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Investigation of granule electrostatic charge generation with normal stress effect

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ABSTRACT

The mechanism of electrostatic charge generation is significant to understand relevant granular electrostatics occurred in granule handling systems. However, the knowledge about single granule charge generation is far from completion. In this work, electrostatic charge generation of single granule sliding along a metal plate was measured and the effects of normal stress in combination with the humidity, saturation and contact area on electrostatics generation were studied. It was found that the electrostatics generated in the process increased with normal stress, which was independent of granule material and humidity. Humidity decreased electrostatics generation but such effect was found to be reduced as the normal stress was increased. In this work, all sampled granules had almost the same increasing rate of electrostatics with time to reach the state of electrostatics saturation. Normal stress was found to be a significant factor effect on the contact area of granule-metal plate.

1. Introduction

In the process of solid-handling, the collisions between granules or granules and walls are inevitable, which are very common in the energy, chemical, pharmaceutical, and material processing industries. Under this condition, the granules become charged and the process of materials charging through contact is called triboelectrification. Such charging process may cause many problems, such as solid clustering, ignition hazards, even explosions [1,2]. In addition, electrostatics discharging also causes a lot of measurement problems and compromises the measuring accuracy even makes the instrument broken. Electrostatics generated in the system may cause non-negligible effect to the measurement. Zhang et al. [3] found that electrostatic charges generated in a pneumatic conveying system caused significant effect on the accuracy of electrical capacitance tomography (ECT) measurements. Yao et al. [4] applied an electrometer (Advantest R8252 Digital Electrometer, Advantest Corporation, Japan) to measure electrostatics in a pneumatic conveying system, where the meter was damaged by the electrostatics discharging. On the other hand, granular electrostatics may bring some benefits to advanced industries. For example, based on the electrostatics generated, some technologies have been developed to measure the flow properties, Xu et al. [5] and Li et al. [6] designed electrostatic sensor array to measure granule velocity in a pneumatic conveying system.

Due to the complexity of influential factors including chemical, physical, the ambient conditions and characteristics of the material used, the mechanisms of charge generation have not been fully understood. Guardiola et al. [7] discovered that electrons transferred from one to the other as two bodies came into contact, and formed an "electrical double layer" of opposite charges, which were located on or near the surface, and the distance between them was only a few molecular diameters. If one body is pulled apart from the other, the electronic equilibrium cannot be re-established, thus one retains more electrons and the other presents deficit. According to the law of conservation of electrons, the amount that one loses equals to that of the other's gains.

In recent half century, electrostatics was widely investigated aiming to clarify the relationship with the influential factors. Guardiola et al. [7] found that the ability of charging increased with granule size and the flow velocity. Ema et al. [8] studied the effect of granule-wall impact velocity as well as the impact angle on the electrostatics generation. Matsusaka and Masuda [9] developed a formulation to evaluate the charge generation by repeated impacts on a wall, which was used to estimate the electrostatics generation and charge distribution. Yao et al. [4] integrated several measurements including digital electrometer, Faraday cage and modular

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parametric current transformer (MPCT) to characterize typical granule flow patterns formed in a pneumatic conveying system under electrostatics effect. In 2006, Yao and Wang [10] continued to investigate granular size and shape effect on electrostatics generated. In the same year, Yao et al. [11] combined digital electrometers, electrical capacitance tomography (ECT) and granule image velocimetry (PIV) to measure and characterize granular electrostatics at the "electrostatic equilibrium state". In 2007, Matsusaka et al. [12] found that the electrostatic charge on particles in solid handling systems could be controlled, not only the polarity but also the amount of charge. More recently, Bunchatheeravate et al. [13] developed a technique to predict particle charge in a straight pipe of any given length, which is applicable to several particle shapes and sizes under the restriction that charge transfer is due to impact charging.

Although a lot of works have been carried out for electrostatics, the working mechanism based on a single granule, for example, the normal stress effect on the electrostatics generation has little been studied. Particularly, the relationship between normal stress and humidity is found in this work. It is known that the normal stress dominates the granule-wall interface touch, which may directly affect the electrostatic charge generation. In this work, a single granule made of PVC was used to slide along an inclined metal plate and generate the electrostatic charge. The normal stress differs with the inclined angle. The electrostatics was measured and the sliding time and distance were recorded simultaneously.

2. Experiment design

2.1. Experimental apparatus

The experimental apparatus used is shown in Fig. 1. The apparatus consists of a stand, two pieces of steel plates (I: thickness 2 mm, length 188 mm, width 60 mm; II: thickness 2 mm, length 550 mm, width 42 mm), a Faraday cage(TR8031, Advantest Corporation, Japan), an electrometer (Advantest R8252 Digital Electrometer, Advantest Corporation, Japan), a computer and a high-speed camera (OLYMPUS, i-speed LT). The Faraday cage was connected to the electrometer and the electrometer was connected to the computer. To avoid surrounding effect, the Faraday cage, plate and electrometer were all grounded. Tweezers were used to carry a single granule on the steel plate that was placed at an inclined position. Under the action of gravity, the granule was able to slide along the inclined plate and fell into the Faraday cage. After each test, the granule was carried out of the cage and put on another metal plate to release the charges on the granule. Such process was repeated for all sample granules. In addition, the sliding process was recorded by the high-speed camera and the granule sliding velocity could be calculated as that the sliding distance was divided by the duration of time taken. The electrostatic charges generated on the granule were measured by the Faraday cage and the data were recorded and stored by the computer automatically at intervals of 0.1 s.

The experiments have two parts. In the first part, 18 white cylindrical PVC (polyvinyl chloride, granule I) granules were tested. The granule details are listed in Table 1. The humidity of the environment was controlled at 50% and 60% respectively for specific test conditions. The surrounding temperature was maintained at 22 °C. The metal plate (length 188 mm, width 60 mm) was mounted on a stand and the inclined angle could be adjusted. In this work, five inclined angles, namely 35°, 40°, 45°, 50°, 55°, were set for the inclined plate. Each sampled granule slid along in a certain length (150 mm) of the metal plate and then fell into the faraday cage. Each granule was tested for three times and the averaged value was obtained in the end.

In the second part, 41 yellow cylindrical PVC (polyvinyl chloride, granule II) granules were tested. The granule details are listed in Table 2. The environment humidity was controlled at the relative humidity RH = 60% and RH = 82%. The environment temperature was set at 22 °C. The inclined angle of the metal plate was set at 36°. The sampled granules slide along the inclined plate within five lengths, as 300 mm, 250 mm, 200 mm, 150 mm and 100 mm, respectively.

2.2. Granule properties

The geometry of Polyvinyl Chloride (PVC) granule used in the experiment is shown in Fig. 2. The granule mass was measured using an electronic balance to an accuracy of 10^{-4} g. The granule height and radius were measured using a vernier caliper to an accuracy of 0.1 mm and the contact area was then calculated. The detail of the sampled granules is shown in Tables 1 and 2.

Granule mass and contact area are known to be two significant elements affecting on charge generation for granule sliding along the metal plane. To compare the property of electrostatic charge

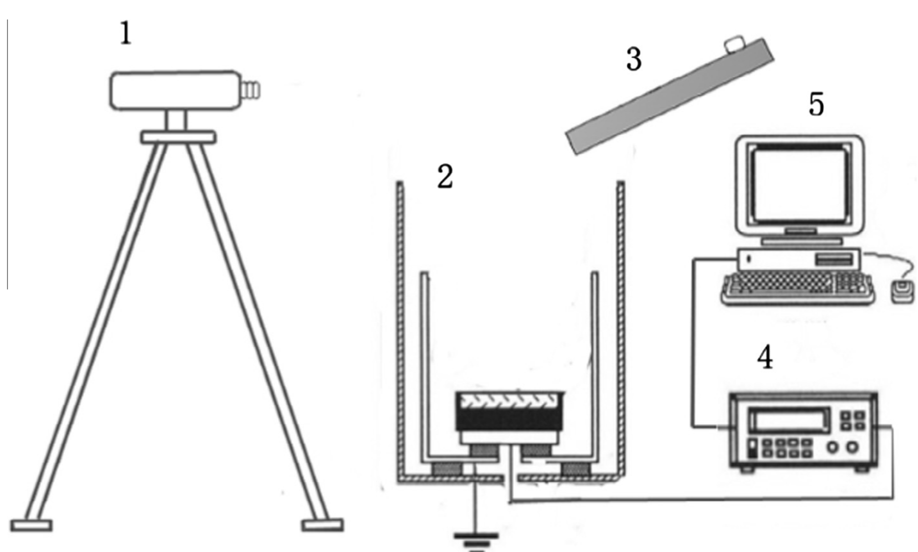

Fig. 1. Experimental setup: (1) high-speed camera; (2) faraday cage; (3) metal plate; (4) electrometer; (5) computer.