental result. The experimental dust is fly ash.

It can be seen from Fig. 5 that non-static -state theory of electrostatic collecting explains the problem that there is obvious bias between the traditional theoretical and experimental data. Classification efficiency based on the non-static collection theory inosculates with experimental data. This is due to three main sally port on calculation method of classification efficiency: □the anti-electric field produced by sedimentary dust layer on polar plate is calculated according to non-static dust collection theory, which modify original electric field; □the turbulence coefficient is deduced when using numerical simulation methods to simulate the dust distribution; □in the transport formula, the unreasonable points of original boundary conditions are revised.

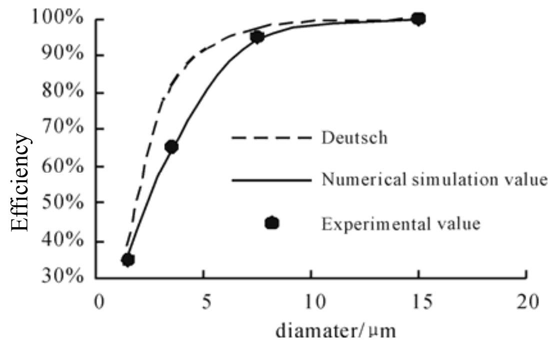


Fig. 5 Comparison of the classification efficiency.

4 CONCLUSIONS

(1) Based on basic principles of static electricity, relationship-formula about plate sedimentary layers of dust accumulation of charge, thickness of dust and resistivity of the particles has been deduced. The anti-electric field produced by accumulated charge has been calculated according to Gauss theorem. Then the new dynamic particle velocity of charged particle is obtained. Complete non-static dust collection theory is established. Theoretical study reveals: With the increase of resistivity in dust layer and thickness of the layer, the anti- electric field generated by the dust accumulated charge increases, and the particle velocity reduces. There is a maximum voltage of collecting efficiency

(2) In order to verify the non-steady-state theory of electrostatic dust collection relationships between collection efficiency and voltage, resistivity of particles and collection efficiency, dust thickness and collection efficiency are studied by experiment The results show that: With the increase of voltage, the collection efficiency increases. Collection efficiency reaches the highest under the best voltage. Since then with the increase of voltage, collecting efficiency starts to decline. With the increase of resistivity of the particles, dust collection efficiency declines. With the gradual increase of the thickness of dust layer, the corona current and collection efficiency declines.

(3) To calculate classification efficiency applies numerical modeling method. Its results basically inosculate with the experimental data. Non-static -state theory of electrostatic collecting explains the problem that there is obvious bias between the traditional theoretical and experimental data, which puzzled domestic and forgien scholastic.

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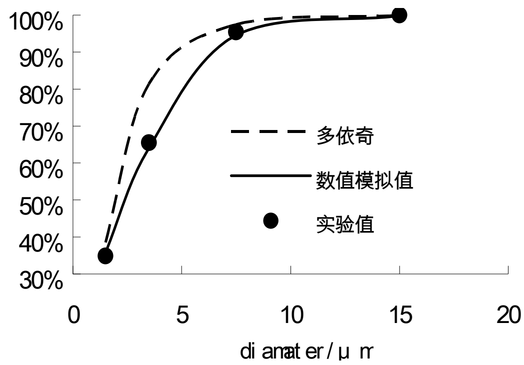

多依奇：Deutsch

数值模拟值：Numerical simulation value

实验值：Experimental value