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Effect of atmospheric dielectric barrier discharge treatment on the triboelectric charging properties of brominated Polyethylene granules

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Abstract. This paper aims to investigate the effect of dielectric barrier discharge (DBD) plasma treatment on the triboelectric charging properties of granular materials containing brominated flame retardants (BFRs). This work focuses on the impact of treatment time and the applied voltage frequency. Experiments were carried out on Polyethylene (PE) particles containing 40000 ppm of bromine (PE 4.6 % of Hexabromobenzene) and BFR-free PE. The DBD treated particles were then charged by triboelectric effect in a multi-cylinder device. The triboelectric charge acquired by each sample was quantified using a Faraday cage connected to an electrometer. The humidity of the ambient air ranged between 51 % and 60 % and the temperature varied from 16.5 °C to 19 °C during the experiments. Results show the significant influence of DBD treatment time on the triboelectric charging of brominated and non-brominated PE granules. In case of brominated PE, the particles acquire less charge than the non-brominated ones. Furthermore, it was found that the charge of DBD-treated particles is influenced by the applied voltage frequency. The observed variation in triboelectric behavior may be attributed to the changes in the roughness and wettability of the polymer surface caused by DBD.

1. Introduction

The rapid and continuous development of technology, along with the growing prevalence of electrical and electronic devices, has led to a significant accumulation of waste electrical and electronic equipment (WEEE). As these devices become obsolete and are phased out, the volume of WEEE reaches unprecedented levels [1-3]. A significant concern associated with WEEE is the presence of toxic elements, such as brominated flame-retardants (BFRs) [4-6]. These substances are commonly used in plastic compounds to mitigate the risk of ignition and slow down the spread of flames in the event of a fire. The problem is that BFRs can be detrimental to human health and the environment [7-9]. This situation poses significant challenges that necessitate effective management and the development of sustainable solutions. Recycling BFR polymers is considered the environmentally preferred process due to the potential environmental risks associated with these materials [8, 10]. Among the various recycling methods available, one commonly employed approach is the tribo-electrostatic separation [11-14]. Triboelectric charge value has an important effect on the outcome of this process. The highest charge on insulating granules is necessary for electrostatic separators to enable their separation by the electric field forces. As tribocharging is a surface phenomenon, plasma treatment methods, which are known to alter the surface condition of insulating materials, can have an impact on it. Previous research [15-18] has demonstrated that exposure to dielectric barrier discharge (DBD) plasma can effectively increase the roughness and wettability of the polymer and modify the triboelectric properties of insulating materials.



This study aims to assess the ability of DBD to modify the surface characteristics and enhance the triboelectric charging properties of Polyethylene (PE) particles containing 40000 ppm of bromine (PE 4.6 % of Hexabromobenzene) and BFR-free PE. The effect of DBD plasma has been studied as a function of treatment time and the applied voltage frequency.

2. Experimental set up

Figure 1 (a) displays a schematic representation of the experimental set-up that was used for the investigation of the effect of non-thermal plasma on the triboelectric behaviour of PE granules. An atmospheric air DBD plasma was created between an active rectangular copper electrode (150 mm in length and 70 mm in width) and a metal belt conveyor (700 mm in length and 70 mm in width, manufactured by CITF Company in Saint Cybardeaux, France), acting as the grounded electrode. The active electrode covered with a glass plate (260 mm \times 180 mm \times 3 mm) was connected to a high voltage power amplifier (Trek model 30/20A; amplification ratio 1 V / 3000 V), supplied by a Yokogawa FG300 function generator. The particles to be treated were dispersed as a monolayer on the surface of the grounded belt. The peak-to-peak voltage U and DBD gap d were kept constant in all experiments at 30 kV and 10 mm, respectively.

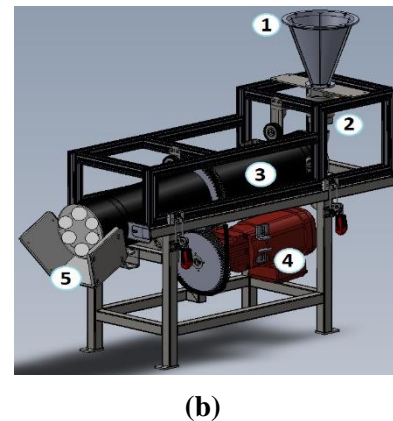
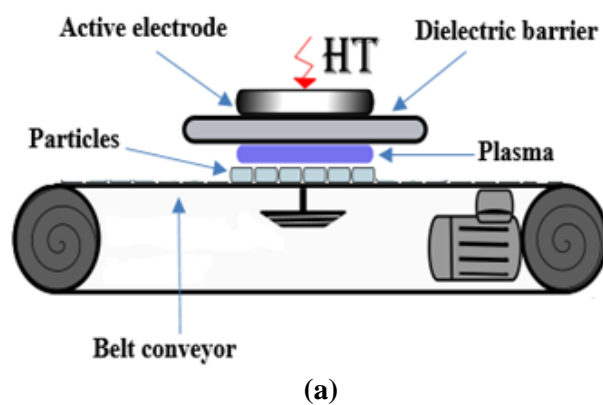


Figure 1. (a) Schematic representation of the DBD experimental bench; (b) Rotating multi-cylinder-type tribocharging device; (1) Inlet funnel, (2) Valve, (3) Assembly of six hollow cylinders, (4) Motor, (5) Tilt adjustment and (6) Outlet hopper.

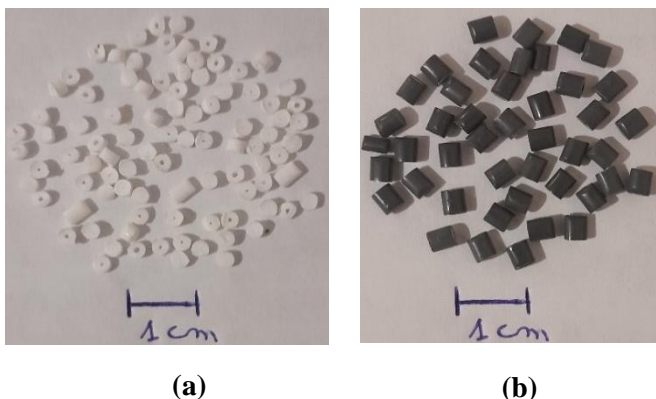


Figure 2. Aspect and size of the particles (a) BFR free PE and (b) 4.6 % BFR PE.

Untreated and DBD treated particles were charged separately in a rotating multicylinder tribocharger manufactured by CITF Company, Saint Cybardeaux, France. The latter consists of a high-density polyethylene (HDPE) cylinder with a diameter of 120 mm and a length of 670 mm (figure 1 (b)). Inside the cylinder, there are six smaller cylinders made of Polyvinyl chloride (PVC) with a diameter of 33 mm and a length of 600 mm.

The optimum operating parameters for the tribocharging device used in this work were set based on the authors' previous work [19], with an inclination angle of 6° and a rotation speed of 100 rpm. After the tribocharging process, the particles were collected in a Faraday cage linked to an electrometer (Keithley Instruments, model 6514) and placed on an electronic balance for charge and mass measurements. The efficiency of DBD treatment is assessed by calculating the charge to mass ratio of the collected granules. The experiments were triplicated and conducted at ambient relative humidity and temperature, which ranged between 51 % - 60 % and $16.5^\circ\text{C} - 19^\circ\text{C}$ respectively.

This study has been carried out on Polyethylene (PE) particles containing 40000 ppm of bromine (PE 4.6 % of Hexabromobenzene) and BFR-free PE (figure 2). The influence of the treatment time and the applied voltage frequency on the effectiveness of the DBD processing of PE granules was investigated.

3. Results and discussion

3.1. Effect of DBD treatment time

The surface modification was monitored by varying the treatment time between 1.2 s to 300 s while keeping the other parameters constant (square AC signal, $U = 30\text{ kV}$, $f = 500\text{ Hz}$, $d = 10\text{ mm}$). The results of the tribocharging experiments are presented on figure 3 (a) and (b), for BFR-free PE and 4.6 % BFR PE granules, respectively. Both types of particles, untreated and DBD treated, acquire a negative charge when tribocharged in the multi-cylinder charger.

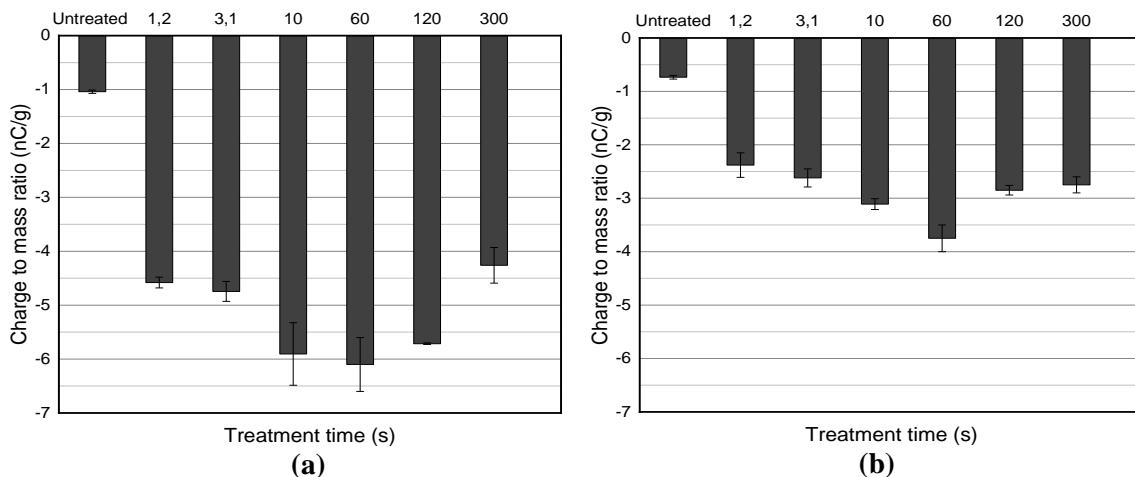


Figure 3. Charge to mass ratio as a function of the treatment time for BFR-free (a) and 4.6 % BFR PE particles (b) (square AC signal, $U = 30\text{ kV}$, $f = 500\text{ Hz}$, $d = 10\text{ mm}$).

The exposure time to DBD plasma significantly influences the charge acquired by triboelectric effect. The charge to mass ratio of treated particles increases with the treatment time, and reaches its maximum value at 60 seconds; beyond this time, the treatment effect begins to decrease.

DBD plasma enhanced the triboelectric charging for both BFR-free PE and 4.6 % BFR PE particles, which suggests that there is a modification on the material surface. The DBD treatment resulted in an increase in the surface roughness of the polymer [15, 16], which generally leads to a larger number of contact points between the bodies in contact, resulting in higher triboelectric charge value [20]. The effect of DBD treatment depends also on the nature of material to be treated. The presented findings indicate that the 4.6 % BFR PE particles acquire less charge compared to the BFR free PE particles. For example, after a 60 seconds of DBD exposure, the charge of BFR-free PE granules was -6.1 nC/g , whereas the 4.6 % BFR PE particles acquire a charge of -3.7 nC/g . This difference can be attributed to the fact that the two materials underwent different degrees of surface treatment, related to the presence of brominated flame-retardants, which modify the chemical properties of each material [15].

3.2. Effect of the applied voltage frequency

A sinusoidal signal of amplitude 30 kV was used to study this effect, for a 10 mm air gap with a 3 mm thickness dielectric barrier. The treatment time t was set to 60 s.

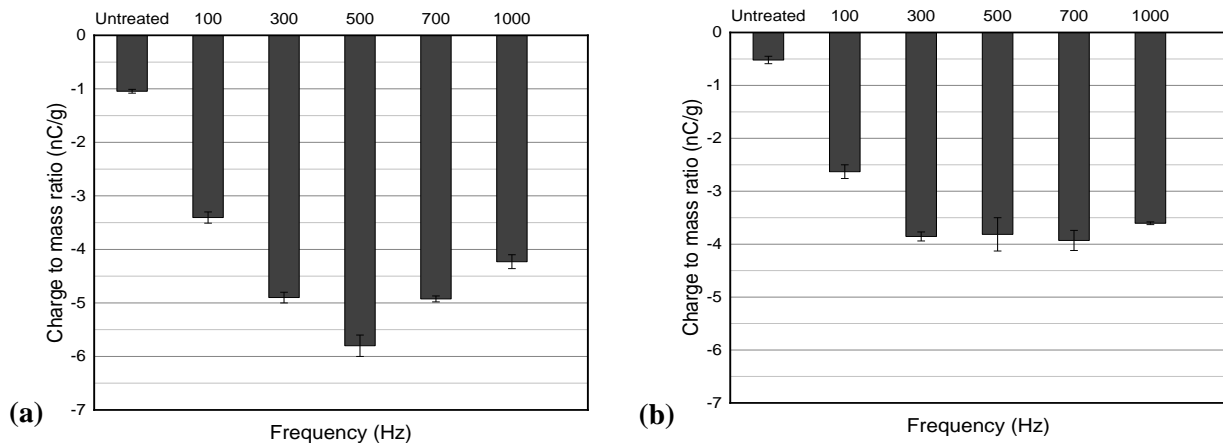


Figure 4. Charge to mass ratio as a function of the applied voltage frequency for BFR-free (a) and 4.6 % BFR PE particles (b) (sinusoidal AC signal, $U = 30$ kV, $t = 60$ s, $d = 10$ mm).

The frequency of the excitation signal was varied between 100 Hz and 1000 Hz. The triboelectric charge of both types of materials was negative and enhanced after DBD plasma treatment for all frequency values (figure 4). The triboelectric charge increased with the frequency; however, the behavior of 4.6 % BFR PE differs from that of BFR-free PE. For example, the charge of the non-brominated PE started to decrease from 500 Hz. As for the 4.6 % BFR PE, the charge remained relatively constant between 300 and 700 Hz, and decreased only when the frequency exceeded 700 Hz. It can be concluded that the changes in plasma morphology with the variation of frequency may indirectly affect the triboelectric behaviour of polymers. R.B. Tyata *et al.* [21] found that the discharge becomes filamentary by increasing the frequency. This may result in a non-homogenous treatment of the polymer surface, and hence in a decrease of the triboelectric charging [15].

4. Conclusions

In this paper, an experimental investigation was conducted to evaluate the effect of DBD exposure on triboelectric charging of PE granules. The parameters of the study were the treatment time and the frequency of the excitation signal.

The findings reported in this study demonstrate that:

(1) DBD plasma exposure can enhance the triboelectric charge for both BFR-free PE and 4.6 % BFR PE particles. By increasing the treatment time, the triboelectric charge of both types of particles attained a maximum at 60 seconds. However, beyond this value, the DBD treatment starts to lose its efficiency.

(2) The applied voltage frequency can also strongly influence the triboelectric charge. At first, the value of the charge to mass ratio increases with the frequency; in the specific conditions of this experiment, for PE granules exposed at frequencies beyond 700 Hz, the tribocharging effect was weaker.

(3) The effect of DBD exposure is stronger on the BFR-free PE than on BFR PE. This is a very important result as it suggests the possibility to electrostatically separate BFR polymers from BFR-free polymers, facilitating the recycling of the latter. Experiments are in progress to demonstrate that the difference in the levels of electric charge acquired by the two classes of particles in a tribocharging device, after being exposed to DBD plasma, is large enough to enable their electrostatic separation.

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