Tribocharging of PP Granules after exposure to a Dielectric Barrier Discharge (DBD). Effect of Exposure Duration, Voltage Amplitude and Frequency

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***Abstract*—Triboelectric charging is used for many applications including electrostatic separation of granular insulating materials. For this application, the granules should get the highest electric charge, so that the electric field forces could easily separate them. Triboelectric charging is a surface phenomenon and dielectric barrier discharge (DBD) is known for its ability to change surface properties of different materials. This study is focused on the evaluation of the DBD factors that might enhance the triboelectric charging properties of Polypropylene (PP) mm-size granules: the discharge duration, as well as the frequency and the amplitude of the high-voltage. After having been exposed to the DBD, the granules were tribocharged in a vibratory device for 5 min. Then, the charge was measured by a Faraday pail connected to an electrostatic voltmeter. The results show that under optimal operating conditions, DBD exposure can enhance the triboelectric charging by about 30%.**

I. Introduction

Until recently, triboelectric charging of insulating materials was only considered as source of electrostatic hazard [1-3]. In such a case, triboelectric charge needs to be the lowest. However, the triboelectric effect is more and more used in electrostatic applications such as the separation of granular mixtures of insulating materials [4-7]. Indeed, the efficiency of the electrostatic separation increases with the level of charge acquired by the particles in tribocharging devices of vibratory-, rotary-, or fluidized-bed-type [6, 8-11]. These devices give high charges but are difficult to be integrated to industrial facilities.

One parameter which influences the acquired charge is the charging duration. The longer the particles stay in the device, the highest is their charge. However, the increase of charge duration implies the decrease of treated quantities in a given unit of time. Moreover, no tribocharging device is able to highly charge all materials.

Tribocharging is known to be a surface phenomenon. With plasma treatment being able to change the surface state of insulating materials [12-15], is can be expected that their tribocharging characteristics could be modified by exposing them to a dielectric barrier discharge (DBD). The aim of this study is to show the effect of ambient-air DBD duration, voltage and frequency on the triboelectric charge of PP particles.

II. MATERIALS AND METHODS

All experiments were carried out at relative humidity of 57.8% - 60.1% and temperature of 18.8 °C – 19.5 °C.

A. Studied particles

This study was made on polypropylene (PP) particles originating from waste electric and electronic equipment. Their size ranged between 2 mm and 6 mm (Fig. 1).

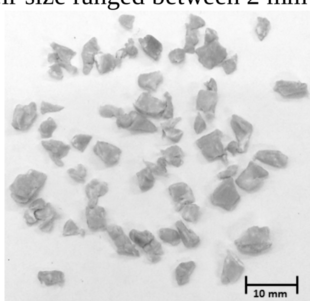

Fig. 1. Photograph of PP particles.

For each experiment, new 7-g samples of PP particles were used.

B. Dielectric barrier discharge set up

Firstly, particles were treated by a dielectric barrier discharge (Fig. 2) under atmospheric conditions. To create this DBD, a square waveform signal was produced by a function generator (Yokogawa FG300). The amplitude and the frequency of the voltage provided by this generator could be changed by the operator up to 20 V and up to 2.5 kHz respectively. The produced signal represented the input a high voltage power amplifier (Trek model 30/20A; amplification ratio 1 V / 3000 V). Thus, the maximum amplitude of the voltage applied to the upper electrode of the DBD reactor was 60 kV (centered on 0 V). A digital oscilloscope (Lecroy, model Waveace 1001) was used to monitor the output signal of the amplifier and also display the effective voltage, which was one of the factors considered in the present study.

Dielectric barrier discharge was created between two aluminum disk-type electrodes of 75 mm diameter. The upper active electrode was mobile whereas the grounded one was fixed. A square glass plate (150 mm x 150 mm x 3 mm) was put on the grounded electrode and represented the first dielectric barrier. Particles to treat were placed on this plate with the help of a cylindrical support (diameter: 75 mm, height: 5 mm) that contained them. A second glass barrier (150 mm x 150 mm x 5 mm) was placed between the upper electrode and this cylinder. Plasma was thus created at the same place where particles were.

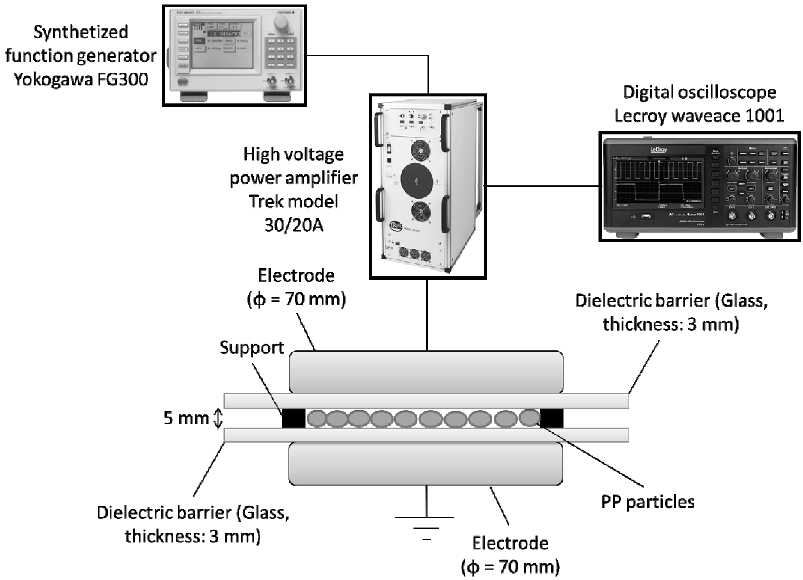

Fig. 2. DBD experimental setup

Based on the results of several preliminary experiments, three DBD factors were considered: signal frequency, *f*, range 50 to 1000 Hz, effective voltage, *U*, range 15 to 27 kV, treatment duration, *t*, range 1 to 600 s. The study was conducted according to a "one-factor-at-a-time" experimental design.

C. Tribocharging

After DBD treatment, the PP particles were tribocharged in a vibratory device (Retsch AS200 basic). Thus, particles were placed in a stainless steel container which was put on the vibrating plate of the device. For all experiments, the tribocharging duration and amplitude were respectively 5 min and 3 mm. Then, particle charge was measured by putting them in a Faraday pail connected to an electrometer (Keithley, model 6514).

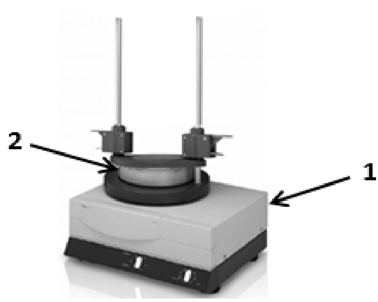

Fig 3. Vibratory tribocharging device. 1: Retsch vibratory device, 2: Stainless steel container (ϕ = 160 mm).

III. Results and Discussion

A. Effect of DBD duration

To create an homogeneous DBD, the effective voltage and the signal frequency were kept constant at 27 kV and 400 Hz respectively.

As shown in Figure 4, DBD duration had a significant effect on the triboelectric charge of PP particles. Without DBD treatment, the 7 g samples got a charge of about 130 nC. This value increased by 32% for 3 s treatment. However, for 30 s, the charge decreased by 39%. In the experiment when the DBD was longer than 30 s, the particle charge quickly decreased. The “antistatic” behavior of the PP particles wass due to the surface modifications produced by the DBD. In fact, under DBD plasma exposure, the roughness and the wettability increase. For short DBD exposure time (like 3 s), particles roughness increases and creates charge traps at their surfaces whereas the wettability does not change significantly. Thus, the acquired charge increase. However, for longer exposure time, PP wettability increases and particles become conductive by absorbing atmospheric moisture [13, 16-22].

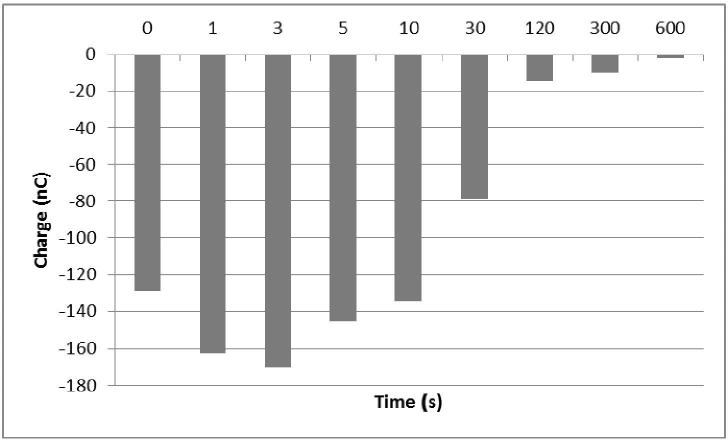

Fig. 4. Effect of DBD duration on PP particles charge. U = 27 kV, f = 400 Hz.

Based on these results, the experiments described here after were carried out using a 3 s treatment duration.

B. Effect of effective voltage

The characteristics of the HV amplifier limited the highest effective voltage to 27 kV for a DBD frequency of 400 Hz. The results in Fig. 5 show that the higher is the voltage, the higher is the acquired charge of particles. Indeed, DBD is more effective for high voltages as it generates more changes in the surface characteristics of the particles, to which it delivers more energy.

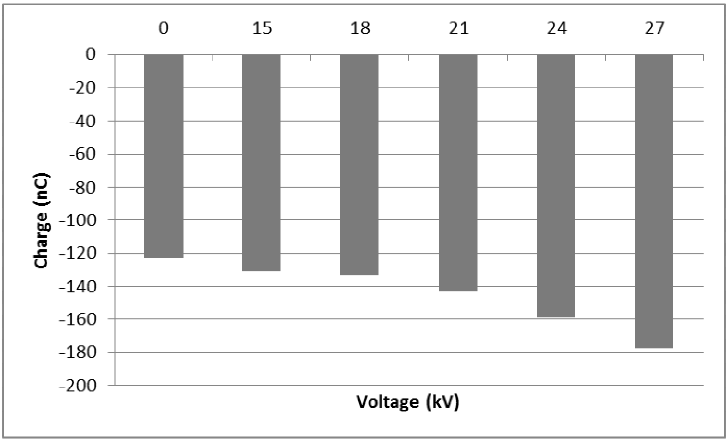

Fig. 5 . Effect of DBD voltage on the triboelectric charge of PP. t = 3 s, f = 400 Hz.

C. Effect of signal frequency

To study the effect of DBD frequency on the tribocharge of PP, the effective voltage and the treatment duration were kept constant at 21 kV and 3 s respectively.

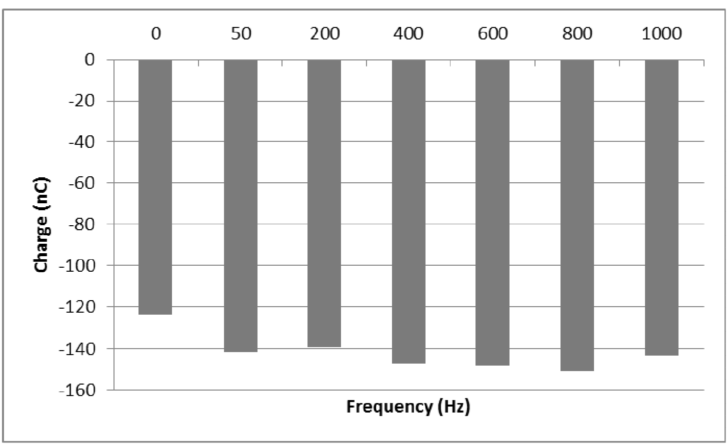

Fig. 6. Effect of DBD frequency on the triboelectric charge of PP particles. t = 3 s, U = 21 kV.

The results displayed in Fig. 6 show that the frequency has not a high influence on the triboelectric charging of PP as long as the DBD is homogeneous. Indeed, some studies show that the DBD is homogeneous up to 800 Hz and become more filamentary beyond this value [22-24]. Thus, some particles are not treated by DBD. That is why charge slightly decreases for 1000 Hz.

IV. Conclusions

The present study points out the influence of DBD treatment on the triboelectric charge acquired by PP particles in a vibratory device. The results confirm that:

- DBD treatment modifies the tribocharging behavior of PP particles,
- Frequency has no influence on PP charge as long as DBD is homogeneous,
- Increasing the effective high voltage applied to the electrode of the DBD reactor for short duration (typically, 3 s) has a significant effect on the tribocharging of PP particles,
- DBD exposure time significantly influences the tribocharge, which can be either improved or highly diminished.

References

[1] L.G. Britton, “Static hazards using flexible intermediate bulk containers for powder handling”, Process Saf. Prog. 12, 1993, pp. 240–250.

[2] I. Berta, “Static electricity hazards: Solid surfaces and gases,” Mercel Dekker, U.S.A., *Handbook of Electrostatic Process,* 1995.

[3] J.E. Vinson and J.J. Liou, “Electrostatic discharge in semiconductor devices: an overview,” Proc. IEEE. 86, 1998, pp. 399–418.

[4] K. M. Forward, D. J. Lacks and R. M. Sankaran, “Mothodology for studying particle-particle triboelectrification in granular materials,” J. of Electrostatics, vol. 67, 2009, pp. 78-183.

[5] A. Iuga, A. Samuila, R. Morar, M. Bilici and L. Dascalescu, “Tribocharging techniques for the electrostatic separation of granular plastics from waste electric and electronic equipment,” Part. Sci. Technol. 34, 2016, pp. 45–54.

[6] A. Mekhalef, S. Messal, K. Medles, T. Zeghloul and L. Dascalescu, “A propeller-type tribocharger for granular plastics mixtures”, Proc. 2016 Electrostatics Joint conf., 2016.

[7] T. Zeghloul, A. M. Benhafssa, G. Richard, K. Medles and L. Dascalescu, “Effect of particle size on the tribo-aero-electrostatic separation of plastics,” J. of Electrostatics, vol. 88, 2017, pp. 24-28.

[8] M. Saeki and A. Masumoto, “Electrostatic Separation of Chopped Waste Electric Cables,” J. of Environment and Engineering, vol. 2, 2007, pp. 227-236.

[9] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami and L. Dascalescu, “Modeling and optimization of a propeller-type tribocharger for granular materials” J. of Electrostatics, vol. 69, 2011, pp. 631–637.

[10] A. Benabboun, A. Tilmatine, Y. Brahami, S.E. Bendimerad, M. Miloudi and K. Medles, “Experimental investigation of electrostatic separators of plastic particles using different charging devices,” Separation Science and Technology, 49:3, 2014, pp. 464-468.

[11] J. Li, G. Wu and Z. Xu, “Tribo-charging properties of waste plastic granules in process of tribo-electrostatic separation,” Waste Management, vol. 35, 2014, pp. 36–41.

[12] K. L. Mittal and D. J. Beebe, *Polymer Surface Modification: Relevance to Adhesion,* Vol 3, VSP Utrecht (Boston), 2004, pp 1-487.

[13] C. S. Ren, K. Wang, Q. Y. Nie, D. Z. Wang and S. H. Guo, “Surface modification of PE film by DBD plasma in air,” Appl. Surf. Sci, vol. 255, 2008, pp. 3421–3425.

[14] M. Thomas and K. L. Mittal, *Atmospheric Pressure Plasma Treatment of Polymers Relevance to Adhesion,* Scrivener Publishing LLC Wiley (Beverly Ma), 2013, pp 1-395.

[15] H. Zhang, H. Li, M. Fang, Z. Wang, L. Sang, L. Yang and Q. Chen, “Roll-to-roll DBD plasma pretreated polyethylene web for enhancement of Al coating adhesion and barrier property,” Appl. Surf. Sci, 2015, pp. 1-7.

[16] A. Mercado-Cabreraa, B. Jaramillo-Sierra, R. López-Callejas, R. Valencia-Alvarado, A. de la Piedad-Beneitez, R. Pena-Eguiluz, S. Barocio-Delgado, A. Munoz-Castro and B. Rodríguez-Méndez, “Surface modification of polypropylene fiber for hydrophilicity enhancement aided by DBD plasma,” Prog. Org. Coat., vol. 76, 2013, pp. 1858–1862.

[17] L. Dascalescu, *An Introduction to Ionized Gases. Theory and Applications*, Toyohashi University of Technology (Japan), 1993, pp. 1–200.

[18] Z. Fang, X. Xie, J. Li, H. Yang, Y. Qiu and E. Kuffel, “Comparison of surface modification of polypropylene film by filamentary DBD at atmospheric pressure and homogeneous DBD at medium pressure in air,” J. Phys. D: Appl. Phys., vol. 42, 2009, pp. 1-9.

[19] K. G. Kostov, T. M. C. Nishime, L. R. O. Hein and A. Toth, “Study of polypropylene surface modification by air dielectric barrier discharge operated at two different frequencies,” Surf. Coat. Technol., vol. 234, 2013, pp. 60–66.

[20] K. G. Kostov, A. L. R. dos Santos, R. Y. Honda, P. A. P. Nascente, M. E. Kayama, M. A. Algatti and R. P. Mota, “Treatment of PET and PU polymers by atmospheric pressure plasma generated in dielectric barrier discharge in air,” Surf. Coat. Technol., vol. 204, 2010, pp. 3064–3068.

[21] Z. Niu, C. Zhang, T. Shao, Z. Fang, Y. Yu and P. Yan, “Repetitive nanosecond-pulse dielectric barrier discharge and its application on surface modification of polymers,” Surf. Coat. Technol., vol. 228, 2013, pp. 578–582.

[22] F. Bekkara, B. Naegoe, Y. Prawatya, Y. Benmimoun, T. Zeghloul, N. Zouzou, “Modifying the surface characteristics of polymers by exposure to dielectric barrier discharge”, presented at SFE’16, Poitiers (France), August 2016.

[23] P. Bruggeman and R. Brandenburg, “Atmospheric pressure discharge filaments and microplasmas: physics, chemistry and diagnostics,” J. Phys. D: Appl. Phys., vol. 46, 2013, pp. 1-28.

[24] R. B. Tyata and D. P. Subedi, “An investigation of the effect of electrode geometry and frequency of power supply in the homogeneity of dielectric barrier discharge in air,” Kathmandu University Journal of Science, Engineering and Technology, vol. 6, 2010, pp. 96-101.