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Electrostatic charging of single granules by repeated sliding along inclined metal plates

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ABSTRACT

In this work, repeated sliding tests for single granules were investigated for their electrostatics generation. Several factors were considered including granule length-ratio, sliding face shape, sliding times, sliding area, sliding velocity, front-facing edge, plate inclined angle and humidity. Generally, it is found that electrostatics increases with granule length-ratio. Two kinds of granular sliding face shapes were used in this work, half circle and rectangle. Under the same working conditions, a granule with the sliding face shape of half-circle tends to produce more electrostatics than that of rectangle. In addition, the efficiency of granule charge generation increases with sliding times although the amount of impact charge is decreased by the initial charge. Electrostatics increases with sliding area, which is independent of granule sliding-face shape and sliding times. Electrostatics also increases with granule sliding velocity. Front-facing sliding with a short edge tends to generate more electrostatics than that with a long edge. In this work, three sliding-plate angles were chosen as 30°,54°,70°, where granules sliding along the inclined plate at 54° acquired the highest electrostatics in comparison with other two angles. Humidity has significant effect on electrostatics as that electrostatics decreases with humidity. At lower relative humidity, the granule length-ratio is found to have more effect on electrostatics.

1. Introduction

Contact or friction charge (triboelectrification) is induced by sudden contact and separation of two materials. The magnitude and the sign of the charge depend on the difference between the work functions or Fermi energy levels of both materials. Triboelectrification has been studied and commercially used for coal cleaning due to its effectiveness and simplicity [1–3] as well as applied for purifying a variety of materials including minerals, PVC and fly ash [4–6] (separating unburned carbon from coal combustion fly ash [4]). Triboelectrostatic separation of fly ash is usually accomplished by triboelectrification of the fly ash passing through two oppositely charged electrodes. Generally, charge generation depends not only on relative conductivities of the materials in contact, but also on the surface situation, such as particle size, shape, the presence of sharp edges, surface roughness, lattice defects, contamination, temperature, humidity [5–7] and so on. In 1969, Cole et al. [8] found that the charge transfer followed a decelerating exponential function with the number of granule-wall collisions and then established one of the earliest theories. Guardiola et al. [9] and Saleh et al. [10] argued that electrostatics increases with granule size as well as the flow velocity of the pneumatic conveying system. In addition, they found that the relative humidity is another significant factor effect on the electrostatics. Ban et al. [11] investigated the characteristics of particle charging and the effects of charging velocity by utilizing a non-intrusive, laser based, phase Doppler velocimeter system, where they gained the charge distribution and the effect of charging velocity on spherical silica particles and some initial separation data for coal and carbon/silica model mixtures. Nomura et al. [12] reported that the absolute value of the saturated specific tribocharging of the powder decreases with increasing humidity. Matsusaka and Masuda [13] developed a novel design on granule charging by repeated impacts on a wall and employed this formulation to investigate a particulate flow system with adjustable amounts of charge, and concurrently they developed a theoretical study to examine the granule charge distribution. Recently, Saleh

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et al. [10] investigated the effects of granule size, solid flow rate, and air velocity on tribocharging. Yao et al. [14] integrated electrometer, electrical capacitance tomography (ECT), high-speed camera and particle image velocimetry (PIV) to investigate the electrostatics of granules in pneumatic conveying systems and confirm an "equilibrium state" for electrostatics generation, which is independent of pneumatic conveying flow rates. When a single granule underwent repeated sliding along the plate, electrostatic charge generated increased with sliding times until reached "equilibrium state" with the equilibrium charge. It is found (Yao et al. [15]) that the equilibrium charge is dominated by several factors, such as sliding area, granule length-ratio, sliding face shape, sliding times, sliding velocity, front-facing edge, and so on.

With more renewable energy generated, power plants across the world have been converted to co-firing with a mixture of coal and biomass as well as solely biomass fuelling. Compared to coal, the shape of biomass particles is complex (enlongated due to their fibrous structure) and the size distribution is over a much wider range. For example, in the work carried by Coombes and Yan [16], the size of willow particle distributes from 180 to 5600 μm. In addition, Guo et al. [17] proposed an integrated model to describe the quantitative relationship between angle of internal friction and granular shape factors, which agreed well with the experimental data. Yao and Wang [18] carried out a comprehensive study of the effects of granular size and shape on electrostatics in recycled pneumatic conveying systems. It is found that granule size and shape causes significant effect on electrostatics generation. On the other hand, electrostatics of granular flow is very complex due to a lot of granules involved in the charging or discharging progress. Investigation of single granules for the impact, contact and behavior may be helpful to fully understand the elementary process of electrostatics generation. "Impact charging experiments" [19–22] for single polymer granules (3 *mm*) were carried out to study the electrostatic charge generation by impact on a metal plate. Single granule with diameter as 30 *mm* was tested for its electrostatics generation by Matsusaka et al. [13] as well as 100 μm granules by Matsuyama et al. [23].

Yao et al. [14,24] and Yao and Wang [18] have done series work involving granular electrostatics in pneumatic conveying systems, where the electrostatics working is very complex i.e. unstable flows, easy-broken pipeline, noises, granule erosion, and granule attrition and so on. As such, a miniature and controllable system was designed in this work, which is able to handle single granule electrostatics generation. So far, there is little publication to make clarification on this point. In this work, more than thousands of granules were processed and the results obtained could meet well with model equations. The equations acquired from the experimental measurement can be used to compare the capability of charge generation via sliding times.

This paper is organized as following. Introduction is listed in the first section. Experimental design is introduced in the second section including experiment apparatus, granule properties and specific experimental design. Some basic variables are defined in this section, including granule, length-ratio, and charge. In the third section, the effects of length-ratio, sliding area, sliding velocity, front-facing edge, plate inclined angle, initial charge and relative humidity on charge generation are analyzed. In the last section, conclusions are summarized.

2. Experiment design

2.1. Experiment apparatus

The experiment apparatus used in the present study is shown in Fig. 1. A stainless steel plate (labeled as 2, thickness 2 mm, length 188 mm) was placed at an inclined position from a stand to allow the sample granule to slide smoothly under the gravity effect. A single granule was put at the top of the pipe and allowed to slide down along the pipe wall and fall into the Faraday cage (3, TR8031, Advantest Corporation, Japan). A high-speed camera (7, OLYMPUS, i-speed LT) recorded the whole sliding process for determination of the sliding time for the respective sliding velocity. The Faraday cage was connected to an electrometer (5, Advantest R8252 Digital Electrometer, Advantest Corporation, Japan) with a cable linked to a computer (6). At each test, electrostatic charges were generated on the granule and the pipe wall with opposite polarity via tribo-electrification, which could be detected by the electrometer (5) as the granule fell into the Faraday cage (3). The data were automatically stored in the computer (6) at intervals of 0.1 s. The mass of single granule was measured using an electronic balance to an accuracy of 10^{-4} g and the mass-to-charge variation of the granule was then calculated. For all test, the metal plate (2), Faraday cage (3) and electrometer (5) were all grounded. A metal plate (8) was used for particles to discharge any residual charges. To achieve a stable (non-rolling) model of sliding, the largest face (shadowed in Fig. 2 (b)) was chosen as the sliding face. In addition, from the movie taken by the high-speed camera (7), the cases of granule sliding were chosen by straight sliding along the metal rather than curve sliding. In this work, 50 half-circle particles and 80 rectangular particles were tested in thousands times.

2.2. Granule properties

Polyvinyl chloride (PVC) granules used in this study have two basic granule shapes: half-circle and rectangular, as shown in Fig. 2 (a) (b). Compositional faces of each basic column are shown in Fig. 2 (b). For rectangular granule (shown in Fig. 2(b)-1), the sliding (shadow) face was in the shape of a rectangle and for the half-circle granule (shown in Fig. 2(b)-2), the sliding (shadow) face was in the shape of a half-circle. Four types of sliding are defined for all granules in Fig. 2(c).

In this work, all tests were carried out with the largest granule face in order to avoid granule rolling or rotating during its sliding on the metal plate, for example, the shape of half-circle was chosen as the sliding surface for a half-cylinder granule and the largest rectangular face was chosen as the sliding surface for a rectangular granule. Single granule size was generally characterized by length (L) and width (W) (shown in Fig. 2 (b)), which was measured by a micrometer to an accuracy of 10^{-4} m. Based on the length and width, the sliding area could be calculated. For all granules tested in this work, the length of the rectangular granules ranges from 2 to 6 mm and corresponding area from 4 to 16 mm^2, the length of half-cylinder granules ranges from 3 to 5 mm with the similar area as rectangular granules.

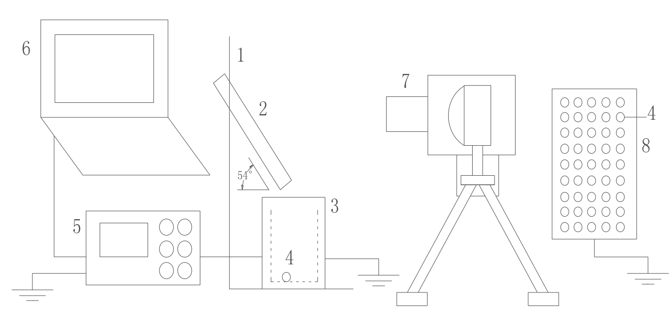

Fig. 1. Particle charging setup: 1. stand; 2. metal plate; 3. Faraday cage; 4. single particle; 5. Electrometer; 6. PC; 7. High-speed camera; 8. metal plate.