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Effects of key factors of rotary triboelectrostatic separator on efficiency of fly ash decarbonization

Tao Youjun [a,b,*], Zhang Ling [a,b], Tao Dongping [c], Xian Yushuai [a,b], Sun Qixiao [a,b]

[a] Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, China University of Mining & Technology, Xuzhou 221116, China
[b] School of Chemical Engineering and Technology, China University of Mining & Technology, Xuzhou 221116, China
[c] School of Mining Engineering, University of Science and Technology Liaoning, Anshan 114051, China

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ABSTRACT

On the basis of understanding the principle of rotary triboelectrostatic separation, dynamic analysis of charged fly ash particles aimed at determining the key factors and separation experiments to improve decarbonization efficiency had been carried out. Variables of electrode plate voltage and corrected wind speed are the key factors which affect the decarbonization efficiency on the separation of fly ash. The results of separation experiments show that: (1) With the plate voltage increasing, the efficiency of decarbonization continuously rises and in its selected range, the optimal voltage level is 45 kV; (2) The corrected wind speed can impact the efficiency of decarbonization significantly: with the speed increasing, the efficiency of decarbonization shows a trend of first decline, then increase and decrease again, and in its selected range, the optimal speed is 2.0 m/s. This study is of significance for the improvement of rotary triboelectrostatic separation performance and its decarbonization separation efficiency.

1. Introduction

Fine coal ash, also called fly ash, refers to the dust that is carried away by flue gas and collected by the dust-collector after coal powder with a certain fineness is burned in a pulverized coal furnace in the processes of coal burning for heating or power generation. According to statistics, about 250–300 kg of fly ash was produced by one tone of coal burned in China [1], and the amount of accumulated coal ash has reached so far 12 billion tons and is still increasing at a speed of 160 million tons per year [2,3].

Fly ash contains a lot of useful substances, such as carbon, cenospheres, pozzolans, and the like, thus it should not be abandoned as waste. At present, fly ash is largely used as construction and building materials in China. However, because of the coal types, coal combustion conditions, and boiler operation conditions, the loss-on-ignition of fly ash is generally 10–15%, even up to 25–39% [4,5], limiting not only its use as construction and building materials, but also the improvement of its overall utilization rate [6–8]. Therefore, study on fly ash decarbonization is of significance.

Currently, fly ash decarbonization technology mainly includes both wet and dry separation methods [9]. The former mainly refers to the froth flotation separation, while the latter mainly refers to the triboelectrostatic separation. Although the effect of fly ash decarbonization through flotation is commonly considered to be the best, it is not widely used yet due to its high cost and poor activity of fly ash. Compared with the froth flotation separation, the triboelectrostatic separation is a dry process with a lower investment and operation cost and more compatible with the widely used dry fly ash emission way in current coal-fired power plants [10]. For this reason, the use of electrostatic separation methods to study fly ash decarbonization has gradually become a hot topic and the triboelectrostatic separation method among many others becomes the most representative method.

2. Principle of triboelectrostatic separation

The general process of fly ash decarbonization through triboelectrostatic separation is as follows. Under the triboelectrostatic action, particles with high surface work function (i.e., carbon particles in pulverized coal ash) undergo friction and collision, becoming negatively charged, while other particles (i.e., ash particles) become positively charged [11]. When entering the triboelectrostatic separator of high voltage electric field, both of the charged particles are subjected to the electric field and move along two

* Corresponding author at: Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, China University of Mining & Technology, Xuzhou 221116, China; School of Chemical Engineering and Technology, China University of Mining & Technology, Xuzhou 221116, China.

E-mail address: tyj9000@126.com (Y. Tao).

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completely different or mutually deviation paths and are successfully separated.

To briefly explain separation process of carbon particles from ash particles in fly ash, the force and motion of a negatively charged particle in an electric field are used as an example. As shown in Fig. 1, when the charged particle enters into the high voltage electric field, it simultaneously experiences the horizontal and vertical drag forces from air, electric field force, and gravity. According to Newton's second law, its motion in the field could be described using the following kinetic equations [12]:

$$\frac{d^2\bar{x}}{dt^2} = \vec{E}\frac{q}{m} - 6\pi\frac{\eta}{m}r\frac{d\bar{x}}{dt} \tag{1}$$

$$\frac{d^2y}{dt^2} = 6\pi r\frac{\eta}{m}\frac{dy}{dt} + g \tag{2}$$

where $\bar{x}$ is the particle's transverse displacement, m; y its vertical displacement, m; t its movement time, s; η the gas viscosity, Pa s; m the particle's mass, kg; r its radius (the particle is approximately considered to be spherical), m; $\vec{E}$ the strength of electric field, V/m; q the electric charge carried by the particle, C; and g is the gravitational acceleration, m/s^2.

The physical meaning of Eq. (1) is that the quotient of the resultant force of both electric field force and air's transverse drag force acted on the charged particle to its mass is the transverse acceleration rate of the particle, and the physical meaning of Eq. (2) is that the quotient of the resultant force of both gravity and air's vertical drag force acted on the charged particle to its mass is the longitudinal acceleration rate of the particle.

The integration of Eq. (1) with respect to time finds the particle's velocity as the function of time:

$$\frac{d\bar{x}}{dt} = \frac{\vec{E}q}{6\pi\eta r}\left(1 - e^{-\frac{t}{m/6\pi\eta r}}\right) \tag{3}$$

In Eq. (3), if $t \gg m/(6\pi\eta r)$ or $t \to \infty$, the particle's horizontal velocity before it leaves the electric field becomes:

$$\left(\frac{d\bar{x}}{dt}\right)_{\text{horizontal}} = \frac{\vec{E}q}{6\pi\eta r} \tag{4}$$

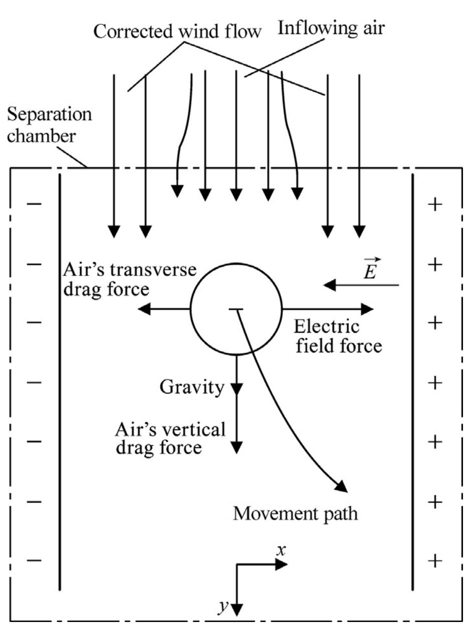

Fig. 1. Forces on charged particle in high voltage electric field.

Under the initial condition, i.e., $t = 0$, $y(0) = 0$ and $dy(0)/dt = V_0$. The coefficient of air resistance to which particles is subjected is defined as $B = 6\pi r\eta/m$.

Integrating Eq. (2) twice with respect to t finds the relationship of the particle's displacement in the y-direction to time as follows:

$$y(t) = \frac{(g + V_0B)e^{Bt} - Bgt - g - V_0B}{B^2} \tag{5}$$

At given B, the particle's movement trajectory is determined by Eqs. (4) and (5). Fig. 2 shows the trajectories of the negatively charged particles with different sizes moving in the electric field. Driven by the electric field, the negatively charged particles move toward the anode, while at the same time the positively charged particles move toward the cathode, thus realizing pulverized coal ash decarbonization separation.

Eqs. (4) and (5) show the trajectory of the charged particles is affected by its mass, charge, and size, as well as by the electric field strength and air flow conditions. The greater the difference in trajectory, the higher the efficiency of fly ash separation. This separation can be achieved by increasing the electric field strength and the particles' electric charge and reducing the negative air flow effect, which is the advantage of the rotational triboelectrostatic separation technology over others [13,14].

3. Experimental system and sample property

3.1. Experimental system

Fig. 3 shows the structure of our rotary triboelectrostatic separation (RTS) system, which consists of the feeding device, rotary charging device, separation chamber, and product collection device.

The basic operation process of the RTS is as follows: (1) Fly ash through the feeding trough together with the inflow air from the vacuum source are injected into the rotary friction chamber; (2) Under the actions of air flow, gravitational force, and high-speed rotation of the friction wheel, fly ash particles bear different magnitude and polarity charges due to their mutual, violent collision and friction (the high-voltage DC source charger is used to accelerate and strengthen the process); (3) All charged particles through the material distributor enter the separation chamber, there positively and negatively charged particles, under the action of high voltage electric field, deviate toward the cathode and anode, respectively, and form their own different trajectories; (4) Finally, these particles with different physical or electric properties are separately collected by the products collector consisting of the vacuum source, small cyclone dust collector, and ore-separating plate, thus completing the whole separation and collection process.

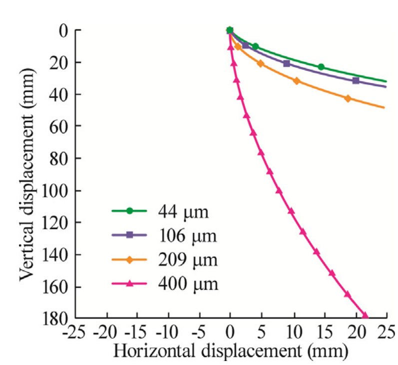

Fig. 2. Trajectories of the negatively charged particles with different sizes.