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# Numerical analysis of contact electrification of non-spherical particles in a rotating drum

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ABSTRACT

Contact electrification is generally referred to as the charge transfer process between particles during collisions. The transferred charge can be accumulated on the surface of the particles especially for insulating materials with irregular shapes, which can lead to a non-uniform charge distribution and eventually affects the charge accumulation process. In this study, in order to investigate the influence of the particle shape on contact electrification, a sphere-tree multi-sphere method and a contact electrification model are implemented into the discrete element method (DEM) to model the charging process of irregular particles in a rotating drum. Irregular particles with various Sauter mean diameters but the same maximum diameter and equivalent volume diameters are considered. The charge distribution and accumulation on the particles are investigated. It is found that the charge transfer originates from the contact between the particle and the drum due to the contact potential difference and initially takes place primarily at the region near the wall of the drum. The charge eventually propagates to the entire granular bed. The charge of the particles increases exponentially to an equilibrium value. For particles with the same maximum diameter, a larger charging coefficient is obtained for the particles with smaller Sauter mean diameters and sphericities, which leads to a faster charge accumulation, while for particles with the same equivalent volume diameter and fill ratio, similar charging coefficients are observed. A non-uniform intra-particle charge distribution is induced on each individual multi-sphere particle.



## 1. Introduction

Contact electrification is generally referred to as a charge transfer process between objects during collisions [1,2]. It occurs commonly in powder handling processes where particles can have intensive mechanical contacts. During the contact, electrostatic charges migrate from one surface to another and accumulate on the particles. The transferred charges can be retained on particle surfaces especially for insulating materials [3,4], which can lead to a non-uniform charge distribution and eventually affect the charge accumulation process. The accumulated charges on particle surfaces will induce electrostatic interactions that can significantly influence the dynamic behaviours of particles, especially when the electrostatic forces become dominant over the gravitation of particles [5]. It can cause segregation [6], agglomeration [7–9], suspension [10] and even explosion [11] within the particle system. These phenomena are usually detrimental and can extremely diminish the performance of powder handling processes. Therefore, the investigation of the charge transfer and accumulation is of the fundamental importance to minimize the electrostatic effects and improve the performance of powder handling processes.

The charge acquisition and distribution within the particle system, which are also called inter-particle charge acquisition and distribution, were investigated experimentally and numerically [2,12–14]. LaMarche et al. [12] examined the charging process of dielectric particles flowing through a metal cylinder and showed that the net charge on the particles increased linearly with an increase in the contact surface area between the particles and the cylinder, while the net charge density of the powder was greater in the region close to the wall compared with that at the centre. They attributed this to the fact that the charge acquisition of the powder initially occurs primarily during the contact between the particles and the cylinder. However, it is extremely difficult to obtain detailed information from each particle in the dynamic system experimentally [15–17]. Therefore, the discrete element method coupled with computational fluid dynamics (DEM-CFD) has been widely used to explore the physical and mechanical behaviours of each individual particle and subsequent bulk properties of the particle system. Pei et al. [13] used the DEM-CFD implemented with a contact electrification (condenser) model to compute the charging process of particles in a fluidized bed. It was found that the electrostatic charge was initially generated after the impact between the particle and the container surfaces in the side regions close to container surfaces due to different

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work functions between particles and container surfaces. Then the charge propagated from the side regions to the central region of the granular bed. Eventually, the charge of the particle system reached an equilibrium state. These phenomena were consistent with the experimental observations of LaMarche et al. [12] and Guardiola et al. [14].

The charging process becomes more complicated when particles of irregular shapes are involved [18–22]. Yao et al. [18,19] investigated the effect of the particle shape on the charging process when the particle is sliding on the surface of a stainless steel pipe. In their study, the polyvinyl chloride (PVC) granules were made into triangular and trapezoidal shapes. Due to the shape difference, particles with larger sliding (contact) area obtained higher electrostatic charge. They also suggested that the particle orientation influenced the sliding velocity. The particles with an orientation which can induce a larger sliding velocity acquired high charge in the process. For insulating materials, the electrostatic charge can concentrate on the contact area and lead to an intra-particle charge distribution on the surface of each particle. Ireland [21] modelled the charge transfer between a 2-D elliptic particle and a tilted surface during impact using DEM. The surface of each particle was divided into segments and the charge was only transferred onto the segments inside the contact area because of the insulting nature of the particle. It was shown that for the contact electrification of an elliptic particle impacting (bouncing) on a surface, the particle with a lower roundness ratio (defined as the ratio of radii between the major axis and the minor axis) led to a larger contact area. In addition, the transferred charge was larger with a larger contact area, which meant that the contact and charge transfer process could be affected by particle shape. Pei et al. [20] investigated the intra-particle charge distribution of elongated particles in a vibrating container. Using the symmetric multi-sphere method [23], the elongated particle was approximated by a row of axisymmetric primary spheres with various sizes. Due to the shape effect, the elongated particles tend to be orthogonal to the vibrating direction and parallel to the top and bottom surfaces, which causes that the larger primary spheres have higher contact rates with container surfaces and other particles and consequently obtain higher charges especially at the early vibrating stage. In other words, for convex elongated particles, the central part of the particle was larger and easier to make contact with the container surface and acquired charge, while for concave elongated particles, the distal part of the particle was larger and more vulnerable to get charged during the vibration. This reveals that the particle shape can cause non-uniform intra-particle charge distribution and consequently different charging behaviours. Matsuyama et al. [22] suggested that the induced potential difference was mainly induced by the local transferred charge at the contact area while the charge at the remote (rear) side to the contact area had less effect on the induced potential difference. Therefore, the particle shape can affect inter- and intra-particle charge distribution and accumulation. However, the study on these effects is still inadequate especially for more complex shapes and various powder handling processes.

In this paper, charge distribution and accumulation of irregular particles in a rotating drum is analysed using DEM implemented with a contact electrification model. A multi-sphere method is used to approximate the particle shape that is illustrated in the next section. The particle profiles and charging process in the rotating drum are presented and discussed. In addition, the intra-particle charge distribution is also examined.

## 2. Methodology

### 2.1. The multi-sphere DEM model

In practical powder handling processes, the shape of the particle is usually non-spherical and irregular. The irregular particle shape can lead to various dynamic behaviours and alter the charging process during powder handling processes. In the current study, to investigate the effect of the particle shape on contact electrification, the particle shape is approximated using a sphere-tree multi-sphere method [24,25]. For instance, the geometry of the particle can be represented by a 3D object. Then the surface of the particle is meshed into triangular elements and the particle is represented using a polyhedron (Fig. 1). The sphere-tree construction toolkit (http://isg.cs.tcd.ie/spheretree/) developed by Bradshaw and O'Sullivan [25] is then used to construct the particle (multi-sphere) with a selection of primary spheres of various sizes to approximate the shape of the meshed particle.

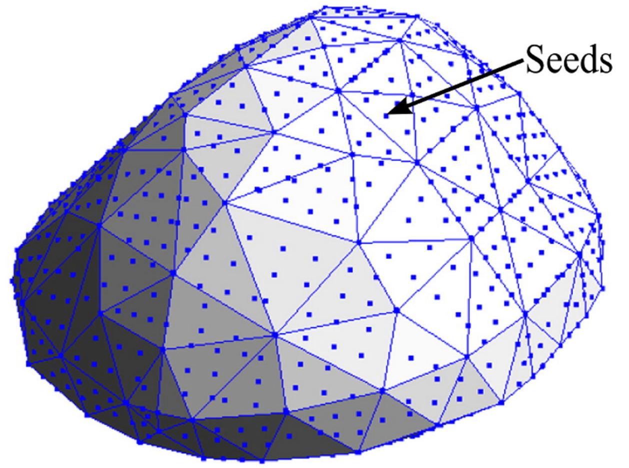


**Fig. 1.** The meshed particle with sample seeds on the surface.

The medial axis approximation method is used to generate the multi-sphere assembled by primary spheres [25]. First, the surface of the polyhedron is sampled with a number of seeds as shown in Fig. 1. Secondly a Voronoi diagram with connected cells is constructed so that each Voronoi cell represents the region of space that is closer to its corresponding seed than any other seeds. Then primary spheres can then be generated within cells and scaled to fit the surface with optimised coverage, e.g., the smallest distance between the seeds and the surfaces of the primary spheres, as shown in Fig. 2.

A merge optimization method can also be used to control and reduce the number of primary spheres [25]. In this method, each pair of neighbouring spheres are merged and approximated by a new parent sphere that should contain the same set of surface seeds covered by the child neighbouring pair. This method can be iterated until the desired number of primary spheres is reached as illustrated in Fig. 3. This

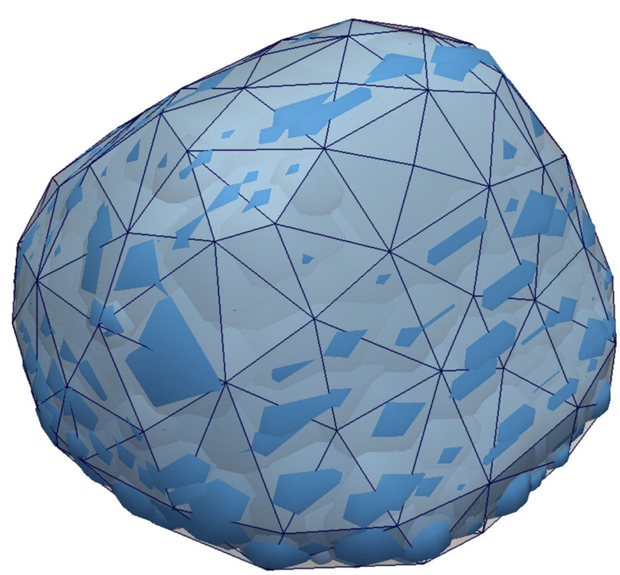

**Fig. 2.** The multi-sphere generated with 500 primary spheres by the medial axis method.