A Propeller-Type Tribocharger for Granular Plastics Mixtures

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***Abstract*— This work is focused on the experimental study of a new propeller-type tribocharging device specifically designed to operate in conjunction with an electrostatic separator for mixtures of granular insulating materials. The device consists in two coaxial aluminum propellers, rotating in a polyvinyl chloride pipe; it has two control variables: the material feed-rate and the rotation speed of the propellers. Virtual instrumentation using the LABVIEW software is used for measuring the mass and the electric charge of the tribocharged samples of four types of polymers: polypropylene (PP), high impact polystyrene (HIPS), high-density polyethylene (HDPE), and polyvinyl chloride (PVC). In accordance with the sign and the magnitude of the charge/mass ratio, the four polymers are arranged in a triboelectric series, starting from the negative polarity: PVC – HDPE – PP – HIPS. The effectiveness of the tribocharging process is validated by using a free fall electrostatic separator. The best results (purities and recoveries higher than 90%) are obtained in the case of PVC/HIPS granular mixtures**.

***Key-words:* Tribocharge, Electrostatic separation, Insulating materials.**

I. Introduction

Recycling of plastics has become a hot issue due to the ever increasing quantities of waste of electrical and electronic equipment (WEEE) that need to be processed every year [1-2]. Various technologies (air-gravity separation, X-ray fluorescence, electrostatic separation and flotation.) are currently employed for the recovery of the materials contained in this kind of wastes [3-8].

Electrostatic separation is a generic term given to an important class of materials processing technologies, widely used for sorting granular mixtures by means of the electric forces acting on charged or polarized bodies [9-13]. During the last 20 years, electrostatic separation has been adopted as the solution of choice for the recycling of the plastic materials from granular WEEE [14]-[17].

The triboelectric effect [15-16] can be effectively employed for charging of granular or powdery insulating materials in a wide variety of mechanical devices (vibratory feeders, rotating tubes, fluidized beds, ...) [17-24]

The propeller-type tribocharging device consists in a cylindrical chamber, made of polyvinyl chloride (PVC). At its upper end, the chamber is provided with one or several aluminum coaxial propellers, driven by a variable-speed DC electric motor. This device entrains the granular materials into a helical motion that is expected to favor their triboelectric charging by granule-to-propeller, granule-to-cylinder wall, and granule-to-granule collisions. The sign and the magnitude of the charge of each granule are determined by the combined action of these three physical mechanisms [25].

The aim of the present work is double: (i) evaluate the tribocharge imparted by the propeller-type device to four types of granular plastics; (ii) validate the possibility of using this tribocharger for the electrostatic separation of several mixtures of such materials.

II. Experimental Setup

A. Propeller-type tribocharging device

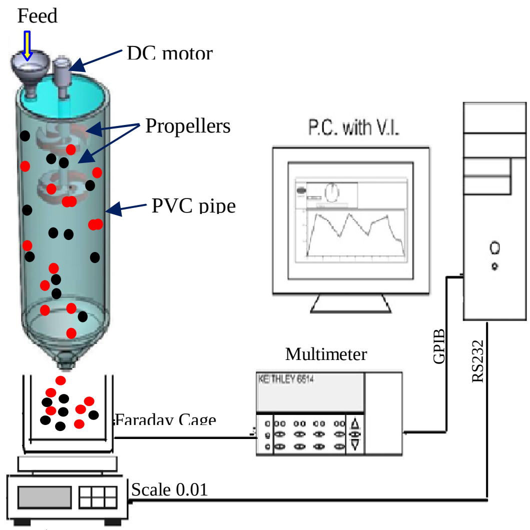

Fig. 1. Schematic representation of the propeller-type tribocharger and of the experimental setup.

The propeller-type tribocharger for granular insulating materials is presented in Fig. 1. A vibratory feeder introduces at a variable feed-rate the granular material into the tribocharger, which consists of a PVC pipe (diameter : 140 mm) and two aluminum propellers (diameter: 80 mm). The propellers are entrained by a variable speed DC motor.

The granular material introduced in the tribocharger has a first impact with the blades of the aluminum propellers. Then, the aerodynamic forces generated by the propellers project the particules towards the walls of the PVC pipe. The multiple impacts with the blades of the propelles and the wall of the pipe charge the particles by triboelectric effect. The tribocharged particles fall then freely into a Faraday cage connected to the electrometer KEITHLEY 6514, and placed on an electronic scale of resolution of 0.1 g.The electronic scale and the electrometer are connected to a PC using RS232 and GPIB cables. The charge and the mass measured by the two instruments are recorded using a custom-designed LabView data acquisition program. The charge/mass ratio is then calculated, to evaluate the tribocharging of each material under test.

B. Electrostatic separation setup

The electrostatic separation experiments are done using a free-fall electrostatic separator (Fig. 2). The granular mixture to be separated is first charged by the propeller-type device. Then, the tribocharged particles fall freely in the electric field generated between the two plate electrodes (length: 1250 mm; width: 540 mm) of the electrostatic separator. The positively- and negatively-charged particles are respectively attracted by the negative (-30 kV)- and positive (+30 kV)-polarity electrodes..

The distance between the upper-edges of the electrodes is 120 mm to obtain maximum electric field strength in that area. The electrodes are inclined at an angle of 5° with respect to the vertical, so that to interfere less with particle separation trajectories.

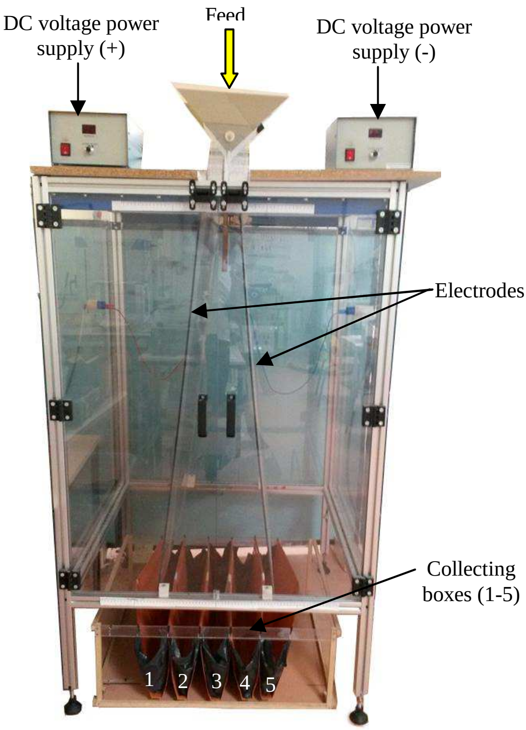

Fig. 2. The free fall electrostatic separator.

The separated product is recovered in five collecting boxes. The negatively-charged particles are collected in boxes 1 and 2, and the positively-charged particles - in boxes 4 and 5. The uncharged particles accumulate in box 3.

III. Material And Method

The granular materials that make the object of the present study are 4 types of polymers: polypropylene (PP), high impact polystyrene (HIPS), high-density polyethylene (HDPE), and polyvinyl chloride (PVC), originating from the processing of WEEE at APR2 company, France. The diameter of the particles is between 1 mm to 5 mm, as shown in Fig. 3. During all experiments, the feed rate of the tribocharger is maintained constant (3 g/s).

A. Charge measurement experiments

A program written in LABVIEW allows the continuous measurement of the charge and the mass of the particles collected in the Faraday Cage, as function of time.

In a first set of experiments, carried out with each of the four types of plastics, the rotation speed *n* of the propeller is varied from 0 to 4000 rpm.

The second set of experiment is performed at constant propeller speed *n* = 4000 rpm, with 3 different sizes of HDPE particles.

The ambient conditions are maintained stable: relative humidity RH = 45-55% and temperature 18°C-21°C, and the results are presented as function of the charge/mass ratio.

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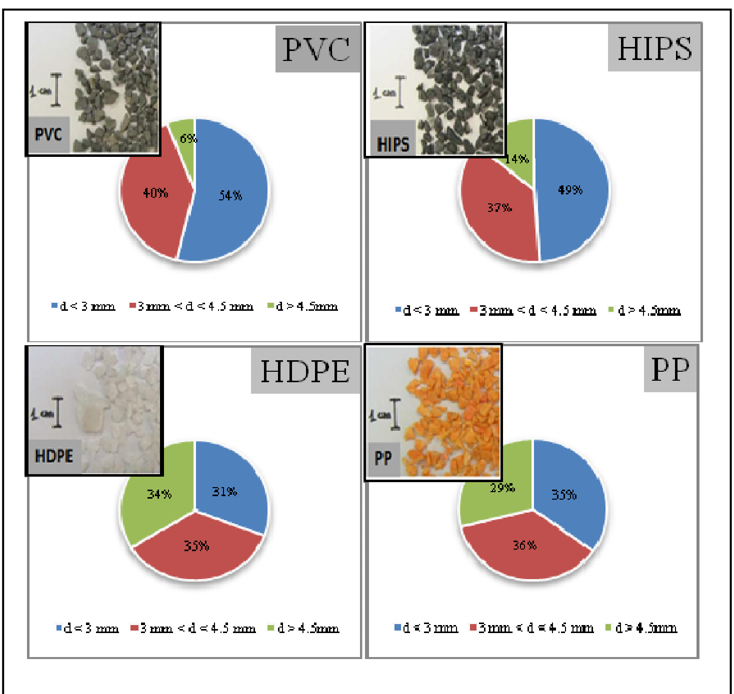

Fig. 3: Size distribution of materials

B. Electrostatic separation experiments

Three electrostatic separation experiments are performed with 200 g – samples of granular plastics. In each sample, PVC represents 50% of the mass. The other material is HDPE, PP or HIPS. The experiments are aimed at validating the efficiency of the new tribocharger.

They are performed in relatively stable weather conditions: relative humidity RH = 40-50% and temperature 18°C-19.5°C.

The negatively-charged PVC particles are collected in boxes 1 and 2 of the separator, and positively-charged particles accumulate in the boxes 4 and 5. The poorly-charged particles fall into the box 3.

The purity and the recovery of the products are calculated for each experiment. The product in each box is also sieved and the distribution of particle size (expressed in percentage) is calculated.

IV. Results And Discussion

A. Tribocharging

The results of a tribocharging experiment carried out on a 20-g-sample of PVC, with the propellers rotating at 4000 rpm, are given in Figs. 4 and 5. The discontinuity on the curves of the charge and of the mass as functions of time correspond to the moment when the propellers are turned-off and the remaining material drops freely in the Faraday cage. It should be noted that about 3 g of particles remain attached to the walls of the tribocharger and this explains why the mass of the product collected in the Faraday cage is less than 20 g. The charge/mass ratio computed from the experimental data is also represented as a function of time, in Fig. 6. Its value is practically constant during the experiment.

Similar results are obtained for the other three polymers under investigation: HDPE, PP and HIPS. Their tribocharging capabilities are analyzed in relation with the values of the charge/mass ratio calculated for each experiment.

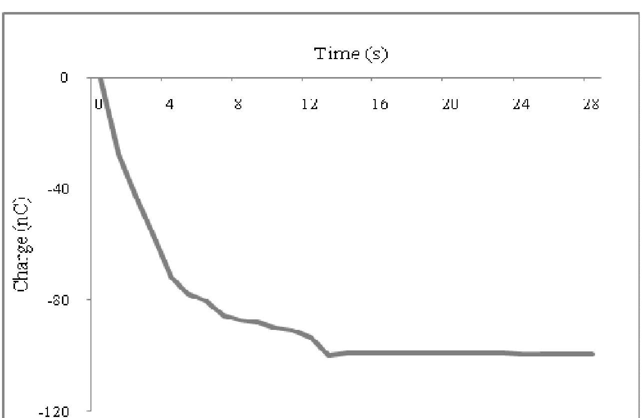

Fig. 4: Variation of the charge as function of time.

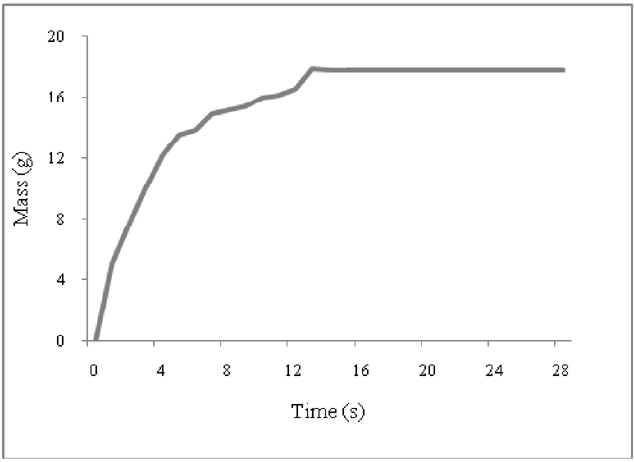

Fig. 5: Variation of the mass as function of time.

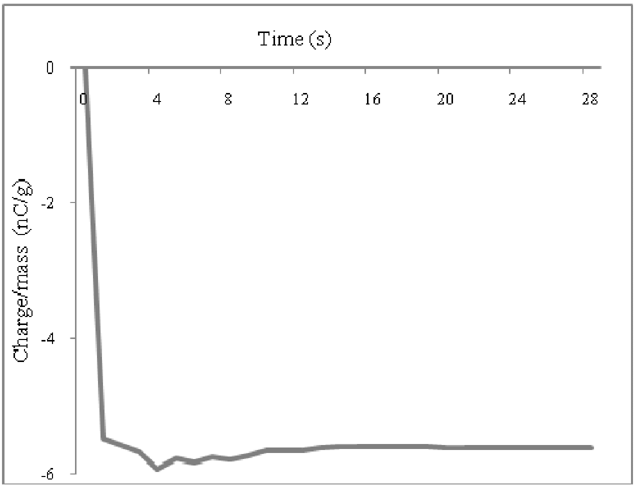

Fig. 6: Variation of charge/mass ratio as function of time.

1) Influence of the propellers speed

Fig. 7 shows that by increasing the rotation speed, the energy exchange between particles and both the blades of the propellers and the wall of the PVC pipe increases and consequently the charge/mass ratio increases.

PP and HIPS particles are positively charged in this tribocharger, while HDPE and PVC are negatively charged. A triboelectric series can be established as follows:
(-) PVC – HDPE – PP – HIPS (+)

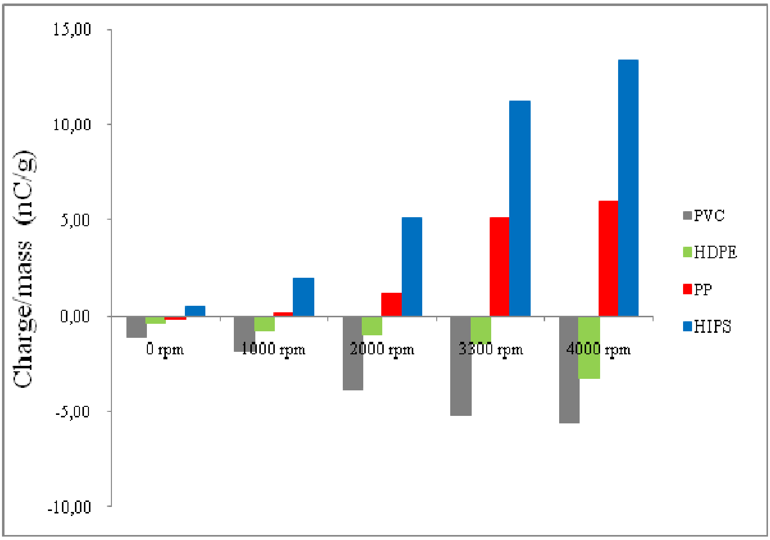

Fig. 7: The charge/mass ratio as function as the propellers speed for each material.

2) Influence of particles size

The results displayed in Fig. 8 show that the HDPE particles of less than 4.5 mm in diameter have a slightly higher charge than those larger than 4.5 mm. This can be explained by the fact that the tribocharging is a surface-related phenomenon and that the larger particles tend to spend less time in the tribocharger (and have less collisions with the blades of the propeller and the walls of the pipe).

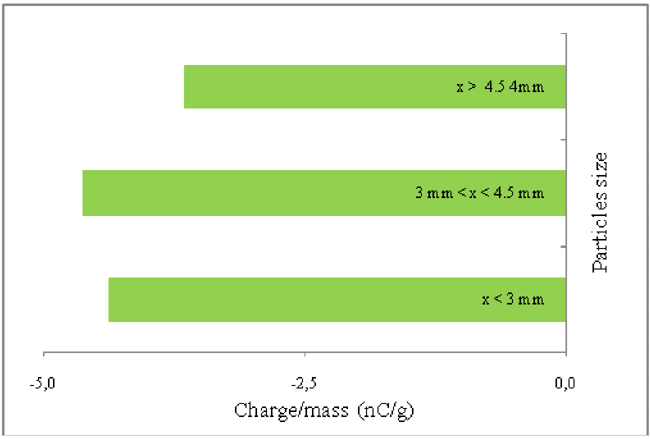

Fig. 8: Influence of the particles size on the charge/mass ratio of HDPE samples.

B. Electrostatic separation

The results of the electrostatic separation experiments are summarized in Table 1. The best separation is obtained for the PVC / HIPS mixture, because the materials are farthest in the triboelectric series. For the materials that are closer to each other in the series, the separation quality is low.

TABLE 1: RESULTS OF SEPARATION EXPERIMENTS

Mixture	PVC		Product 2	
	Rec (%)	Purity (%)	Rec (%)	Purity (%)
PVC/HDPE	69.00	87.18	34.53	95.12
PVC/PP	72.13	96.46	81.51	97.95
PVC/HIPS	94.74	97.91	93.08	97.92

The PVC particles are always negatively charged and recovered in boxes 1 and 2. In box 1 the particle size is always less than 3 mm, because of the higher density of PVC. The PVC particles are heavier than the others, so the positive electrode attracts mainly the particles that are smaller than 3 mm. Few particles that are larger than 4.5 mm care collected in the boxes 1 and 5 (Figs. 9 to 11).

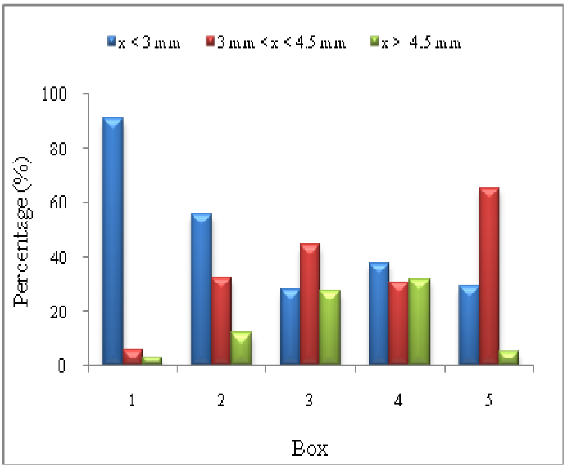

Fig. 9: Distribution of particle size in each collecting box for a 50%PVC / 50% HDPE sample.

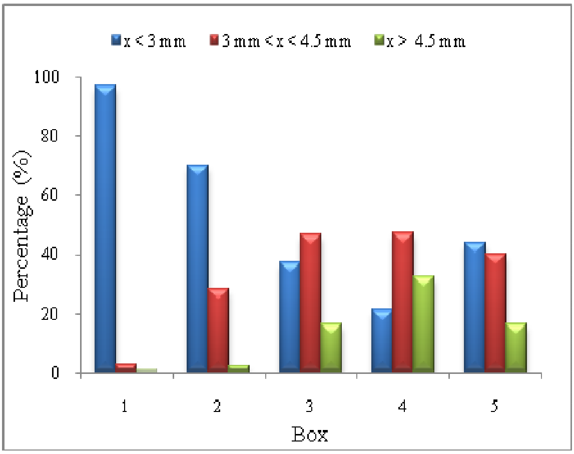

Fig. 10: Distribution of particle size in each collecting box for a 50% PVC / 50% PP sample.

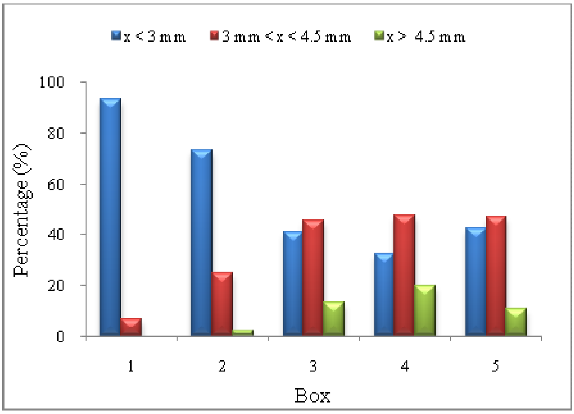

Fig. 11: Distribution of particle size in each collecting box for a 50% PVC / 50% HIPS sample.

V. CONCLUSIONS

The propeller-type tribocharger is highly effective in processing mm-size granular plastics. The experiments have proven the charge acquired by these granular materials is related to the energy exchange during the collisions with the blades of the propeller and the walls of the tribocharger. The best tribocharging results are obtained at high speed of propellers.

The combination of the propeller-type tribocharger with free-fall separator gives the best results when the materials that compose the mixture are distanced in the triboelectric series. The larger-size particle sizes are poorly separated because of the poor ratio between the electric and gravitational forces that act on them.

REFERENCES

[1] H.-Y. Kang, J.M. Schoenung, " Electronic waste recycling: a review of U.S. infrastructure and technology options," *Resour. Conserv. Recy.*, vol. 45, pp. 368-400, 2005.

[2] H. Aizawa, H. Yoshida, S. Sakai, "Current results and future perspectives for Japanese recycling of home electrical appliances," *Resour. Conserv. Recy.*, vol. 52, pp. 1399-1410, 2008.

[3] M. Schluep and al., "Sustainable innovation and technology transfer industrial sector studies," *in Recycling—From E-waste to Resources*, Bonn, Germany: UN Environ. Program UN Univ., 2009.

[4] Q. Xiuli, J. A. S. Williams, and E. R. Grant, "Viable plastics recycling from end-of-life electronics," *IEEE Trans. Electron. Packaging Manuf.*, vol. 29, no. 1, pp. 25–31, Jan. 2006.

[5] J. Li, H.Z. Lu, J. Guo, Z.M. Xu, Y.H. Zhou, "Recycle technology for recovering resources and products from waste printed circuit boards," *Environ. Sci. Technol.*, vol. 41, pp. 1995-2000, 2007.

[6] S.M. Al-Salem, P. Lettieri, J. Baeyens, "Recycling and recovery routes of plastic solid waste (PSW): a review," *Waste Manage.*, vol. 29, pp. 2625-2643, 2009.

[7] D. Lazarevic, E. Aoustin, N. Buclet, Nils Brandt, "Plastic waste management in the context of a European recycling society: comparing results and uncertainties in a life cycle perspective," *Resour. Conserv. Recy.*, vol. 55, pp. 246-259, 2010.

[8] F.O. Ongondo, I.D. Williams, T.J. Cherrett, "How are WEEE doing? A global review of the management of electrical and electronic wastes," *Waste Manage.*, vol. 31, pp. 714-730, 2011.

[9] F.S. Knoll, J.E. Lawver, and J.B. Taylor, "Electrostatic separation," in: *Ullmann's Encyclopaedia of Industrial Chemistry*, 5th ed., vol. B2, pp. 20-1 to 20-11, 1988.

[10] S. Bendimerad, A. Tilmatine, M. Ziane, and L. Dascalescu, "Plastic wastes recovery using free-fall triboelectric separator," *Int'l. J. Environ. Stud.*, vol. 66, pp. 529–538, 2009.

[11] M. Younes, A. Tilmatine, K. Medles, A. Bendaoud, A. Samuila, and L. Dascalescu, "Numerical Modeling of Insulating Particles Trajectories in Roll-type Corona-Electrostatic Separators," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 16, pp. 629-634, 2009.

[12] L. Dascalescu, "Progresses in corona-electrostatic separation technologies and equipments," *Proc. Annual Meeting Ins. Electrostatics*. Tokyo, Japan, pp. 31-54, 1993.

[13] Y. Higashiyama and K. Asano, "Recent progress in electrostatic separation technology," *Part. Sci.Technol.*, vol. 16. pp. 77-90, 1998.

[14] A. Tilmatine, S. Bendimered, F. Boukhoulda, K. Medles, and L. Dascalescu, "Electrostatic separators of particles. Application to plastic/metal, metal/metal and plastic/plastic mixtures," *Waste Manage.*, vol. 29, no. 1, pp. 228–232, Jan. 2009.

[15] J. M. Crowley, *Fundamentals of Applied Electrostatics*. NewYork: Wiley-Interscience, 1985.

[16] W. R. Harper, *Contact and Frictional Electrification*. Oxford, U.K.: Clarendon, 1967.

[17] I. I. Inculet, G. S. P. Castle, and J. D. Brown, "Electrostatic separation of plastics for recycling," *Particulate Sci. Technol.*, vol. 16, no. 1, pp. 91–100, Jan. 1998.

[18] L. Calin, A. Mihalcioiu, A. Iuga, and L. Dascalescu, "Fluidized bed device for plastic granules triboelectrification," *Particulate Sci. Technol.*, vol. 25, no. 2, pp. 205–211, Mar. 2007.

[19] 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 equipement," *Part. Sci. Tech.*, vol. 34, pp. 45-54, 2016.

[20] J. Li, G. Wu, and Z. Xu, "Tribo-charging properties of waste plastic in process of tribo-electrostatic separation," *Waste Management*, vol. 35, pp. 36–41, 2015.

[21] M.E.–M. Zelmat, A. Tilmatine, M. Rezouga, R. Gouri, K. Medles, and L. Dascalescu, "Experimental analysis of a cyclone tribocharging device for free-fall triboelectric separation of plastic particles," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 20, pp. 1584-1589, 2013.

[22] A. Benabboun, A. Tilmatine, Y. Brahami, S. Bendilerad, M. Miloudi, and K. Medles, "Experimental investigation of electrostatic separators of plastic particles using different charging devices," *Separation science and technology*, vol. 49, pp. 464-468, 2014.

[23] G. Dodbiba, J. Sadaki, K. Okaya, A. Shibayama, and T. Fujita, "The use of air tabling and triboelectric separation for separating a mixture of three plastics (cyclone)," *Min. Eng.*, vol. 18, pp. 1350–1360, 2005.

[24] M. Rezoug, R. Ouiddir, W.Aksa, K. Medles, M. Bilici, and L. Dascalescu, "Tribo-aero-electrostatic separator for tenary mixtures of granular plastics," *IEEE Trans. Ind. Appl.*, vol. 51, pp. 1161-1167, 2014.

[25] M. Miloudi, K. Medles, A.Tilmatine, M. Brahami, and L. Dascalescu, "Modeling and optimization of a propeller-type tribocharger for granular materials," *J. Electrostat.*, vol. 69, No. 1–3, pp. 631-637, 2011.