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The charging efficiency and flow dynamics of micropowder during jet milling/electrostatic dispersion

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ABSTRACT

Jet milling is a highly efficient method for preparing micro-sized powder in many areas of industry. However, aggregation of the micro-sized powder during processing often offsets the advantages of jet milling to a certain extent. In this work, we discuss a new method to prepare micro-sized powder through the combination of jet milling and electrostatic dispersion(J/E). This method helps to achieve the dual goal of producing fine powders and concurrently maintaining the dispersiveness of the powder product. Calcium carbonate ($CaCO_3$) powders with two different mean particle sizes (10.93 and 25.43 μm) were used as raw materials. The effects of the preparation parameters (the charging voltage and the air pressure) on the charging efficiency of the powder were investigated. We have also simulated the flow dynamics of particles in the J/E chamber using COMSOL Multiphysics software. The results indicate that the charge to mass ratio (q/m) of the powder increases with the increase of the charging voltage until it reaches saturation, and the saturation charge of the raw powder with a larger mean size is higher at an air pressure of 0.3 MPa. When the charging voltage was −60 kV, the q/m of the raw powder with a smaller size reached its maximum at 0.2 MPa, whereas that of another type of the powder achieved its maximum at 0.3 MPa. This suggests that the q/m is determined by the competition between the two conflicting factors, i.e. the refined particle size and the charging time, both influenced by the air pressure and the mean particle size of the raw powder at a given charging voltage. In addition, simulation of the flow dynamics reveals that the dispersion of the particles is enhanced during the transport in the J/E chamber, with increases in the jet velocity and the charging voltage. The effect of the charging voltage is more obvious.

1. Introduction

Because of their high specific surface area, high surface energy and activity that may lead to excellent properties, micro-sized powders have been widely used in many industrial application including chemical, pharmaceutical and mineral sectors. Traditional methods for preparing micro-sized powder suffer from impurity contamination, chemical pollution and so on. Jet milling is an innovative method developed in the last two decades that has many advantages such as the ability to produce micro-sized particles with a narrow particle size distribution, the absence of contamination, a low wear rate and noise level, and a small footprint [1–4]. As such, it has attracted great interest of many investigators. Eskin and Voropayev [5] demonstrated some simple methods for calculating gas–solid flows within the nozzles and jets of an opposed jet mill. The efficiency of the particle acceleration throughout the entire system was numerically estimated. It indicates that the air flow has a negligible influence on the process of particle motion within the milling zone. The efforts have allowed the optimal particle size range that can be efficiently milled in the jet mill to be determined. Bentham et al. [6] analyzed particle breakage in a single jet region in the fluidized bed to identify the role of jet hydrodynamics and material properties. The particle breakage in the jet can be estimated by coupling a hydrodynamic model of the jet with the kinetics of single-particle impact breakage. This approach works satisfactorily for a number of particulate solids but poorly for some others. Hoyer et al. [7] evaluated the potential of jet milling for large scale protein-loaded micro-particle production. Thiolated micro-particles prepared by the jet milling technique were demonstrated to be stable and to have controlled drug release characteristics following first-order release kinetics. The studies suggest that jet milling might be a useful tool for the production of protein-loaded particulate drug delivery systems. Ghambari et al. [8] first used target jet milling to convert cast iron scraps to powders, and they 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 (<45 μm) decreases. They also found that the existence of graphite flakes in the cast iron matrix plays the most important role in particle breakage. Shaibani et al. [9] utilized target jet milling and conventional ball 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. What is more jet-milled powder exhibits better compaction behavior than the ball-milled powder, and it did not require any additional treatment before compaction.

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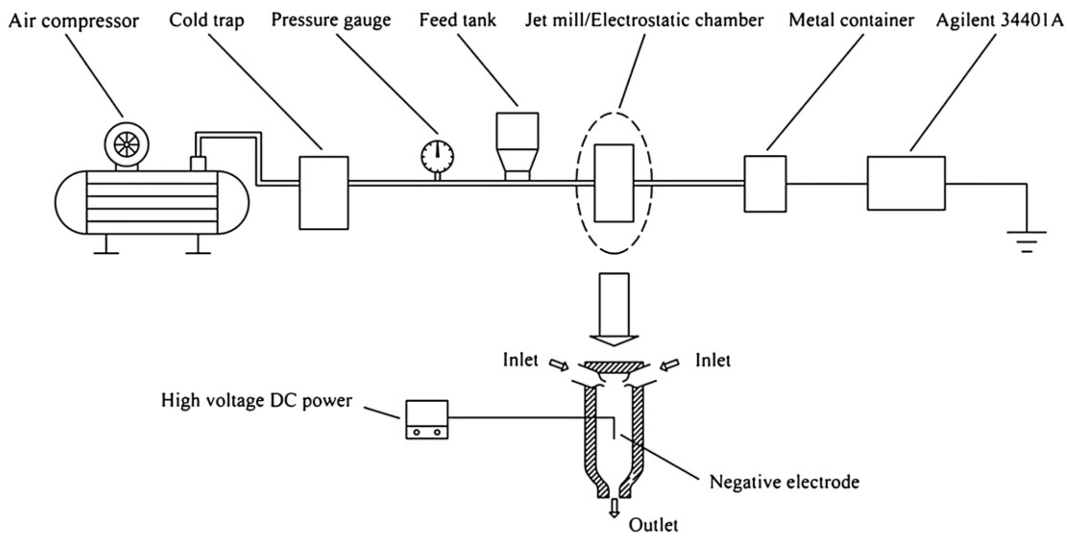

Fig. 1. Schematic diagram of the jet milling/electrostatic (*J*/*E*) dispersion system.

Although jet milling has many advantages, the cohesive forces, especially the electrostatic attraction caused by friction of particles during jet milling process, may lead to the formation of aggregates that offset the advantages of jet milling to a certain extent [10–12]. To exploit its applications, it then becomes necessary to develop a technique to effectively reduce the aggregates and to enhance the dispersion of the powder in jet milling. The current methods associated with dry dispersion of the powder are mainly dependent on mechanical forces or surface modification. Unfortunately, mechanical methods are not able to achieve a stable condition of dispersion because they make little contribution to changes in the surface forces between the particles. The particles may aggregate again when the disrupting forces are removed. Although surface modification enables ultrafine particles against aggregation perpetually, it may change the properties of the powder. This change will more or less influence its subsequent application, and sometimes it may produce a greater negative effect. Therefore, in order to achieve complete dispersion in air and maintain the stability of the dispersion and the inherent properties of the powder, an alternate should be identified.

Electrostatic dispersion is an innovative method to disperse the fine powder in air and was proposed by Ren and Xu et al. [13–15]. It employs electrostatic effects to mitigate or eliminate aggregation, as particles carrying charges of the same sign repel each other. The more the amount of charges the particles carry, the stronger the repulsive force. If the repulsion is larger than the attraction between the aggregated particles, the particles will be dispersed. It has been reported that the dispersion of powder in air can be greatly and effectively improved in 7 days [16]. Masuda [17] also compared various methods for dry dispersion of fine particles and claimed that electrostatic charging is a very promising way to achieve the dispersion of particles in air.

Recently, we developed a new method for the preparation of micropowder that combines jet milling with electrostatic dispersion (denoted as *J*/*E* henceforth). Using this method, we achieved the dual goal of producing fine powders and maintaining the dispersion and the related inherent properties. In the following sections, we will first

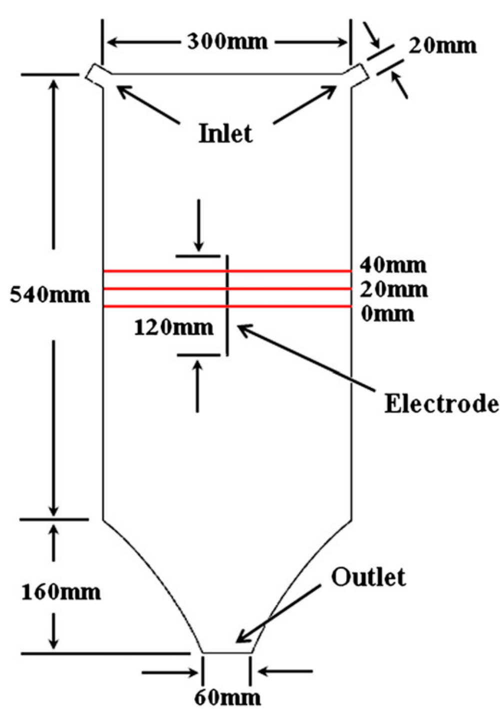

Fig. 2. The size of the *J*/*E* chamber for simulation.

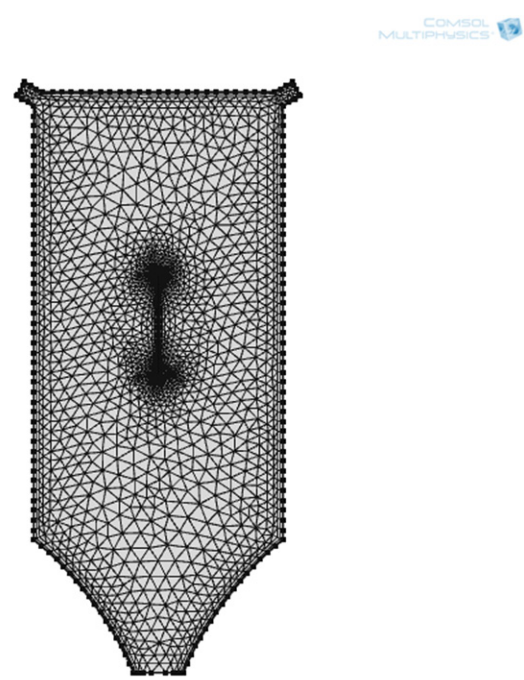

Fig. 3. Schematic of the meshing scheme for finite element modeling of the flow dynamics.