Factors that Influence the Efficiency of a Tribo-Aero-Electrostatic Separator for Finely-Grinded Matter

Sara Messal[1], Abdelkader Mekhaleff [2], Karim Medles[2], Thami Zeghloul[1], Lucian Dascalescu[1*]
[1]PPRIME Institute, CNRS – Université de Poitiers - ENSMA
IUT, Angoulême, France
[2]Université Djillali Liabes, Sidi-Bel-Abbes, Algeria
e-mail: lucian.dascalescu@univ-poitiers.fr

***Abstract*—The aim of this work is to evaluate the effects of several factors that affect the selective sorting of fine particles in a two-rotating-disks-type tribo-aero-electrostatic separator. The experiments are carried out on a synthetic mixture composed of 50% Acrylonitrile Butadiene Styrene (ABS) and 50% Polystyrene (PS) particles of size 250 to 1000 microns. The six factors under study are: the high voltage, the rotation speed of the disks, the duration of the tribo-charging process, the duration of the separation, the fluidisation air flow rate, and the initial mass of the granular mixture to be processed. The performance of the separator is evaluated by setting up a measurement system that enables the continuous and simultaneous recording of the charges and the masses of the separated products. The conclusions of this study will serve at the optimum design of an industrial electrostatic separator for the recycling of micronized plastics from waste electric and electronic equipment.**

I. INTRODUCTION

Numerous research studies have been made on the electrostatic separation of granular insulating materials [1-2], with many industrial applications in the area of waste electric and electronic equipment (WEEE) recycling. However, few investigators have studied the electrostatic separation of finely grinded matter (i.e., granule diameter < 1 mm), and the existing applications are mainly in mineral processing, or in food industry [3-4].

The classic electrostatic separation technologies for granular mixtures of plastic wastes involve the pre-charging of the product using a tribocharging device, such as a fluidized bed, a tribocyclone, a ventilator, a rotating drum or a vibratory feeder [5-11]. The charged granular mixture is then separated by the Coulomb forces exerted in the intense electric field of a free-fall or drum-type electrostatic separator [12-14].

Many works have been published on the optimization of such triboelectrostatic separation technologies. The researches carried out in several American, Japanese, European, Canadian and Algerian laboratories, have largely proved the efficiency of tribo-electrostatic separators in the selective sorting of mm-size granules [15-21].

They have also pointed out the problems that still have to be solved prior to industrial application of the electrostatic separation of finely-grinded wastes. The main difficulty is to control the trajectories of the particles, which are strongly affected by the aerodynamic forces [22-23]. However, two different types of tribo-aero-electrostatic separators capable to separate these particles have recently been described. In one of them, the electric field is generated between two rotating disks electrodes connected to high-voltage supplies of opposite polarities and entrained by a variable-speed motor [24]. In the other, two vertical parallel-plate high-voltage electrodes of opposite polarities alternatively move in and out of the fluidized bed containing the finely-grinded mixture of materials to be separated [25]. Both of them have proved their effectiveness in the separation of fine plastics particles, originating from WEEE.

The aim of this paper is to evaluate the effects of several factors that affect the selective sorting of fine particles in a two-rotating-disks-type tribo-aero-electrostatic separator. The performances of this separator are evaluated by setting up measurement systems that enable the simultaneous recording of the charges and masses of separated products.

II. EXPERIMENTAL SET UP

The novel two-rotating-disks-type tribo-aero-electrostatic separator (Fig. 1), designed by the authors and built by the CITF Company, Saint Cybardeaux, France, is able to sort granular or micronized materials through the use triboelectric effect as physical mechanism of electrical charging.

Fig. 1. Two-rotating-disks-type tribo-aero-electrostatic separator;
1: Variable speed DC electric motors, 2: Separation chamber, 3: Disk electrodes, 4: Collecting boxes, 5: Air blower, 6: Control panel, 7: Faraday cages, 8: Scales.

Up to 750 g of micronized materials can be introduced in the fluidized bed generated inside the separation chamber of dimensions 160 x 160 x 240 mm, made of transparent PMMA walls. The fluidization air is provided by variable-speed air blower of 1.5 kW / 4000 rpm / 166 m^3/h. The fluidized bed has a maximum height of 10 cm from the porous plate that uniformly distributes the air in the separation chamber.

The tribo-electrisation of the materials inside a fluidized bed is due to the multiple particle-to-particle and particle–wall collisions.

The electric field is generated between two rotating disk electrodes (stainless steel; diameter: 220 mm; thickness: 2 mm) that are distanced at a variable interval ranging from 40 to 120 mm. The disks are connected to reversible (positive or negative) high voltage power supplies, and entrained at variable speed by electric motors. The products are recovered in two collecting boxes.

III. Materials and methods

The mixture of particles to be separated simulates the composition of micronized waste electric and electronic equipment (WEEE). For each experiment, a sample containing 100 g of Acrylonitrile Butadiene Styrene (ABS) and 100 g of Polystyrene (PS) is used. The average diameter of the particles of the mixture ranged between 500 µm and 1000 µm.

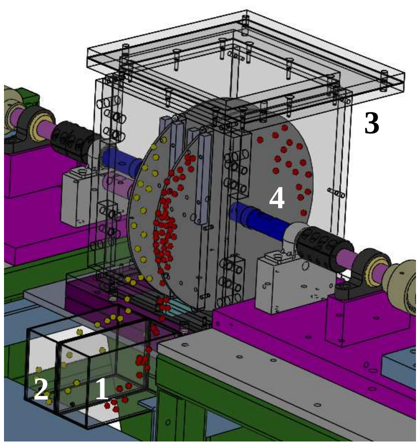


Fig. 2. Two-box collecting system of the laboratory two-rotating-disks-type tribo-aero-electrostatic separator; 1: Collecting box for positively-charged ABS particles; 2: Collecting box for negatively-charged PS particles; 3: Separation chamber, 4: Disks.

The process is multifactorial, and the experimental analysis is carried out by considering all possible factors: the high voltage U [kV], the rotation speed of the disks v [rpm], the duration of the tribo-charging process t_c [s], the duration of the separation t_s [s], the fluidisation air flow rate n [m^3/h], and the initial mass of the granular mixture to be processed m [g], using measurement systems that enable the continuous and simultaneous recording of the charge and masses of separated products. The equipment used in the laboratory consists of two electronic balances with the upper limit 2 kg, with a resolution of 0.1 g, two Faraday cages connected with two electrometers Keithley 6514, a data acquisition card GPIB, and the software LabVIEW 6.

Each experiment involves the following steps:

- Introduce the ABS/PS mixture in the separation chamber,
- Switch on the measuring devices: the electronic scales, electrometers to which are also connected the Faraday cages
- Switch on the electrical equipment: the air blower, the electric motors, and the high voltage power supplies.
- Start the data acquisition software LabVIEW 6.
- Turn off the electrical equipment.
- Stop the data acquisition.
- Clean the electrostatic separator.

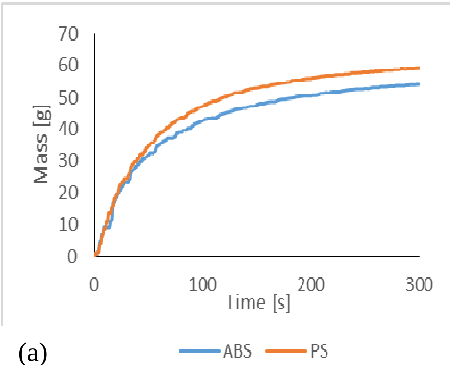
A set of six experiments is performed, at a constant distance between the disks electrodes: 120 mm.

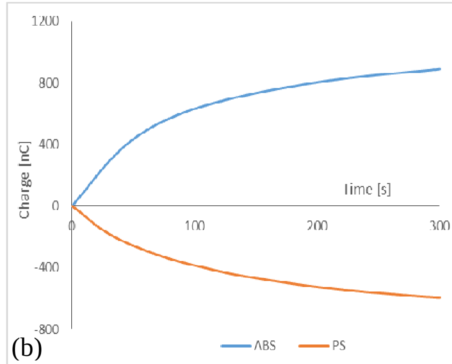
- A first experiment is performed for a duration of t_s = 300 s, for U = ±8 kV, v = 30 rpm, m = 200 g, n = 6.4 m^3/h, and t_c = 0 s.
- The duration of the second experiment is t_s = 100 s. The initial mass m of the granular mixture to be processed is varying from 200 g and 400 g, with the other control variables of the process maintained at constant values: U = ±8 kV, v = 30 rpm, n = 6.4 m^3/h, and t_c = 0 s.
- The effect of the duration of the tribo-charging process t_c is investigated in the third experiment. Thus t_c is successively 0 s, 10 s and 20 s.for U = ±8 kV, t_s = 100 s, v = 30 rpm, m = 200 g, and n = 6.4 m^3/h.
- In the fourth experiment, the fluidisation air flow rate n is varied between 6 m^3/h and 6.8 m^3/h, at U = ±8 kV, t_s = 100 s, v = 30 rpm, m = 200 g, and t_c = 0 s.
- The control variable under investigation in the fifth experiment is the rotation speed of the disks v, which is varied between 15 rpm and 65 rpm, at U = ±8 kV n = 6.4 m^3/h, t_s = 100 s, m = 200 g, and t_c = 0 s.
- Finally, in the sixth experiment, the high voltage U is varied between 4 kV and 20 kV, at n = 6.4 m^3/h, t_s = 100 s, v = 30 rpm, m = 200 g, and t_c = 0 s.

All the experiments are performed in stable ambient conditions (relative humidity: 45% to 57%; temperature: 18°C to 20°C).

IV. Results and discussion

The results of the first set of experiments are given in Fig. 3. They show only a slight difference between the masses of ABS and PS particles collected after 300 s. The charge/mass ratio of the PS particles, which charge less in contact with the PMMA walls, is only 2/3 of that recorded for the ABS. The larger the initial mass in the fluidized bed, the larger are also the quantities of products collected in a unit of time (Fig. 4).The charge/mass ratio of the collected products slightly decreases with the increase of the initial mass of the treated sample (Fig. 4.b). Indeed, when the fluidizing bed is high (i.e., when the initial mass is larger), the particles need less charge for being attracted to the electrodes.





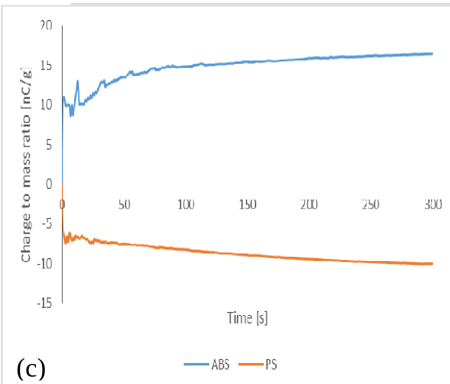


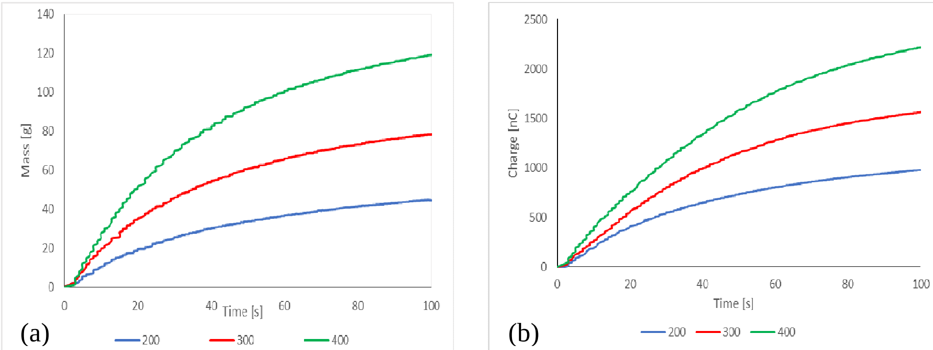
Fig. 3. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for a 200 g sample of a granular mixture composed of 50% ABS and 50% PS (air flow rate: n =6.4 m^3/h; applied high voltage: U = ±8 kV; rotating speed of the disk electrodes: v = 30 rpm; and duration of the pre-charging t_c = 0 s).

The variation of mass, charge and charge/mass ratio is similar for the PS product collected during the tribo-aero-electrostatic separation process of the 200 g, 300 g and 400 g samples of the granular mixtures under study.

The duration of the pre-charging has little effect on the outcome of the separation (Fig. 5).The longer pre-charged ABS particles are slightly faster collected than the non-pre-charged ones (Fig. 5.a), as they have a higher charge/mass ratio (Fig. 5.c). The PS particles have a similar behaviour. These materials are known to charge very well by triboelectric effect. Other couples of insulating materials may require a pre-chargement prior to the start of the tribo-aero-electrostatic separation.

The fluidisation air flow rate drastically influences the conditions of particle charging and hence the rate at which the products are separated and collected (Fig. 6).The higher flow-rates are accompanied by more numerous and more intense particle-particle collisions. Thus, the higher charge/mass ratios attained at higher air flow rates (Fig. 6.c) favour the rapid separation of the particles.

The rotational speed of the disk electrodes does not significantly influences the outcome of the separation (Fig. 7.a).This result is quite surprizing, when examined in relation with the charge vs time curves displayed in Fig. 7.b. However, a simple explanation can be given to the higher charge/mass ratios of the particles collected at lower values of the rotational speed of the electrode (Fig. 7.c).



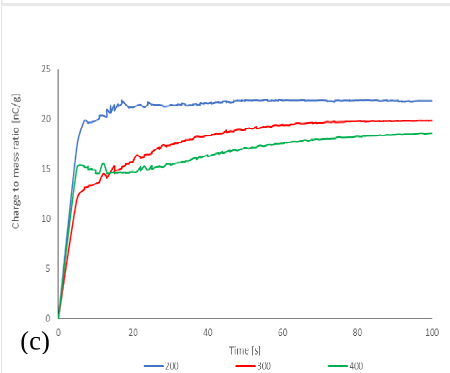
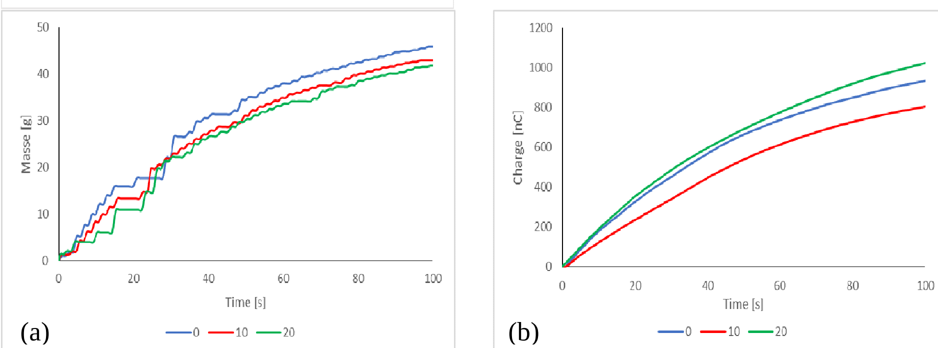


Fig. 4. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for the ABS product recovered from 200 g, 300 g and 400 g samples of a granular mixture composed of 50% ABS and 50% PS (air flow rate: n =6.4 m^3/h; applied high voltage: U = ±8 kV; rotating speed of the disk electrodes: v = 30 rpm; and duration of the pre-charging t_c = 0 s)



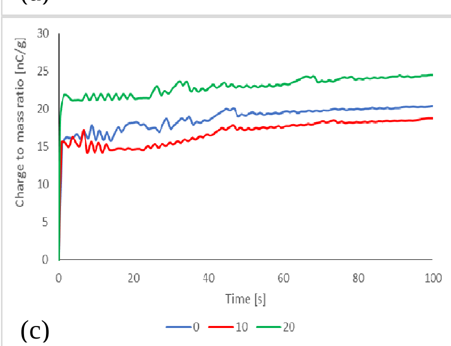
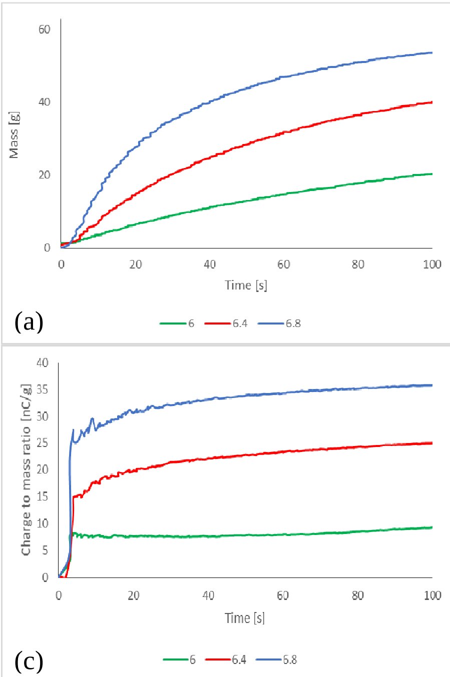


Fig. 5. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for the ABS product recovered from a 200 g sample of a granular mixture composed of 50% ABS and 50% PS, pre-charged for three charge durations t_c = 0 s, 10 s and 20 s (air flow rate: n =6.4 m^3/h; applied high voltage: U = ±8 kV; rotating speed of the disk electrodes: v = 30 rpm).



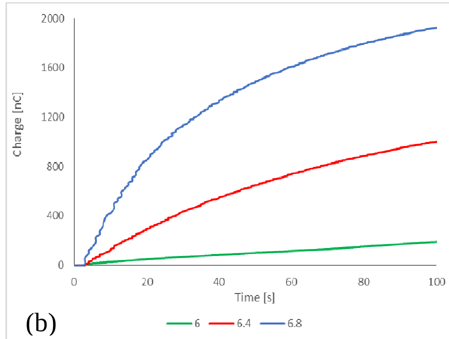
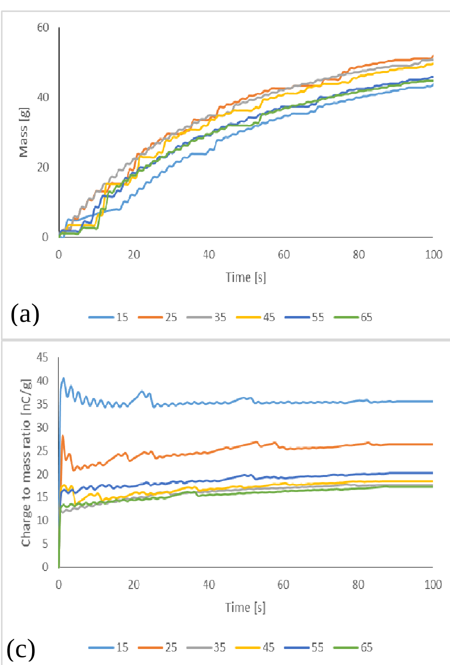


Fig. 6. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for the ABS product recovered from a 200 g sample of a granular mixture composed of 50% ABS and 50% PS, charged for three air flow-rates n = 6 m^3/h, 6.4 m^3/h and 6.8 m^3/h (applied high voltage: U = ±8 kV; rotating speed of the disk electrodes: v = 30 rpm; and duration of the pre-charging t_c = 0 s).



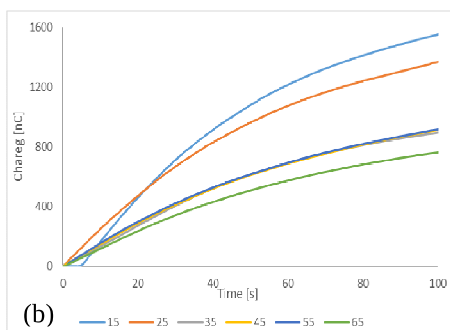
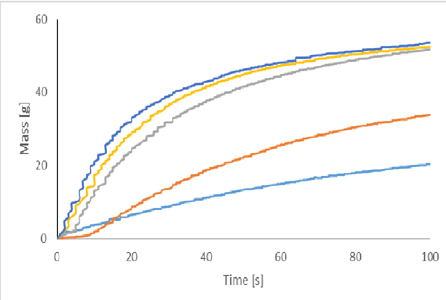
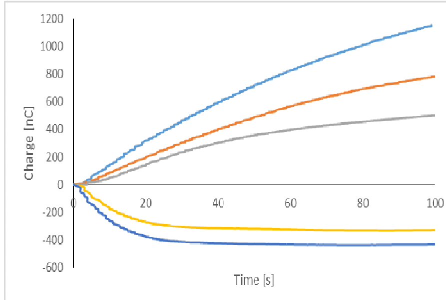


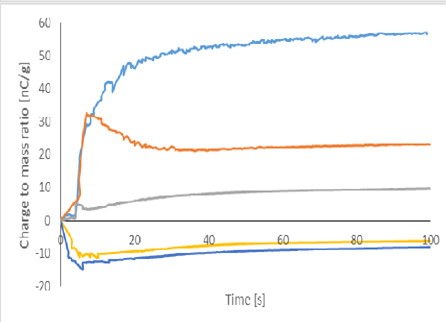
Fig. 7. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for the ABS product recovered from a 200 g sample of a granular mixture composed of 50% ABS and 50% PS, with the disk electrodes rotating at various speeds (air flow rate: n =6.4 m^3/h; applied high voltage: U = ±8 kV; and duration of the pre-charging t_c = 0 s).



(a)



(b)



(c)

Fig. 8. Mass (a), charge (b) and charge/mass ratio (c) vs. time, for the ABS product recovered from a 200 g sample of a granular mixture composed of 50% ABS and 50% PS, with the disk electrodes energized at various high-voltages (air flow rate: n =6.4 m^3/h; rotating speed of the disk electrodes: v = 30 rpm; and duration of the pre-charging t_c = 0 s).

At speeds higher than 30 rpm, the particles form a mono-layer at the surface of the disks. In contact with an electrode of opposite polarity, the particles may lose part of their charge. At speeds lower than 30 rpm, the particles are collected as a multiple-layer. As many of them do not come into contact with the electrode, they preserve their charge, and hence the charge/mass ratio of the collected product is higher than at higher speeds.

As expected, the separation is faster at higher levels of the voltages applied to the disk electrodes (Fig. 8.a). Quite surprisingly, at higher voltages, the charge of the collected particles is similar to that of the collecting electrodes. When the potential of the disks exceeds 16 kV in absolute value, a corona discharge occurs from their sharp edges. In their free fall to the Faraday cages in which they are collected, the particles cross the corona discharge zones at the edges of the electrodes and modify their charging state.

V. Conclusions

The disk-type tribo-aero-electrostatic separator presented in this paper may be an effective solution for the recycling of micronized plastics mixtures, obtained from WEEE.

The duration of the pre-charging and – beyond a certain threshold – the rotational speed of the disk electrodes, do not affect the outcome of the separation. The factors that have a significant effect on the separation process are: the applied high-voltage, the fluidisation air flow rate, and the mass of the product to be separated. Further research work will focus on process optimization and its possible applications in food industry.

REFERENCES

[1] L. Calin, L. Caliap, V. Neamtu, R. Morar, A. Iuga, A. Samuila, and L. Dascalescu, “Tribocharging of granular plastic mixtures in view of electrostatic separation,” IEEE Trans. Ind. Appl., vol. 44, pp. 1044-1051, 2008.

[2] M. Bilici, L. Dascalescu, C. Dragan, O. Fati, A. Iuga, and A. Samuila, “Tribocharging and electrostatic separation of mixed granular solids in fluidized bed devices,” IEEE Trans. Diel. Electr. Insul. vol. 18, pp. 1476-1483, 2011.

[3] Y. Hemery, X. Rouau, V. Lullien-Pellerin, C. Barron, and J. Abecassis, “Dry processes to develop wheat fractions and products with enhanced nutritional quality,” Journal of Cereal Science, vol.46, pp.327–347, 2007.

[4] F. Cangialosi, M. Notarnicola, L. Liberti, and J.M. Stencel, “The effects of particle concentration and charge exchange on fly ash beneficiation with pneumatic triboelectrostatic separation,” Separation and Purification Technology, vol. 62, pp. 240–248, 2008.

[5] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami, and L. Dascalescu, “Modeling and Optimization of a Peopeller-type Tribocharger for Granular Materials” J.Electrostat, vol. 69, pp. 631-637.2011

[6] M. Sarki and A. Masumoto, “Electrostatic Separation of Chopped Waste Electric Cables”, Journal of Environment and Engineering, vol. 2, No. 2, 2007

[7] A. Iuga, L. Calin, V. Neamtu, A. Mihalcioiu, and L. Dascalescu, “Tribocharging of plastics granulates in a fluidized bed device“J. Electrostat, vol. 63, pp. 937-942, 2005.

[8] 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, vol. 34, pp. 45 – 54, 2016.

[9] Y. Higashiyama and K. Asano, “Recent progress in electrostatic separation technology”, particulate science and technology, vol.16:1, pp.77-90, 1998

[10] S. Kazmierczak, P. Anglaret et J. Filippi, “ Technologie Génie Chimique” Centre régional de documentation pédagogique, Tomes 3, 1989.

[11] S.L. Escalante, G. Touchard, and G. Dominguez, « Electrification study in dielectric material fluidized beds for different fluidization regimes », Annual report conference on electrical insulation and dielectric phenomena, pp.694-697, 2002.

[12] J.D. Brown, and P.F. Wynen, “Tribo-charging and Electrostatic Separation of Mixed Electrically Insulating Particles”, U. S. Patent Vol.6, pp.927-354, August 9, 2005.

[13] W. Aksa, K. Medles, M. Rezoug, M. Boukhoulda, M. Bilici, L. Dascalescu, “Two stage electrostatic separator for the recycling of plastics from waste electrical and electronic equipment”, Journal of Electrostatics, vol. 71, pp.681-688, 2013.

[14] A. Tilmatine and L. Dascalescu, “Set-point identification of a free-fall triboelectrostatic separation process for plastic particles”, International Journal of Environmental Studies, vol. 67, no. 1,pp. 27–40, February 2010.

[15] A. Tilmatine, K. Medles, M. Younes, A. Bendaoud, and L. Dascalescu, “Roll-type versus free-fall electrostatic separation of tribocharged plastic particles,” IEEE Trans. Ind. Appl., vol. 46, no. 4, 1564–1569, Jul./Aug. 2010

[16] M. Miloudi, , M. Remadnia, C. Dragan, K. Medles, A. Tilmatine, and L. Dascalescu, “Experimental Study of the Optimum Operating Conditions of a Pilot-Scale Tribo-Aero-Electrostatic Separator for Mixed Granular Solids”, IEEE Trans. Ind. Appl., vol. 49, no. 2, pp. 699- 706, 2013.

[17] M. Boukhoulda, M. Miloudi, K. Medles, M. Rezoug, A. Tilmatine, and L. Dascalescu, “Experimental Modeling of a New Triboelectrostatic Separation Process for Mixed Granular Polymers”, IEEE Trans. Ind. Appl., vol. 49, no. 6, pp. 2375- 2381. 2013.

[18] M. Miloudi, L. Dascalescu, LI. Jia, K. Medles, A. Tilmatine, “Improved Overall Performances of a Tribo-Aero-Electrostatic Separator for Granular Plastics From Waste Electric and Electronic Equipment”, IEEE Trans. Ind. Appl., vol. 51, pp. 4159-4165, 2015.

[19] W. Aksa, K. Medles, M. Rezoug, R. Ouiddir, A. Bendaoud, and L. Dascalescu, “Modelling and optimization of a separator for granular mixtures of multiple insulating materials.” IEEE Trans. Ind. Appl., vol. 51 pp. 4743-4751. 2015.

[20] H. Daiku, T. Inoue, M. Tsukahar, H. Maehata, and K. Kakeda, “Electrostatic Separation Technology for Waste Plastics”, in Conf. Rec. IEEE Annu. Meeting, pp. 562 – 565, Dec 2001.

[21] C. Park, H. Jeon, and J. Park, “PVC removal from mixed plastics by triboelectrostatic separation”, Journal of Hazardous Materials, vol. 144, pp. 470–476, 2007.

[22] A. Mekhalef, K. Medles, F. Boukhoulda, A. Tilmatine, S. Messal, L. Dascalescu, “Study of a tribo-aero-electrostatic separator for mixtures of micronized insulating materials », IEEE Trans. Ind. Appl. vol 51, no 5, pp. 4166– 4172, 2015.
[23] S. Messal, T. Zeghloul, A. Mekhalef, and L. Dascalescu. “Sorting of finely-grinded granular mixtures using a belt-type corona-electrostatic separator”. Conf. Rec. IEEE/IAS Annual Meeting, Dallas, October 18-22 2015.
[24] A. Tilmatine, A. Benabboun, Y. Brahmi, A. Bendaoud, M. Miloudi, and L. Dascalescu, “Experimental investigation of a new triboelectrostatic separation process for mixed fine granular plastics”. IEEE Trans. Ind. Appl, vol. 50, pp. 4245 – 4250, 2014.
[25] Y. Brahami, A. Tilmatine, R. Ouiddir, A. Bendaoud, K. Medles, and L. Dascalescu, “Experimental Modelling of a New Triboelectrostatic Separation Process for Micronized Plastics.” IEEE Trans. Ind. Appl, vol. 51, pp.4145 – 4150, 2015.