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Original Research Paper

Numerical simulation on the electric charge decay of micropowder prepared by jet milling/electrostatic dispersion

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ABSTRACT

Preparation of micropowder by the combination of jet milling and electrostatic dispersion is an innovative method. By means of this method, it can achieve the dual goal of producing fine powders and maintaining the dispersiveness. While, the electric charge carried by particles will vanish gradually when refined powder is stored in air, which lead to that the dispersion effect of charged particles will weaken and even disappear. In this paper, a model of electric charge decay of charged particle in air is established, the influence of particle size, relative humidity of the atmosphere, relative permittivity and initial q/m i.e. charge to mass ratio of charged micropowder on the decay process are evaluated. In addition, the non-contact measuring experiment is designed to verify the simulation results as well. The results indicate that the q/m of charged particle decreases as exponential relationship with the storage time, the remained q/m and its decay rate of particle with smaller size is lower during the whole process. The decay rate of charged powder increases with the increase of relative humidity in air. Particles with higher relative permittivity has a lower decay rate of charge, and the decay rate of particles with larger initial charge to mass ratio would also be higher. The numerical results of the model could reveal the rules in electric charge decay process well in general.

1. Introduction

Jet milling is a widely used method to prepare micropowder in the chemical, pharmaceutical and mineral industries since it has a lot of advantages such as the ability to produce micropowder with narrow particle size distribution, absence of contamination, small footprint, low wear rate and noise, and so on [1–3]. As such, it has attracted great interest of many investigators. Shaibani et al. [4] utilized conventional ball milling and target jet milling to produce powders from gray cast iron scraps. Jet milling was demonstrated to be a much more efficient process for making powder from gray cast iron scrap compared with ball milling. Kravchenko et al. [5] examined the effect of ball grinding and jet milling on the particle size distribution and specific surface area of the powders produced from blast-furnace slag, the results showed the effectiveness of jet milling. Ghambari et al. [6] used target jet milling to convert cast iron scraps to powders, and pointed out that the pulverization rate increases with increasing feed rate for particles larger than 45 μm while the rate of production of fine particles decreases. Palaniandy and Azizli [7] carried out fine grinding testwork of talc with jet mill by varying the feed rate, classifier rotational speed, and grinding pressure at five levels. Then the optimum feed rate, classifier rotational speed, and grinding pressure for talc were obtained.

Although jet milling has many advantages, the cohesive forces, especially the electrostatic attraction caused by friction of particles during the process, would lead to the formation of agglomerates which offsets the advantages of jet milling to a certain extent [8–10]. To extend the applications of this method, it is necessary to develop a technique to reduce the agglomerates effectively and to enhance the dispersiveness of the powder in jet milling. The methods relating to dry dispersion could be summarized as following: (1) the dispersion by mechanical flows, acceleration and shear flows; (2) the dispersion by the impact on target; (3) dispersion by mechanical forces [11]. But all of methods mentioned above could not change the surface force between the particles. The stabilization of dispersion could not be achieved and the particles may agglomerate again when the disrupting force is removed. In order to achieve the full dispersion of powder in air, not only does the

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agglomeration process need to be disrupted, but also the dispersion should be stabilized against re-agglomeration. Ren et al. [12,13] and Xu et al. [14] proposed a new idea of the electrostatic anti-agglomeration according to Coulomb's principle, in which the particles would be charged with same charge and dispersed by utilizing coulomb repulsive force among particles. It is reported that the dispersiveness of powder in air could be improved greatly for 72 h-7 days effective time by this method [15]. Masuda [16] analyzed various methods relating to the dry dispersion of fine particles and concluded that the electrostatic charging seems to be a promising new way on this subject.

Hence, we developed a new method for preparation of micropowder by combining jet milling with electrostatic dispersion (denoted *J/E* henceforth). By means of this method, we can achieve the dual goal of producing fine powders and maintaining the dispersiveness. The charging efficiency, flow dynamics, and dispersiveness of the particles during *J/E* process have been studied in research articles [17,18]. While, the electric charge carried by particles will vanish gradually in air, which lead to that the dispersion effect of particles will weaken and even disappear. Up to now, many theoretical and experimental investigations are force on the particle charge process of micropowder [19–24]. However, the research of electric charge decay of charged particle, especially natural decay in air, is rarely reported. In this paper, a model of electric charge decay of charged particle in air is established, the influence of particle size, relative humidity of the atmosphere, relative permittivity and initial charge to mass ratio of the micropowder on the decay process are evaluated. Besides, one kind of non-contact measuring experiment is designed to verify the simulation results as well. The research results are helpful to reveal the dispersive timeliness of charged micropowder prepared by *J/E* method, and provide a theoretical guide for how to maintain the charge on particles for high dispersiveness.

2. Numerical simulations

In this section, the model of electric charge decay of the charged particle prepared by *J/E* method is established first. Then, based on this, the modeling approach, meshing, boundary and initial conditions are explained in detail. Finally, the physical property parameters of micropowders and the simulation parameters are provided.

2.1. Governing equations of particle electric charge decay

The electric charge decay process of the charged particle is very complex as various physical processes may occur simultaneously in that zone. The model would be far too complex if we attempt to consider all possible scenarios. Fortunately, the process of the most importance is the decay process of charged particle, which should be our ultimate concern. All the studies performed up to date indicate that neglecting the subordinate factors in the zone does not significantly affect the results of calculation. Therefore, we believe the physical model can be simplified as follows:

(1) The charged particle can be assumed to be uniform and treated like balls of radius R and density ρ. Hence, the mass of a particle can be expressed as:

$$m = \frac{4}{3}\pi\rho R^3 \tag{1}$$

(2) The electric quantity of charged particle is Q, which is distributed on the particle uniformly. Therefore, the charge to mass ratio of a particle can be expressed as:

$$\frac{q}{m} = \frac{3Q}{4\pi\rho R^3} \tag{2}$$

(3) The temperature of atmosphere remains constant during the process, which has no effect on the decay process.
(4) The particle-particle interactions are neglected as well, for the micropowder prepared by *J/E* method has good dispersiveness, there exists a certain distance between the particles.

When the particle is charged, there is a gradient of electric potential between the particle and the surrounding air, which is the main reason for the loss of charge. According to the Moreau-Hanot and Pauthenier field charging theories [25,26], we believe that the charge decay of ball-like particle is a reverse process. Then, the decay process can be assumed as:

$$Q = \left[1 + 2\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\right] \cdot 4\pi R^2 \varepsilon_0 | -\nabla\varphi | \frac{\tau}{t + \tau} \tag{3}$$

The time constant τ which is given by:

$$\tau = -\frac{4\varepsilon_0 \nabla\varphi}{\vec{j}} = \frac{4\varepsilon_0}{en\mu} \tag{4}$$

Because the large amount of moisture in air may form conductive paths for the charge transportation, here we assumed that the mobility μ of charge is related to the relative humidity of atmosphere:

$$\mu = -A \cdot \ln Hr \tag{5}$$

where, $\vec{j}$ is the density of charge transfer current, φ the electric potential, ε_0 the permittivity of vacuum, ε_r the relative permittivity of particle, A the correction coefficient related to the mobility, Hr the relative humidity of atmosphere, which could be measured with a hygrometer, especially $0 < Hr < Hs < 1$, here Hs is the saturation relative humidity. In a short time step, the decrease of electric quantity on a particle is equal to the amount of transfer current density integrate with the whole particle surface:

$$\frac{dQ}{dt} = -\oint_S \vec{j} \cdot d\vec{s} \tag{6}$$

According to the Gauss divergence theorem, Eq. (6) could be rewritten as:

$$\frac{dQ}{dt} + \iiint_\Omega \nabla \cdot \vec{j}\, dv = 0 \tag{7}$$

On the other hand, based on the basic law of electromagnetism, the relationship between electric quantity and electric potential for the ball like particle is:

$$dQ = 4\pi\varepsilon_0 R d\varphi \tag{8}$$

Hence, the following relationship could be obtained:

$$\frac{dQ}{dt} = \iiint_\Omega \frac{3\varepsilon_0}{R^2} \frac{d\varphi}{dt} dv \tag{9}$$

Combination of Eq. (7) and Eq. (9) results in a nonlinear partial differential equation which governs the evolution of the charge decay:

$$\frac{3\varepsilon_0}{R^2} \frac{d\varphi}{dt} + \nabla \cdot \vec{j} = 0 \tag{10}$$

By solving the above equations, the electric potential and the electric quantity of the particle can be obtained. As such, the charge to mass ratio (denoted q/m henceforth) of particle can be