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Application research on coating to adjust the cohesive force between dust and polar plate

Y. Zhang, Wei Yu*, Min Li

School of Automotive and Transportation, Qingdao University of Technology, Shandong, Qingdao, 266520, China

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In order to improve the dust collecting efficiency of electrostatic precipitator, starting from the polar plate material, established mechanical model of dust collecting process, analysised the influence of polar plate material to dust collecting, designed experimental device to measure dust cohesive force, measured the dust collecting effect when use coating, results showed that: according to the different nature of the dust, used reasonable Polar Plate coating can improve ESP dust collecting effect.

Keywords: electrostatic precipitator, dust, experiment device, cohesive force.

INTRODUCTION

Mine underground dust is the main factor to cause silicosis. Electrostatic precipitator (ESP) is widely used for mine dust capturing and recovery. Its basic principle is the use of high-voltage discharge, the gas ionization, charged dust move to collecting dust polar plate, then dust separate from the gas stream, so achieve the purpose of purifying gas. At the same time, many factors influence on ESP's collecting dust effect, such as temperature, humidity especially electrostatic dust characteristics. Conventional ESP is suitable for collecting dust with 104-1011Ω·cm resistivity, while for high resistivity dust, the cohesive force between dust and collecting polar plate is large and difficult to rapping and fighting off, and the dust deposited on the collecting plate has slow discharge rate, which is prone to generate the phenomenon of anti-corona and "secondary emissions" for the low resistivity dust. In order to improve the performance of ESP, many domestic and foreign experts have done a lot of research [1-6], Tang Min-kang [7] studied on particle coagulation and high resistivity dust characteristics, Zhi Xue-yi, Ye Qing studied on dust formation mechanism, growth pattern and coagulation mechanism [8, 9]. In order to improve the mine ESP efficiency, article starting from the relationship between polar plate material and dust cohesive force, adjust cohesive force between dust and polar plate, solve the rapping problem, improve the dust collection efficiency.

* To whom all correspondence should be sent:

E-mail: zhyoliang@163.com

EFFECT OF POLAR PLATE MATERIAL ON THE DUST CHARGE

According to the theory of molecular heat physics, any matter has certain degree thermoelectric in high temperature conditions, but emit a lot of electron only when the temperature reaches the critical emission temperature. Different materials have different critical emission temperature, according to the temperature environment in underground mine, can choose a suitable electronic work function lower polar plate material, the polar plate can be stable emit electron in ESP, make dust charging, achieve the purpose of energy efficiency.

Analysis electron how to escape from materials surface

For the different environment especially under different temperature conditions, it is not a definite concept that ESP polar plate material electron work function is the good to improve dust collection efficiency. The work requiremented vary according to the change of external conditions, article through reducing definition formulas to describe the main factors of affecting electron work function, to provide the scientific basis for selecting suitable polar plate material.

The application of single electron approximation method to discuss the energy behavior of plurality electron. Assuming no electronic interaction, and motion in the potential field of a single finite barrier. Single electron statewave function can be obtained by means of the Schrodinger equation:

$$\left[-\frac{1}{2}p^2+U_{eff}\right]\Psi_i=E_i\Psi_i \tag{1}$$

U_{eff} is effective surface potential.

In the infinite surface potential should be constant constant potential. In the positive colloid, independence total electron energy is:

$$E_T = 2\sum_t^{occ} E_i \tag{2}$$

Here to consider the electron spin. Occ said all electron number if its occupied state, represented by the density of states:

$$E_T = 2\int_{-\infty}^{E_F} E\rho_t(E)dE \tag{3}$$

E_T can be divided into two parts: body and surface, the surface energy:

$$E_S = 2\int_{-\infty}^{E_F} E\rho_S(E)dE \tag{4}$$

Because the surface caused the presence of small changes in the density of states at the Fermi level, the excess electron is empty offset, these electrons on the surface energy contribution is negative:

$$-2\int_{-\infty}^{E_F} E\rho_S(E)dE$$

Expressions of surface energy is:

$$E_S = 2\int_{-\infty}^{E_F}(E-E_F)\rho_S(E)dE =$$

$$= 2\int_{-\infty}^{E_F}(E-E_F)\left[-\frac{1}{4}\delta(E)+\frac{1}{\pi}\frac{d\eta(E)}{dE}\right]dE =$$

$$= \frac{E_F}{2} + 2\int_0^{E_F}\frac{d\eta}{dE}\times\frac{E-E_F}{\pi}dE \tag{5}$$

Application condition of electrical neutrality $\eta(E_F) = \pi/4$, obtained

$$E_S = \frac{2}{\pi}\int_0^{E_F} E\frac{d\eta}{dE}E \tag{6}$$

The above results based on hypothesis of isolated electronic. But the actual situation is much more complicated, when the electron motion energy exceed surface energy, electron will escape from the surface material Choice ESP polar plate material in the actual, not only to consider the interaction between electrons, but also consider the effect of orientation of the metal crystals.

The work function of dust space collision

When ESP working, polar plate material because of its nature or affected by the outside world, electron escape phenomenon often appear, and the escaping electrons and dust happen elastic collision in space and make dust become charged objects. These phenomena generated due to electron work fuction plays a considerable influence on ESP work efficiency.

The so-called electron escape depth (also known as the mean free path) refers to the electronic experience average distance before elastic collision. The electron mean free path and its kinetic energy have direct relationship with polar plate material. D.R.Penn proposed the theoretical formulais:

$$\lambda(E_k) = \frac{E_k}{a(\ln E_k + b)} \tag{7}$$

$\lambda(E_k)$ is the mean free path when the electron kinetic energy is E_k.; *a*, *b* are two parameters related to the plate material properties

Used this formula can calculate the mean free path of common materials.

Although the electron mean free path changes with the electron kinetic energy and material properties need to continue to study, but a large number of experimental results shown that, the relationship between escape depth and kinetic energy trend seems to be a general curve, as shown in Figure1.

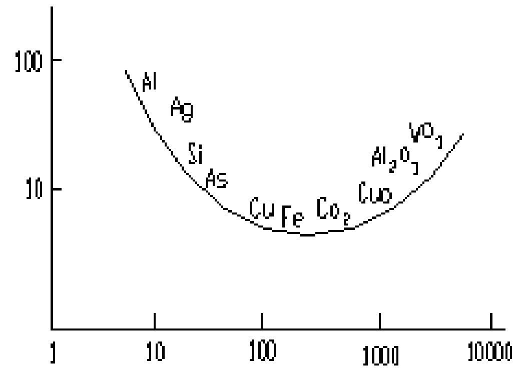

Fig. 1. Relation diagram between escape depth and kinetic energy.

In general, $\lambda(E_k)$ varies with the nature of the material, the energy is generally in the range between 200 and 2000 eV, in this energy range, $\lambda(E_k)$ change with $E_k/2$, approximately, namely $\lambda = k\sqrt{E}$, *k* is constant.

For various kinds of dust, they collision can not produce energy more than 200 eV, according to above derivation data, kinetic energy of dust collision can not make electron escape, so the study of ESP can ignore the work function when dust collision in space.

THE INFLUENCE OF COATING ON FORCE CONDITIONS OF DUST

The existing theory of dust trapping considers that, when dust gets into the border region of laminar flow where Coulomb force plays the role, and attaches to the collecting dust polar plate, the dust can be arrested on the set.

After dust particles in the electric force field are separated from the airflow and attached to the collecting dust polar plate, dust whether re-entering the flow or not depends on the force conditions of the dust particles. If the cohesive force is greater than the bonding force, the dust particles can be firmly attached to, or may be desorption and re-entering the flow which results in the so-called "secondary dust" phenomenon. After particles attached to the polar plate, the main forces are as following:

The molecular force between dust layer and polar plate, f_1, which has a small effective distance about 10-8cm, and

$$f_1 = \pi UDL \tag{8}$$

Where, U- intensity per unit area;

D- diameter of dust layer;

L- the effecting distance of molecular force on the contacting face.

The molecular force between dust particles, f_2, and

$$f_2 = \pi U \frac{D_1 D_2}{D_1 + D_2} L \tag{9}$$

Where, D_1, D_2 - diameter of particles.

The gravity of dust layer, f_2, and

$$f_3 = mg = A\ \delta_d\ r_d \tag{10}$$

Where, A- area of deposited dust;

δ_d - dust layer thickness;

r_d - the heap rate of dust layer.

The brushing force of wind power, f_4, is given by

$$f_4 = 0.5\ \xi v^2 rS \tag{11}$$

Where, ξ - resistance coefficient;

v - air flow speed;

r - the gas density;

S - the projected area of dust particles on the air flow direction.

Electric force, f_5, and

$$f_5 = \varepsilon_0 \left(\varepsilon_d E_d^{\ 2} - E_P^{\ 2} \right) / 2 \tag{12}$$

Because $E = \rho j$, the equation (12) can be rewritten as:

$$f_5 = \varepsilon_0 j^2 \left(\varepsilon_d \rho_d^{\ 2} - \rho_P^{\ 2} \right) / 2 \tag{13}$$

Where, ε_0 -vacuum dielectric constant;

ε_d -dust relative dielectric constant;

E_d -the average field strength within dust layers;

E_p -dust space field strength;

j -current density;

ρ_d , ρ_P -apparent resistivity of dust layer and electric field respectively.

Whether dust attaches to polar plate stably or not, it does not depending on the electric field force which performances adhesive force or bonding force, but depending on the resultant force of those forces acting on dust particles which performances adhesive force or bonding force. Under normal conditions, the electric force changes with the dust particles resistivity, and other forces have little influence on dust resistivity.

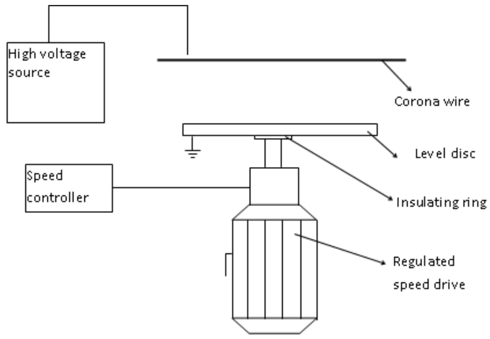

Fig. 2. Centrifugal force measuring device.

In view of the difference of dust resistivity, to discuss the stable attachment of dust on the polar plate, F_0 can be used to represent the resultant force of f_i (i =1, 2, 3, 4), that is, $F_0 = \sum f_i$, then the total force acted on particles is $f = f_0 + f_5$, and if with a coating F= $F_0 + f_5$.The greater dust resistivity is, the greater f_5 is, and also the greater the coating resistivity is, the greater f_5 is.

Through discussion [10], we can see that the field force used to maintain a suitable cohesive force between dust layer and polar plate is generated mainly by the coating. The resistivity of the coating should be in the range of 1.1 × 105 Ω· cm to 1.1 × 1012 Ω· cm. For the selection of coating materials, using lipid polymer as the main raw material is quite suitable. In experiments, we have selected the polyurethane which contains 23% graphite to be the coating material. Coating thickness has little impact on coating resistivity, which can be ignored, and in the experiments, we have set the coating thickness of 10μm.

EXPERIMENTAL STUDY ON THE IMPACT OF COATING TO DUST COHESIVE FORCE

The principle of centrifugal force determination

Centrifugal force method is to use centrifugal force to measure the dust cohesive force. Dust is placed on a flat steel plate which is mounted on a centrifuge, so that the dust will rotate along with centrifuge. Therefore, dust receives the action of centrifugal force $f\left(f = mr\omega^2\right)$, when the centrifugal force is just greater than the dust cohesive force, the dust will fly out from the plate. At that time, measure the centrifuge speed and the horizontal position of dust out of steel plate, and then by doing force analysis we can determine the quantity of the cohesive force of dust layer.

Experimental device

A set of centrifugal force measuring device is designed and assembled in laboratory, as shown in Figure 2.

Force analysis of dust on the centrifuge

The main forces acting on dust in the rotating disc are gravity (mg), supportive (N), friction ($F_{friction}$), centrifugal force ($F_{centrifua}$), cohesive force between dust ($F_{1cohesive}$), as well as the cohesive force between dust and disc ($F_{2cohesive}$), as shown in Figure 3.

In the vertical direction, the equation of force balance:

$$N=mg+F_{2cohesive} \tag{14}$$

In the horizontal direction, the force balance equation:

$$F_{1cohesive}+F_{friction}=F_{centrifugal} \tag{15}$$

At the moment when the dust just flying out, dust should be subject to the maximum static friction force, that is

$$F_{friction}=\mu_s \cdot N \tag{16}$$

Where, μ_s - the largest static friction coefficient of dust with steel plate.

The micro-dust gravity can be neglected, then have

$$N\approx F_{2cohesive} \tag{17}$$

Generally, the quantity of cohesive force between dust and steel plate is 2～3 times larger than that of among dusts, if take 2 times, have

$$F_{1cohesive}+F_{friction}=F_{1cohesive}+2\mu_s F_{1cohesive}=(1+2\mu_s)F_{1cohesive} \tag{18}$$

For centrifugal force, have

$$F_{centrifuga}=m\omega r^2 \tag{19}$$

Considering equations (15), (18) and (19), hence

$$(1+2\mu_s)F_{1cohesive}=m\omega r^2 \tag{20}$$

Finally, the calculated formula of adhesive force is:

$$F_{1cohesive}=\frac{m\omega r^2}{1+2\mu_s} \tag{21}$$

The cohesive force between dust and polar plate is $F_{cohesive}=2F_{1cohesive}$.

Experimental Results

By using centrifugal force measuring device, data of cohesive force between high resistivity dust, which is lime powder, and polar plate at different high voltage are measured. We found that with the polar plate coated or uncoated, the cohesive force between lime powder and polar plate has big changes. In order to see the changes directly, the measured data are plotted in Figure 4.

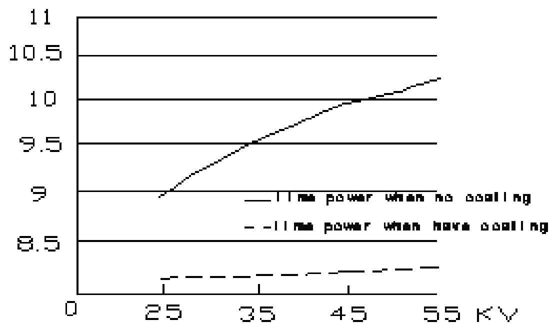

Fig. 4. Cohesive force between lime powder and polar plate with coating or no coating.

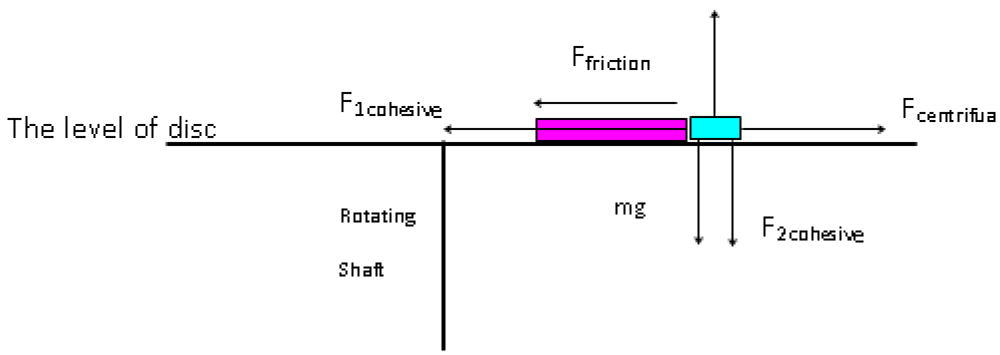

Fig. 3. Force analysis of dust on the rotating disc.

CONCLUSIONS

(1) ESP electronic work function of polar plate material had great influence on the efficiency of removing dust.

(2) Designed and assemblied a set of centrifugal force measuring device to measure cohesive force between polar plate and dust, the determination result is accurate.

(3) According to the different nature of the dust, used reasonable Polar Plate coating can improve ESP dust collecting effect.

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