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Experimental investigations of granular shape effects on the generation of electrostatic charge

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ABSTRACT

In solid processing systems, electrostatic problems are commonly observed for granules of various shapes. However, a complete understanding of the basic dependence of electrostatic charge generation on particle shape has yet to be established. This observation motivated the present study on examining the effect of granular shape on electrostatics. In this study, polyvinyl chloride (PVC) granules (diameter 1.1–4.1 mm, in the shape of a triangle or trapezium) were first discharged to remove any residual charges and subsequently their electrostatic charging characteristics were studied by allowing a granule to slide along a pipe wall. Several factors such as granular front-facing angle, length-ratio, sliding area, sliding orientation, sliding times, and relative humidity were considered when studying their effects on the electrostatic charging of granules. It was found that triangular granules with smaller front-facing angles tended to generate more electrostatic charge. The amount of electrostatic charge increased with granular length-ratio and sliding area but decreased with humidity. In addition, granular sliding in the orientation of the front-facing angle (for triangular granules) or the short side (for trapezoidal granules) generated more electrostatic charge than that in the orientation of the long side. For both granule shapes, the electrostatic charge increased with granular sliding times and reached a saturated state after around 8–9 sliding movements. The saturated electrostatic charge increased with either granular length ratio or sliding area.

1. Introduction

Granular material is commonly used in solid-handling or pneumatic conveying systems in the energy, chemical, pharmaceutical, and material processing industries. Various shapes of granules are commonly observed in these granular systems because of repeated mechanical attrition (Bemrose & Bridgwater, 1987; Yao, Wang, Lim, & Bridgwater, 2006) caused by the interactions between the granular material and system parts (such as feeder, valves, pipe wall and so on). During these processes, solid particles also have a natural tendency to acquire electrostatic charges (Bi, 2005; Yao, Zhang, Wang, Matsusaka, & Masuda, 2004) through tribo-electrification caused by repeated collisions between particles with surfaces of different material types. This charging process can be responsible for many phenomena occurring in them, such as solid clustering, ignition hazards, and even explosions (Ohsawa, 2003; Watanabe, Ghadiri, Matsuyama, Ding, & Pitt, 2007). Electrostatic effects and the associated charge generation mechanisms are complex phenomena and often dependent on a variety of factors such as the physical, chemical, and electrical characteristics of the material used and the ambient conditions. This may give rise to poor reproducibility of experiments where such phenomena are the main focus of an investigation. As a result, the number of studies reported in the literature which involve measuring or calculating electrical charges on particles in granular flow systems has been limited because of the inherent difficulties in such investigations. Matsusaka and Masuda (2003) developed a formulation for the variation of particle charging caused by repeated impacts on a wall, and employed the formulation to particle charging in a granular flow where each particle carried a different amount of charge. They then theoretically analyzed the particle charge distribution. Later, Matsusaka, Fukuda, Sakura, Masuda, and Ghadiri (2008) developed the theory of the study of electrostatic phenomena caused by impact charging in dilute gas–solid flow, particularly on the

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origin of pulsating electric signals generated in metal pipes. Zhu, Wang, and Lin (2010) developed a complete modeling method for the study of hydrodynamic and electrostatic deposition of dry powders, where the flow field, electric field, and particle distribution were integrated into the simulation. Nwose, Pei, and Wu (2012) developed a coupled discrete element method and computational fluid dynamics (DEM/CFD) for the study of the effects of electrostatic charge on powder flow behavior during die filling in a vacuum and in air, in which long range electrostatic interactions were implemented. In addition, the method of measuring important electrostatic properties, the technique of detecting granule charging, and the application of granule charging were described. Yao and Wang (2006) carried out a comprehensive study of the granular size and shape effect on electrostatic charge in a continuous recycled pneumatic conveying system. Yao, Zhang, Wang, and Liang (2006) integrated various instruments including electrometers, electrical capacitance tomography (ECT), and particle image velocimetry (PIV) to characterize granular behavior and determine the electrostatic equilibrium state for a pneumatic conveying system. Nomura, Satoh, and Masuda (2003) and Guardiola, Rojo, and Ramos (1996) conducted many measurements to confirm that humidity was one of the factors that controlled the electrostatic charging phenomenon.

In this paper, the electrostatic charging of (initially discharged) PVC granules was studied and a simple and effective method was applied to investigate the influence of granular shape on electrostatic charging. Various granular shapes arising from mechanical attrition in a rotary valve (Yao, Wang, et al., 2006) together with the electrostatic charge of single particles after sliding along a metal pipe were characterized using specific charge and specific charge density. Behaviors at the level of single particles were examined. The present study aimed to uncover the effects of granular shape on electrostatic charging at the single-particle level.

2. Experimental

A method similar to that of Yao and Wang (2006) was applied to investigate the effect of granular shapes on electrostatic charging. A granule sample was placed on an inclined stainless steel pipe (54°) and allowed to slide down under the action of gravity into a Faraday cage (TR8031, Advantest Corporation, Japan) placed at the end of the pipe. The Faraday cage was connected to an electrometer (Advantest R8252 Digital Electrometer, Advantest Corporation, Japan) that was connected to a computer. The humidity of the environment was controlled at around 50% and the temperature was maintained at around 28 °C. During each test, the pipe, Faraday cage, and electrometer were grounded. For a single granule with several faces, the most stable face was chosen as the working face to avoid rolling motions as the sample granule slid down (Yao & Wang, 2006). The mass of a single granule was measured using an electronic balance to an accuracy of 10^{-4} g and the mass-to-charge ratio of the granule was then calculated. The length of each side of the sliding face was measured using a micrometer to an accuracy of 10^{-4} m. The sliding area and each angle of the sliding face were then calculated. Sample granules were discharged for at least 24 h before each test. In this study, because of sliding friction, electrostatic charges were generated on the granule and the pipe wall with opposite polarity via tribo-electrification. The electrostatic charge

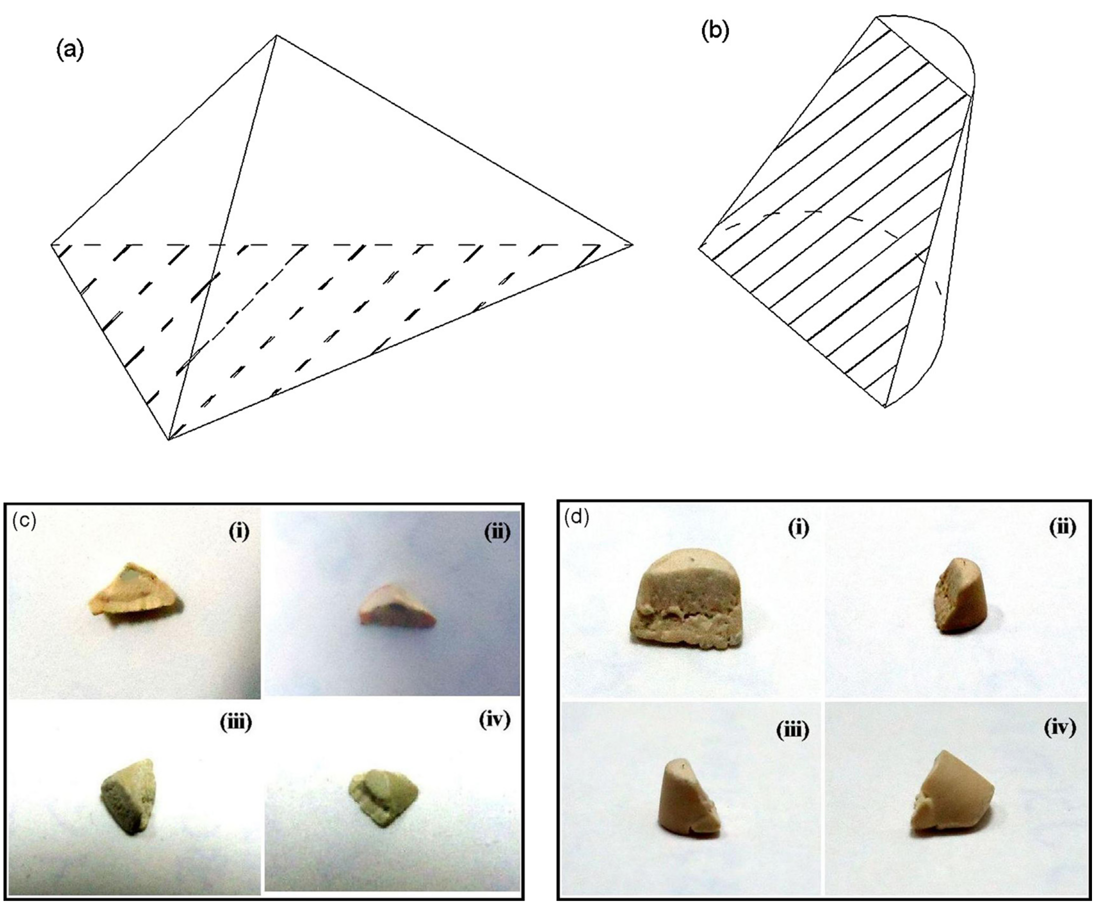

Fig. 1. Granule shape of (a) triangle and (b) trapezium. Microscope images of (c) triangular granule and (d) trapezoidal granule.