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Experimental investigation on electrostatic characteristics of a single grain in the sliding process

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ABSTRACT

Electrostatic charging resulted by sliding contacts of particles and wall is ubiquitous in gas-solid systems. However, the mechanism of sliding electrification involved the initial charge is still unclear. In the current paper, to accurately obtain triboelectric charge, the initial charge and the final charge were measured. A quantitative comparison of the experimental results and the value of theoretical model based on the condenser model is provided. And the results suggest the final charge of the grain is linear with the initial charge for a short sliding distance, whereas the experimental data become scattered for a long sliding length. The longer sliding length generation was found to generate more triboelectric charge, and the influences of the normal load on the triboelectric charge density were analyzed by considering the contact area. It provides a comprehensive perspective that the triboelectrification is fundamentally described as a synergistic effect of the sliding contact area and the real contact area.

1. Introduction

Electrostatic charges of particles are common in gas-solid two-phase flows such as in pneumatic pipelines and fluidized bed reactors. Excessive static charges may affect the bubble hydrodynamics, interfere with the entrainment of particles and cause particle-wall adhesion [1–4]. When the charge reaches an extensively high level, it will cause an electrostatic discharge, even results in fire and explosion hazards [1,5].

The particle-wall contact charging is found to dominate the charge generation in gas-solids pneumatic transport lines [1]. Many investigations have been conducted to study the electrostatic charging in a gas-solid two-phase flow. Masuda et al. [6] paid special attention to the electrification due to collisions between particles and the pipe wall in gas-solids pipe flow. Contact areas and collision numbers were the critical factors for generating static charge in the pipe. He et al. [7] measured the particle charge density in an elbow-type fitting and a straight pipe with a novel dual-material probe. A semi-empirical transferred current model was built, which involved the effects of particle charge density, solid flux, particle collision velocity and angle on charge generation. Grosshans and Papalexandris [8] numerically simulated design parameters and their interactions on the electrostatic charge to minimize the charge of powders in the transport pipes. The simulation showed the charge of powders decreased dramatically with the decreasing of the conveying air velocity.

As the collision electrification of multi-particles with the pipe wall was quite complicated, a simplifying approach by employing a single particle has been performed by many researchers to study the mechanism of the electrostatic charging in the pipe. For the case of particle impact on the metal plate, Noriaki and Yuji [9], and Watanabe et al. [10] found both the impact area and the impact charge were a function of the impact velocity. Meanwhile, the impact charge was linear with the impact area. Matsusaka et al. [11] studied the repeated impacts between an elastic sphere and a metal plate, and the effect of the impact numbers on the transferred charge was analyzed. The results suggested that the charge of the sphere increased with the number of impacts and then approached an equilibrium value. In experiments of Yamamoto and Scarlett [12], particle charges before the impact and after the impact were detected by two Faraday cups to investigate the effect of the initial charge on the impact charge. Results manifested that the impact charge was relevant to both the initial charge and the surface work functions. Matsuyama and Yamamoto [13] investigated the electrification of single polymer particle with two separated targets for successive impacts. The first impact charge was found to be linear with the initial charge which was consistent with their previous work. The influence of the initial charge on the impact charge was also reported by Chowdhury et al. [14] in a single particle-metal collision test.

The correlation of the contact electrification in conjunction with the initial charge, the contact area, and impact numbers has been previously represented by a condenser model [10,14]. In dilute phase pipe flow, the static electrification of particles was mainly attributed to the collisions with the pipe wall [15]. Hence, many researchers employed the capacitor charging model in the gas-solids pipe flow [9,11,16]. The charge

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(a) POM grains

(b) PA grains

(c) HDPE grains

Fig. 1. Pictures of test grains.

density followed an exponential equation as a function of pipe length, which the specific charge enlarged with the pipe length, and then reached a saturated value.

However, when dealing with the situation of the partial slip at the tube wall in a gas-solid pipe or the plug flow in the dense phase pneumatic conveying line, frictions will be the dominant pattern between particles and wall rather than collisions [17,18]. Elsdon and Mitchell [19] measured the charge generated by rolling or sliding contact between a sphere and an insulated sheet. Polar polymers became

Table 1
Properties of grains in the experiment.

Grains	Height/mm	Diameter/mm	Roughness/μm	Density/g·cm^{-3}
POM #1	3	6	5.57	1.41
POM #2	6	6	6.18	1.41
POM #3	9	6	8.81	1.41
PA#1	3	4	6.80	1.13
PA#2	6	4	11.00	1.13
HDPE	5	5	2.59	0.95

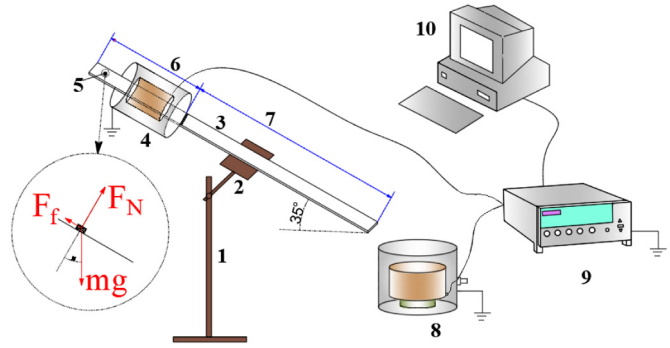

Fig. 2. Scheme of the experimental apparatus. 1. Stand, 2. Pallet, 3. PVC plate, 4. Throughout-type Faraday Cup, 5. single grain, 6. Induction segment, 7. Effective friction segment, 8. Faraday Cup, 9. Electrometer, 10. Computer.

positively charged when sliding with both metals and non-polar polymers. The relationship with the normal contact force and the charge density has also been revealed that the charge per unit length was directly proportional to the square root of the normal load. Several authors have reported the friction electrification experiments for identical samples [20–22]. Shaw and Hanstock [20] supposed that the asymmetry of friction generated different surface strain which in turn causes charge transfer. Henry [21] stated that the temperature difference caused by the frictional heating yielded the exchanged charge of the specimen slipping over the plate. On the contrary, the results by Lowell and Truscott [22] indicated neither the sliding speed nor the temperature difference was associated with the generation of electrostatic charge. It was the electron states rather than the physical distinctions resulted in net charge transfer during the asymmetric rubbing. Ireland [23] proposed that the sliding could provide a cumulative surface area by changing the contact pattern. Then Ireland built a novel model of dynamic particle-surface tribocharging by taking the work of sliding friction at the interface into consideration [24]. Yao et al. [25] performed repeated sliding charging experiments using single granules sliding against a metal plate. Granule length-ratio and sliding face shape were suggested to play roles in charge generation. During the same sliding process, a semi-cylindrical granule generated more electrostatic charge than a rectangular face. Furthermore, results indicated the length-ratio and the sliding area affected the equilibrium charge of the granule significantly. Using the same experimental apparatus, Zhao et al. [26] stated electrostatic charge increased with sliding area and sliding speed.

Although efforts to study the electrostatic charge of sliding friction on the wall of single particles have been undertaken as well, the mechanism of charge transfer for the sliding electrification is still lack of understanding. Little consideration of the initial charge of the particle

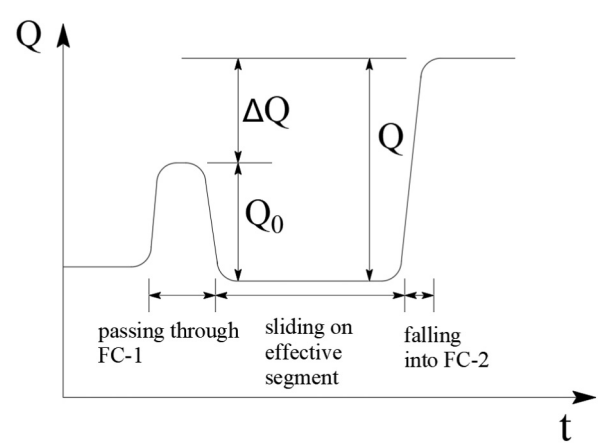

Fig. 3. The charge signals versus time.