Advanced Powder Technology 28 (2017) 2735–2740

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Analysis of triboelectric charging of particles due to aerodynamic dispersion by a pulse of pressurised air jet

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ARTICLE INFO

Article history:
Received 11 July 2017
Accepted 31 July 2017
Available online 12 August 2017

Keywords:
Triboelectric charging
Powder dispersion
CFD modelling

ABSTRACT

Triboelectric charging of powders causes nuisance and electrostatic discharge hazards. It is highly desirable to develop a simple method for assessing the triboelectric charging tendency of powders using a very small quantity. We explore the use of aerodynamic dispersion by a pulse of pressurised air using the disperser of Morphologi G3 as a novel application. In this device particles are dispersed by injection of a pulse of pressurised air, the dispersed particles are then analysed for size and shape analysis. The high transient air velocity inside the disperser causes collisions of sample particles with the walls, resulting in dispersion, but at the same time it could cause triboelectric charging of the particles. In this study, we analyse this process by evaluating the influence of the transient turbulent pulsed-air flow on particle impact on the walls and the resulting charge transfer. Computational Fluid Dynamics is used to calculate particle trajectory and impact velocity as a function of the inlet air pressure and particle size. Particle tracking is done using the Lagrangian approach and transient conditions. The charge transfer to particles is predicted as a function of impact velocity and number of collisions based on a charge transfer model established previously for several model particle materials. Particles experience around ten collisions at different velocities as they are dispersed and thereby acquire charges, the value of which approaches the equilibrium charge level. The number of collisions is found to be rather insensitive to particle size and pressure pulse, except for fine particles, smaller than about 30 μm. As the particle size is increased, the impact velocity decreases, but the average charge transfer per particle increases, both very rapidly. Aerodynamic dispersion by a gas pressure pulse provides an easy and quick assessment of triboelectric charging tendency of powders.

1. Introduction

During powder transport, particles collide with the containing walls and with each other, resulting in triboelectric charging [1]. Triboelectric charging in powder processing is generally undesirable as it results in reduced powder flowability and can also pose safety issues such as dust explosion. The current state of understanding has been reviewed by Matsusaka et al. [2]. Organic powders such as active pharmaceutical ingredients and excipients are particularly prone to extensive charging [3]. In pharmaceutical industry this can lead to uneven dosage of APIs in formulations. It is therefore important to understand and control the charging behaviour of particles during powder handling.

The charge transfer to/from a single particle impacting a wall has been investigated by various researchers [4–18] and recently reviewed by Matsusaka et al. [2]. The charge transfer in a single impact depends on the initial charge on the particle, the impacting particle velocity which in turn affects the contact area. Based on the work of Matsusaka et al. [19], charge transfer in an impact process takes place during the unloading stage and its magnitude is linearly proportional to the maximum deformed contact area. Matsuyama and Yamamoto [11] found that the charge transfer on impact is dependent on the particle initial charge and there is a limiting value beyond which the particle no longer gains further charges, referred to as the equilibrium charge. Zarrebini et al. [20] used the disperser of Morphologi G3 (Malvern Instruments, Worcestershire, UK) to measure the triboelectric charging of powders and found it to be an efficient way to evaluate the triboelectric charging of bulk solids, requiring only a small sample quantity. The design of this disperser has changed from the metal foil rupture as evaluated by Zarrebini et al. [20] to the one shown in Fig. 1. The capsule comprises two parts, a bottom part having a sample well, where a small quantity of powder is placed and a top part for dis-

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http://dx.doi.org/10.1016/j.apt.2017.07.026
0921-8831/

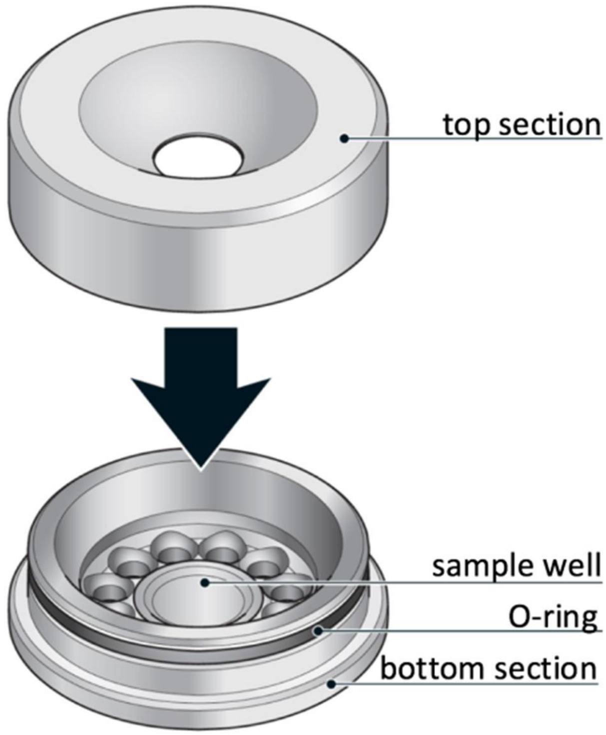

Fig. 1. Morphologi G3 dispersion capsule (courtesy of Malvern Instruments).

persion. The two parts are dovetailed and sealed via an O-ring. A pulse of pressurised air is injected from the top, causing rapid dispersion by collisions of powder particles with surrounding walls within the capsule. The dispersed powder comes out from the bottom outlets of the capsule.

Recently, Alfano [21] used this disperser to characterise the triboelectric charging of pharmaceutical powders. The transferred charge per unit mass (referred to as charge to mass ratio) acquired by the particles was found to be inversely proportional to the diameter of the particles. An inverse relationship was also found between the charge to mass ratio and the volume of sample.

In this study, numerical modelling is carried out to predict the trajectory of the particles, their impact velocities and the corresponding charging behaviour using the new Morphologi G3 disperser. The air flow inside the disperser is turbulent and transient, hence to capture the effect of turbulence on the predicted particles trajectories and impact velocities, Computational Fluid Dynamics (CFD) modelling approach is used.

2. CFD modelling

2.1. Continuous phase

The continuous phase is air and its flow is modelled using the continuity and Navier-Stokes equations [22] with three-dimensional, transient flow assumption. The turbulence is modelled using the scale adaptive simulation model [23] due to its advantage in better prediction of fluid velocity profiles in flows of transient nature. The method gives a better prediction of turbulence compared to the eddy viscosity based and Reynolds Stress turbulence models [24]. The modelling of flow near the wall is carried out using standard wall functions with smooth wall assumption. The air is considered to be compressible as the density of the air is expected to vary significantly due to large variations in pressure particularly at higher inlet pressures.

2.2. Discrete phase

The discrete phase comprises spherical particles which are initially placed in the sample well. The particles get dispersed due to a pulse of pressurised air injected from the top. The coupling between the air and particles is one-way, i.e. the air flow influences the trajectories of the particles, but the momentum exerted by the particles on the gas phase is ignored. This assumption is valid for particulate flows which are very lean. The particle trajectory is computed by solving the equation of motion of particles considering the drag, gravitational and buoyancy forces. A widely used spherical drag law proposed by Morsi and Alexander [25] is used for the calculation of drag coefficient. The dispersion of particles due to turbulence is taken into account by enabling the discrete random walk model [26]. The impact of particles on the walls causes the particles to acquire charges. The charge build-up on the particles is taken into account considering only particle-wall collisions. The charge transfer between particles due to inter-particle collisions is ignored. The space charge effect is also neglected. Similarly, any possible breakage of particles due to high-velocity wall impact is also not considered. The restitution coefficient (defined as the ratio between the rebound and incident velocities) is assumed to be 0.5 for both normal and tangential components for all the particle sizes considered. Charge transfer upon impact is given by:

$$\frac{\Delta q}{\alpha \Delta s} + \frac{q_i}{q_{\max}} = 1 \quad (1)$$

where Δq is the amount of charge transferred to the particle, q_i is the impacting particle charge, q_{max} is the equilibrium charge and

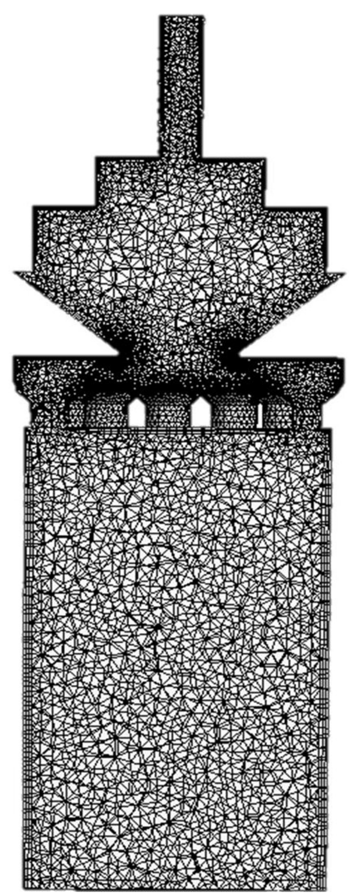

Fig. 2. Cross-sectional view of the mesh used for CFD analysis.