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Methodology for studying particle–particle triboelectrification in granular materials

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ABSTRACT

A critical challenge for experimental studies of triboelectric charging is to generate reproducible and unambiguous data that can be linked to theoretical concepts. We have developed a methodology to investigate the triboelectric charging of granular materials due solely to particle–particle interactions (i.e. no particle–wall interactions). The methodology is based on a particle flow apparatus that generates a fountain-like flow in which the particles contact only other particles, but no equipment surfaces. Non-contact methods of measuring charge and separating particles by charge are employed so that probe-particle charging does not occur.

1. Introduction

Triboelectric charging of granular systems is widely observed in industrial [1] and natural [2] systems. The particle polarity is determined by the material properties (in a way that is not understood), as described empirically by the triboelectric series [3]; the charging process is currently so poorly understood that it is not even clear whether it is the transfer of electrons or ions that causes charging [4,5]. To make progress in this regard, it is important for experiments to measure properties under well defined conditions. For example, a flowing granular material can become triboelectrically charged due to interaction with other particles or external surfaces. In general, particles will become charged by both types of interactions, which complicates a theoretical understanding of the charging process. In this paper, we develop a methodology to address the triboelectric charging due only to particle–particle interactions.

Many industrial processes have long been troubled by triboelectric charging of powders and particulate systems. In the pharmaceutical industry, many products are produced in granular form and triboelectric charging can cause these particles to aggregate, leading to quality control problems of the final product [6]; this is an important issue, as eighteen percent of FDA recalls are due to potency or content non-uniformity [7]. Similar problems can occur in pharmaceutical application: for example, the triboelectric charging during dispersal from dry powder inhalers can cause problems with drug delivery [8]. Triboelectric charging is known to cause problems for polyolefin production in gas-phase polymerization reactors, where the charging can cause resin particles to adhere to the reactor wall and to each other, which can ultimately lead to formation of polymer sheets that necessitate a reactor shut down for removal [9]. Dust explosions can be caused by triboelectric charging of particles, where the electric potential difference between particles causes electrical breakdown that can ignite flammable dust particles [10].

Triboelectric charging commonly occurs in numerous natural phenomena. Lightning is produced by the triboelectric charging of dust and ice particles, producing large electric potentials that lead to electrical breakdown [11]. In dust devils, large bipolar electric fields, with electric potentials of several thousand kilovolts, are generated by the triboelectric charging of sand or dirt [12]; these large electric fields have the potential of damaging electronic equipment [13]. In volcanic plumes, the ash particles charge by contact with other ash particles, producing electric potentials large enough for gas breakdown (volcanic lightning) [14].

Laboratory experiments have been used to investigate the factors which lead to triboelectric charging of granular systems. The sign and magnitude of the charge transferred between particles depend on several factors such as particle composition, particle size and shape, impurities and relative humidity [15]. It is advantageous to reduce the number of variable parameters in order to investigate the effect of individual variables. A controlled environment will

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limit charging caused by impurities and humidity, and so triboelectric experiments are often performed in vacuum [16].

Various experimental configurations have been used to determine the triboelectric charging of granular materials. However, in all these cases, charge transfer may occur between equipment surfaces and the particles, so that the charging due to particle–particle interactions is not isolated. Previous studies used fluidized beds to charge particles and then used planes [17], cups [18,19] or powder pumps [20] to transfer the particles to measuring instruments. The particles may be separated by charge via an external electric field before the charges are measured [20]. Vertical arrays of Faraday pails have been used to separate particles by both size and charge [21,22].

Measuring the charging behavior of the particles inside a fluidized bed would eliminate undesirable charging with equipment surfaces as the particles are transferred and thus allow a measurement of the charge due only to particle–particle interaction. In this regard, Murtomaa et al. designed a ring probe that moves up and down outside of the fluidized bed wall, measuring the electric potential within the bed as a function of height [23].

We describe here a methodology to investigate triboelectric charging due strictly to particle–particle interactions. This methodology is based on three key ideas: (1) a particle flow apparatus that causes contact between particles but not with other surfaces; (2) a non-contact method of measuring the magnitude of electrostatic charging; and (3) a non-contact method for separating particles by polarity of their charge.

2. Experimental setup

2.1. Particle flow apparatus

An apparatus, shown in Fig. 1a, has been designed for studying the triboelectric charging arising solely from particle–particle

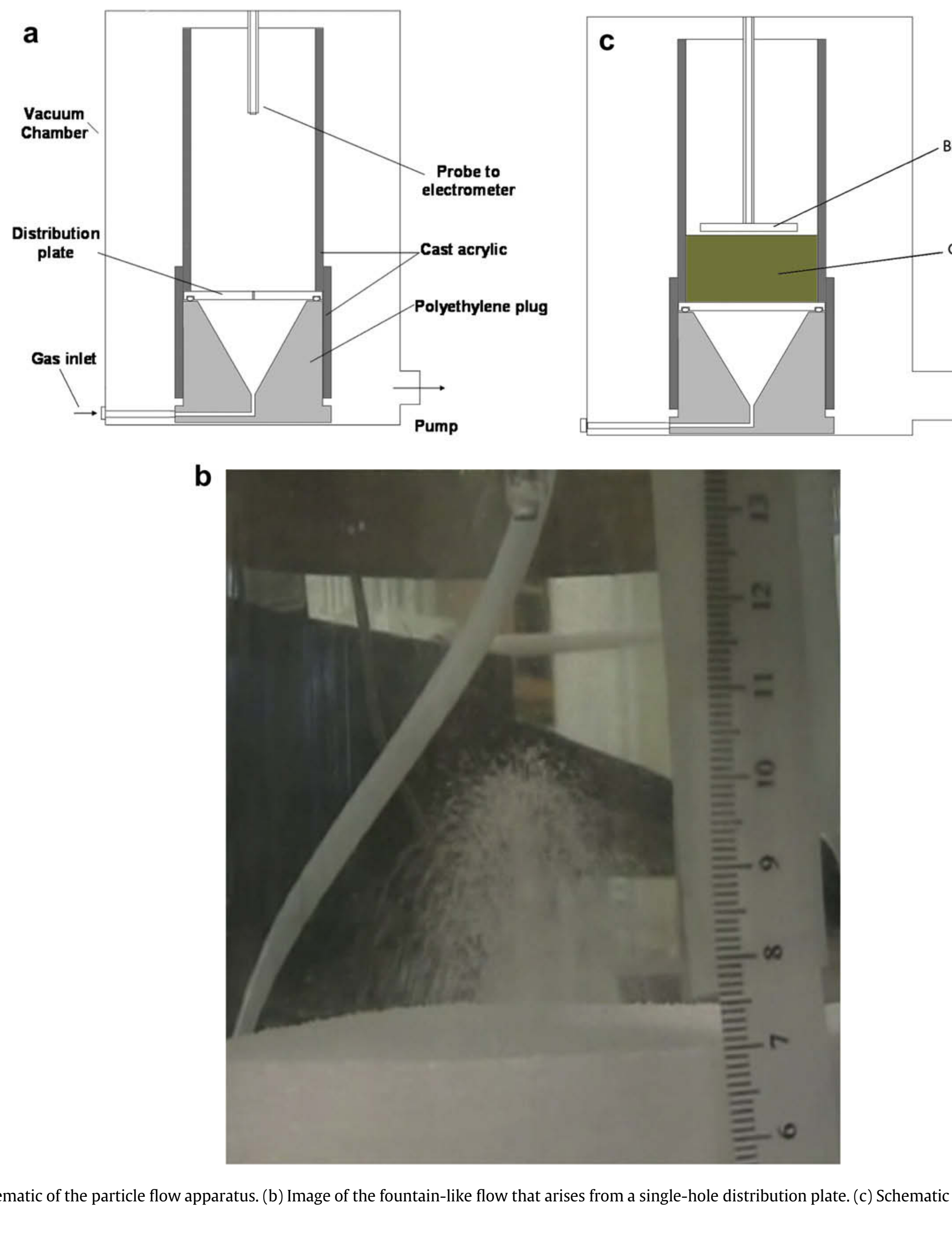

Fig. 1. (a) Schematic of the particle flow apparatus. (b) Image of the fountain-like flow that arises from a single-hole distribution plate. (c) Schematic of charge separation apparatus.