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Influence of the geometrical parameters of a dielectric barrier discharge reactor on the subsequent tribocharging of granular polymers

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ABSTRACT

Tribocharging of insulating materials is a pivotal step in several electrostatic applications in which the charge value has an important consequence on the outcome of the process. The Dielectric Barrier Discharge (DBD) at atmospheric pressure is an excellent energetic plasma source having the aptitude to change surface properties and, thereby, to enhance triboelectric charging of granular insulating materials. This paper aimed to investigate the influence of dielectric barrier geometrical parameters on the triboelectric charge of the DBD-treated Polypropylene (PP) and Polyvinyl Chloride (PVC) mm-size granules. The studied parameters include the air gap between the upper barrier and the surface of the granular layer, the number of granular layers, as well as the material forming the dielectric barrier and its position. After being treated for 3 s, the granules were triboelectrically charged in a vibratory device for 2 min. The charge the DBD-treated and untreated particles acquire by tribocharging was measured using a Faraday pail connected to an electrometer. Experimental results show that the air gap and the properties of the dielectric barrier can influence the mean value of the discharge current and enhance significantly the triboelectric charge of DBD-treated granules. Best results were obtained when the air gap did not exceed 4 mm and material with high permittivity was used as a barrier.

1. Introduction

Triboelectricity and the consequent electrostatic discharges have long been known to cause a multitude of more or less serious problems in many industrial processes [1,2]. However, the triboelectric effect is more and more used as a charging mechanism in several electrostatic applications, such as: separation of insulating materials from granular mixes [3–5], triboelectric based sensors [6,7], energy harvesting [8] … etc. In each application, the result of the process depends on the triboelectric charge level acquired by the materials. Therefore, it is very important to improve the triboelectric charging methods of the processed materials in relation with the requirement of each specific application.

Triboelectricity is a phenomenon of electric charge transfer between two bodies brought into contact; after their separation, one material acquires positive and the other negative in into contact [9]. Charge exchange between insulators in contact can occur by one or several of the following physical mechanisms: electrons [10], ions [11], or material transfer [12].

The electrostatic separation of the constituents of granular insulating mixtures is a major domain of application of the triboelectric effet. In the recycling industry, for instance, the plastic wastes are usually crushed and screened to obtain a granular mixture (typical granule size: 5 mm), which is then charged in appropriate tribocharging devices. Finally, the tribocharged granules are separated in a high-intensity electric field. The outcome of the process depends on the combined action of mechanical and electrical forces [13]. Therefore, in order to improve the rate of recovered products, the granules must acquire a high charge so that the electrical forces could overcome the mechanical forces.

Several previous studies have attempted to improve the design of tribocharging devices and optimize their operation. They recommend the increasing of charging time and air speed in the case of fluidized bed devices [14–16], and applying higher voltages to the electrodes of the separators [16]. However, these solutions for enhancing the tribocharging effect require high energy consumption, an issue that hampers their wider industry application.

The Dielectric Barrier Discharge (DBD) in atmospheric air is known to change the surface properties of polymers. Some studies on surface treatment modification have shown that DBD changes the surface roughness [17] and enhances the wettability (hydrophilic properties) [18,19]. This energetic plasma source has the aptitude to

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Table 1
Main physical properties of the granules of plastics employed in the experiments.

Granule	PVC	PP
Colour	Grey	Yellow
Average mass [mg]	25	20
Dielectric rigidity [kV/mm]	14–20	22–25
Density [kg/m3]	1300–1580	890–910

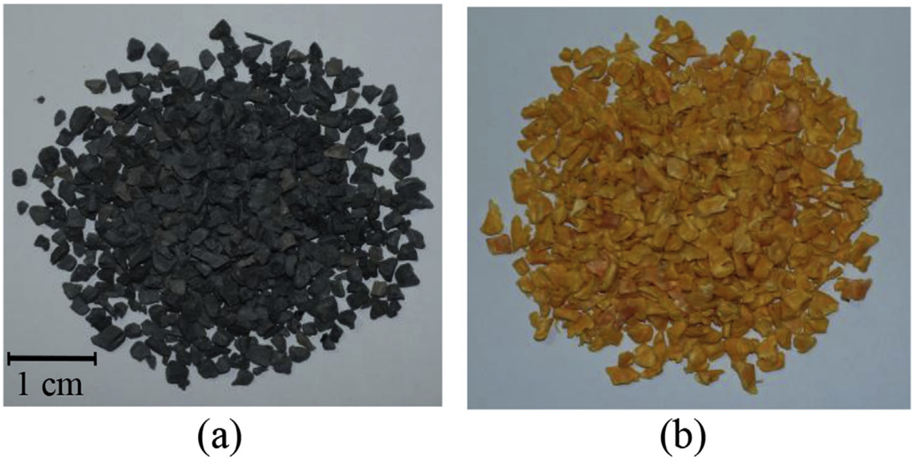

Fig. 1. Photograph of insulating particles: (a) PVC; (b) PP.

modify the surface properties and, thereby, to enhance triboelectric charging [20,21] or to neutralize charged granular insulating materials [22]. Recent researches about the enhancement of the triboelectric charge of insulating granular using DBD surface treatment technique have pointed out the effect of several electrical parameters such as: signal shape, exposure duration, voltage amplitude and frequency [23,24].

The interaction between the energetic plasma species [25] and the surface of the polymers increases the roughness of the latter and also its wettability by grafting polar groups [21]. The increase in roughness is accompanied by the creation of new charge traps on the surface. The importance of surface roughness and its influence on triboelectric process for a sliding contact between polymeric plate materials has been emphasized by Neagoe et al. [26]. During the sliding contact, a point from one of the surfaces makes several contacts with the points of the other surface. The more the points of contact are, the higher the triboelectric charge acquired by the two bodies. On the other hand, the increase in wettability leads to an increase in the surface conductivity of materials by absorbing moisture. Therefore, modification of surface properties by DBD plasma may enhance the triboelectric charge.

The aim of the present paper is to evaluate the effect of the geometrical parameters of a DBD in ambient air, on triboelectric charging of the non-thermal plasma-treated granular plastics wastes. Such DBD has the advantage of needing no expensive gas supply and pumping systems. The studied parameters include the air gap length, the number of granular layers, as well as the material of the dielectric barrier and its position. Granular Polyvinyl Chloride (PVC) and Polypropylene (PP) samples were employed to carry out the experiments in this study, as they are widely used in industrial applications. Large quantities of wastes containing these plastics should be recycled, and electrostatic separation might be the best way to do it.

2. Materials and methods

2.1. Granular samples

This study was made on samples of PVC and PP granules, originated from waste electric and electronic equipment (WEEE), processed by APR2 Company, Bonnières-sur-Seine, France. The main physical properties of the two granular materials are given in Table 1; their aspects and sizes can be examined in Fig. 1. The particles have irregular shapes, with their longest dimension up to 4 mm and 6 mm for PVC and PP, respectively. The shortest dimension was roughly 2 mm ± 0.2 mm.

2.2. DBD experimental set-up

The PVC and PP samples were treated separately by a DBD in atmospheric air. The electrical parameters were fixed in all experiments. The experimental setup is shown on Fig. 2. A square waveform signal was produced by a function generator (Yokogawa FG300), and the treatment duration was $t = 3$ s. The amplitude and the frequency of the voltage provided by this generator were fixed at 20 V and at 800 Hz respectively. This signal was applied at the input of a high-voltage power amplifier (Trek model 30/20A; amplification ratio 1 V/3000 V) that supplied the electrodes of the DBD reactor. The voltage and current waveforms at the output of the amplifier were recorded using a digital oscilloscope (Lecroy, model Waveace 1001). The DBD system consisted of two parallel aluminium disk-type electrodes (75 mm diameter, with a thickness of 10 mm). The upper active electrode could be moved up and down to change the air gap length, while the grounded electrode was fixed. Two square plates (150 × 150 mm, with a thickness of 5 mm) were used as dielectric barriers, one posed at the surface of the lower grounded electrode and the other placed next to the upper active electrode.

In most of the experiments, 7 g granular samples were carefully deposited as a 2 mm ± 0.2 mm thick monolayer at the surface of the dielectric barrier of the bottom (grounded) electrode. All samples were neutralized using a commercial AC corona air ionizer before being exposed to DBD plasma.

To obtain a double or a triple-layer, 14 g and 21 g of granules were respectively spread on the same area as the 7 g samples. The air gap length was measured from the upper surface of the mono- or multi-layer of particles to the surface of the dielectric layer of the upper (active) electrode of the DBD reactor.

Based on the results of several preliminary experiments, four adjustable geometrical parameters of DBD were considered, namely: the air gap length, the number of dielectric layers, the nature of the