Tribo-aero-electrostatic Separation of Micronized Waste Plastics

Imed Eddine Achouri[1, 2], Thami Zeghloul[1*], Karim Medles[1] , Gontran Richard[1],
Hamou Nouri[2] , Lucian Dascalescu[1]
[1]PPRIME Institute, University of Poitiers – IUT, Angoulême, France
[2] Ferhat Abbas University of Setif-1, Algeria
* e-mail: thami.zeghloul@univ-poitiers.fr

***Abstract*— Electrostatic separation of granular plastics mixtures has become a well-established technology, with industrial applications in the area of waste electric and electronic equipment (WEEE) recycling. The aim of this work is to validate the feasibility of selectively sorting of micronized waste plastics in a two-rotating-disks-type tribo-aero-electrostatic separator. The experiments are carried out on a binary mixture composed of Polypropylene (PP) and Polycarbonate (PC) particles of size 250 µm to 500 µm. A measurement system was set-up to enable the continuous and simultaneous recording of the charges and masses of the separated products. It was thus possible to evaluate the performances of the separator operated at various applied high-voltages.**

I. Introduction

Every year larger quantities of plastics wastes are generated. Before recycling, plastics must be sorted according to their type [1]. Tribo-electrostatic separation represents a solution for the selective sorting of plastic mixtures [2-3], this technique is simple, energy-saving and able to lead to high quality of the separation products [4]. In this process, the particles are first triboelectrically charged and then fed into an electric field separator [5]. The particle trajectories are deflected in the electric field according to the polarity and amount of charge [6-7].

Currently, research and development efforts are focused on the development of the separation of granular waste plastics [8-9], for the protection of the environment. In spite of noticeable research efforts targeted at the performance optimization of the various types of electrostatic separators [10-11], the industry application of such technology still faces major difficulties, related to the specific behaviour of fine (sub-millimetre-size) particles [12].

In order to address this problem, a new type of tribo-electrostatic separator has been developed at the Applied Electrostatic Research Unit of the PPRIME Institute, on the Angoulême Campus of the University of Poitiers. The aim of the present paper is to evaluate the efficiency of this new device in the separation of a PP/PC granular waste, with particle size in the range 250 µm - 500 µm. By continuous measurement of the masses and charges of the particles collected at the outlet of the separator, it was possible to analyse the effect of the high-voltage applied to the electrode system on the purity of the products and asses the perspectives of industry application of this new technology .

II. EXPERIMENTAL SET-UP

The new 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 of triboelectric effect as physical mechanism of electrical charging. The equipment consists of a separating chamber of 160 mm x 160 mm x 240 mm, made of transparent PMMA walls, enclosing two rotating-disk-type electrodes, entrained at adjustable speed by two DC electric motors. The two disks, which have a diameter of 220 mm and a thickness of 2 mm, are spaced from each other by a variable gap ranging from 40 mm to 120 mm. They are energized from two high-voltage generators of opposing polarities (SPELLMAN, 30 kV / 0.5 mA).

Four-hundred-gram samples of the powdery mixture to be separated are introduced in the separation chamber, which also serves as fluidized-bed-type tribo-charging device. The fluidized bed is generated by the injection of air from a variable speed blower (1.5 kW / 4000 rpm / 166 $m^3.h^{-1}$), through the porous material that composes the base of the separation chamber. In this fluidized bed, the particles collide with each-other and with the PMMA walls of the chamber, so that they get charged by tribo-electric effect. The charged particles are then attracted to the two disk electrodes and stick to them. By rotating, the disk electrodes carry the separated particles to the product collector. Indeed, the front face of the chamber has slots through which the disks come out, so that two brushes may remove the particles which stick to them.

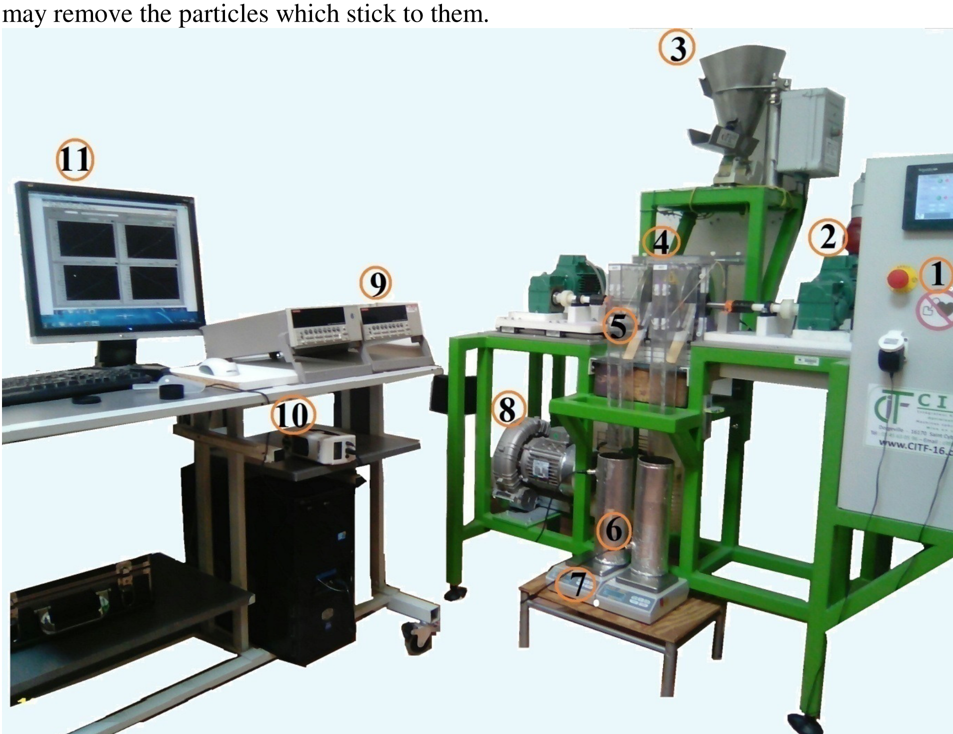

Fig.1. Photograph of the two-rotating-disks-type tribo-aero-electrostatic separator; 1: Control panel; 2: Variable speed DC motors; 3: Vibratory feeder; 4: Separation chamber; 5: Rotating disk electrodes; 6: Faraday cages; 7: Scales; 8: Air blower; 9: Electrometers (Keithley 6514); 10: Portable colorimeter NH310, 11: Computer.

The separated products are recovered in two Faraday cage collectors connected to two electrometers (KEITHLEY, model 6514) and placed on two electronic scales with a resolution of 0.1 g and an upper limit of 2 kg. The electrometer and the two scales are connected to a PC via GPIB and RS232. The charges and masses measured by the instruments are recorded using a data acquisition program piloted by Lab View.

The separator is equipped with a control panel allowing direct reading or instantaneous acquisition of all the operating data: the high voltages applied to the electrode system; the rotation speeds of the two disks; the speed of the air blower; the flow rate of the fluidisation air.

III. MATERIALS AND METHOD

The powdery material mixture used in the present study comprised two types of particles, mauve PP and white PC, supplied by APR2 Company, a French company specialized in recycling waste electrical and electronic equipment (WEEE). The size of these particles is typically between 250 µm-500 µm, and their electrical properties are given in a Table 1.

The study was performed with 400-g samples composed of 50% PP and 50% PC particles, at various high voltage applied to the electrode system. These experiments were all carried out on the same machine, by the same operators, using the same samples and under the same climatic conditions of humidity *RH*=50-65% and temperature *T*=14-19°C, in order to eliminate any cause of variability in the separation process.

TABLE 1: ELECTRICAL PROPERTIES OF PP AND PC MATERIALS

Electrical properties	**Polypropylene (PP)**	**Polycarbonate (PC)**
Conductor or insulator	Good insulator	Good insulator
Electrical resistivity (µohm.cm)	$3.3e^{22}$ - $3e^{23}$	$1e^{20}$ - $1e^{21}$
Dielectric constant (relative permittivity)	2.1 - 2.3	3.1 - 3.3
Dissipation factor (dielectric loss tangent)	$3e^{-4}$ - $7e^{-4}$	$8e^{-4}$ - 0.0011
Dielectric strength $1*10^6$ V/m	22.7 - 24.6	15.7 - 19.2

The experimental procedure consisted of the following steps: (1) Introduce the PP/PC mixture in the separation chamber; (2) Switch on the measuring devices: the electronic scales and the electrometers to which are connected the Faraday cages; (3) Switch on the electrical equipment: the air blower, the electric motors, and the high voltage power supplies; (4) Start the data acquisition software Lab VIEW 6; (5) Turn off the electrical equipment; (6) Stop the data acquisition; (7) Clean the electrostatic separator.

The experiments were carried out at a constant distance of 120 mm between the electrodes and at a rotating speed of 50 rpm. The purity was measured using a portable NH310 colorimeter. A calibration table was set up for mixtures of products ranging from 0% to 100% in steps of 10% for product PP and from 100% to 0% for -10% for product PC. The colorimeter provides measurements in several modes: *L*, *a*, *b*, *C*, and *h*.

IV. Results and Discussion

The results of the calibration procedure of the colorimeter (Table 2) enabled the formulation of mathematical models for the purity of the products, as a function of the five parameters *L*, *a*, *b*, *C*, and *h*. For example, the purity of the PP product was expressed as follows:

$$PP(\%) = 477 - 5.83\, L + 1.1\, a + 13.4\, b + 5.8\, C + 0.092\, h \qquad (1)$$

Table 2: Calibration table for mixtures of products ranging from 0% to 100%

PP (%)		100	90	80	70	60	50	40	30	20	10	0
Parameter	**L**	50.8	52.9	55.0	56.4	60.0	62.7	65.6	69.6	73.9	81.3	95.3
	a	29.2	27.6	25.2	24.6	19.8	19.3	17.8	14.4	12.0	8.9	0.2
	b	-28.0	-26.8	-25.2	-25.1	-21.1	-20.5	-18.9	-15.3	-12.5	-7.5	3.7
	C	40.4	38.5	35.6	35.1	28.9	28.2	26.0	21.0	17.4	11.7	3.7
	h	316.2	315.8	314.9	314.4	313.1	313.2	313.4	313.1	313.9	320.0	87.5
PP (%) from (1)		**101.6**	**91.8**	**81.4**	**72.2**	**62.6**	**49.7**	**40.7**	**32.2**	**21.1**	**9.3**	**0.8**

The effect of the applied high-voltage *U* on separation of the collected granules is illustrated by the results represented on Figs. 2 to 5. The non-smooth aspect these curves is due to fact that a tiny proportion of charged particles detached from the electrodes may be attracted to some parts of the ducts that transfer them to the Faraday cages.

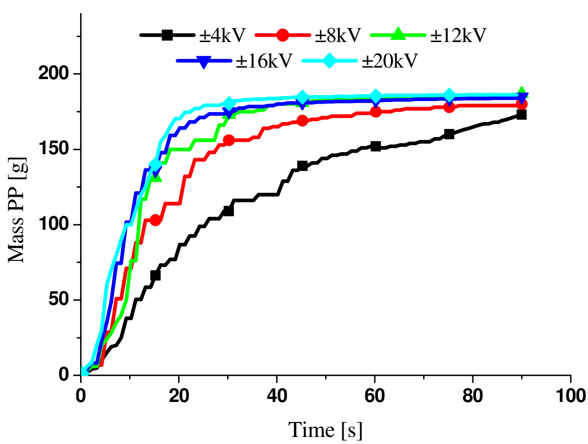

Fig. 2. Variation of the mass of separated PP granules as function of time, at different voltage values *U*= ±4; ±8; ±12; ±16; ±20 kV.

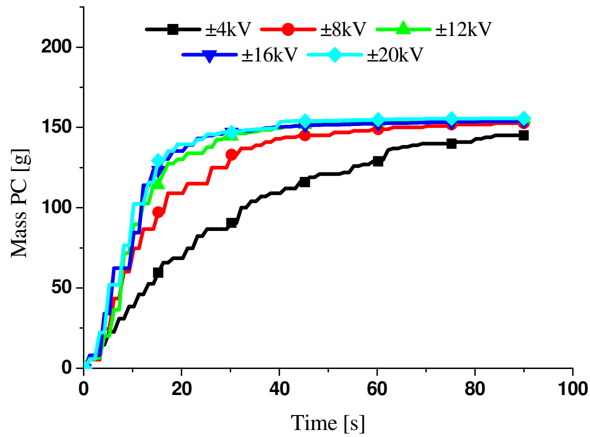

Fig. 3. Variation of the mass of separated PC granules as function of time, at different voltage values *U*= ±4; ±8; ±12; ±16; ±20 kV.

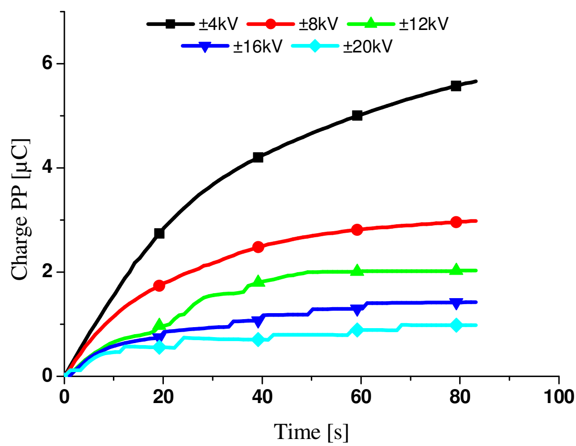

Fig. 4. Variation of the charge of separated PP granules as function of time, at different voltage values *U*= ±4; ±8; ±12; ±16; ±20kV.

The increase of *U* intensifies the electric field in the separation zone and facilitates the separation. For each experiment, the purity of samples was measured and analysed three times, as shown in Fig. 8. The final average values of the purity are given in Fig. 9. The higher values of the voltage favor the rapid separation of the products but reduce purity.

From these results, the optimum value of the voltage applied to the electrodes is ±4 kV, this means that the separation is good at the small voltage value with a percentage of the purity of 90.7% PP and 92.1% PC, with mass and electric charges values successively m_{PP}=161.7 g, $q_{PP} = 5.73\times10^{-6}$ C and m_{PC}=139.6 g, $q_{PC} = -7.32\times10^{-6}$ C.

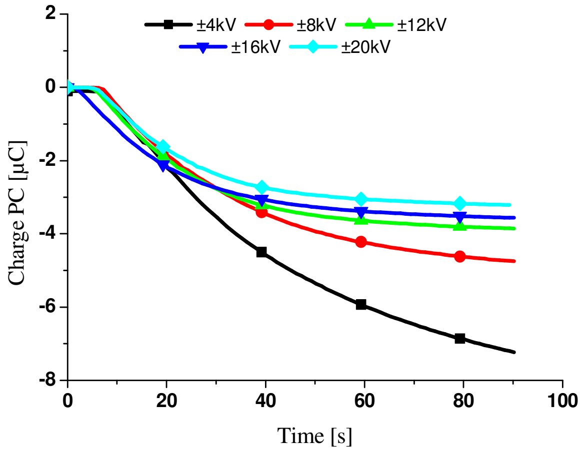

Fig. 5. Variation of the charge of separated PC granules as function of time, at different voltage values *U*= ±4; ±8; ±12; ±16; ±20 kV.

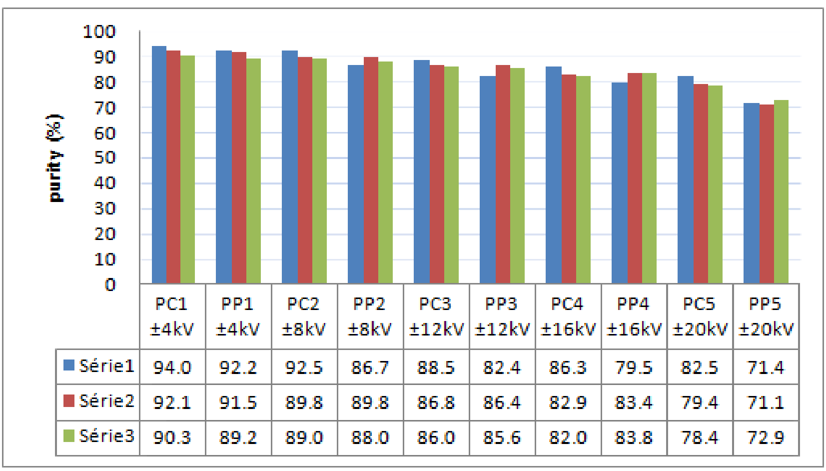

Fig. 6. The purity of samples is measured three times at different voltage values *U*= ±4; ±8; ±12; ±16; ±20kV

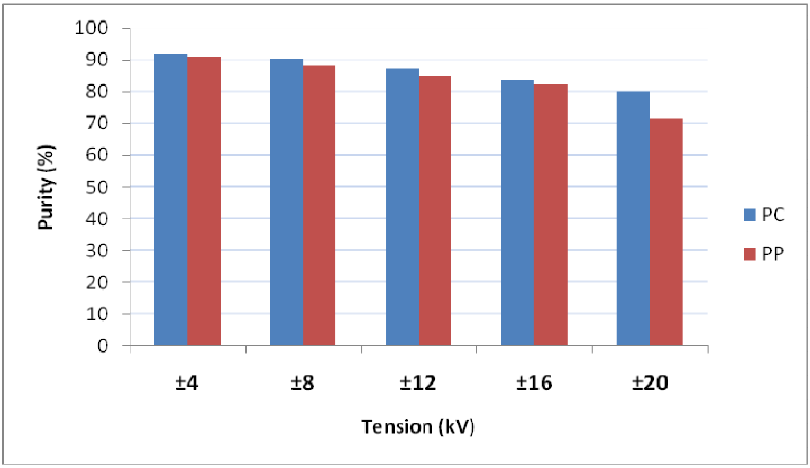

Fig. 8. The average purity at different voltage values *U*= ±4; ±8; ±12; ±16; ±20kV

V. Conclusions

The two-rotating-disk-type tribo-aero-electrostatic separator developed on the site of Angoulême of PPRIME Institute of Poitiers, is a multifunctional installation. It enabled the study of the feasibility of electrostatic separation on a PP/PC powdery mixture.

The main conclusion of the present work can be formulated as follows;

1. The purity of the separated products can be conveniently evaluated using a colorimetric method.
2. The higher voltages applied to the electrodes does not necessarily lead to better separation.
3. If the voltages are high, the fine particles lose rapidly their charges in contact with the electrodes.
4. The optimal value of the separation voltage can be experimentally determined.
5. Purities higher than 90% can be obtained for both collected products.

Acknowledgment

The authors also acknowledge with thanks the support of APR2 Company, for financial support, and CITF Company, for the contribution to the manufacturing of the new equipment. Part of this work was completed within the framework of a FEDER project, co-financed by the European Union.

References

[1] M.J. Pearse, and T.J. Hickey, "The separation of mixed plastics using a dry triboelectric technique," *Resour. Conserv. Recy.*, vol. 3, pp. 179– 190, 1978.

[2] T. Zeghloul, A. Mekhalef, G. Richard, K. Medles, and L. Dascalescu, "Effect of particle size on the tribo-aero-electrostatic separation of plastics," *J. Electrostat*, vol. 88, pp. 24-28, 2017.

[3] A. Mekhalef, K. Medles, M.F. Boukhoulda, A.Tilmatine, S. Messal, and L. Dascalescu, “Study of a tribo-aero-electrostatic separator for mixtures of micronized insulating materials,” *IEEE Trans. Ind. Appl.*, Industry Applications, vol. 51, pp. 4166-4172, 2015.

[4] A. Tilmatine, S. Bendimerad, F. Boukhoulda, K. Medles, and L. Dascalescu, “Electrostatic separation of particles. Application to plastic/metal, metal/metal and plastic/plastic mixtures”, *Waste Management* vol. 29, pp. 228-232, 2009.

[5] 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.

[6] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami, and L. Dascalescu,“Optimisation of belt-type electrostatic separation of granular plastic mixtures tribocharged in a propeller-type device,” *J. Phys., Conf. Series*, vol. 301, no. 1, p. 012067, 2011.

[7] A. Tilmatine, S. Bendimerad, M. Younes, and L. Dascalescu, “Experimental analysis and optimisation of a free-fall triboelectric separator of granular plastic particles,” *Int. J. Sustain. Eng.*, vol. 2, no. 3, pp. 184–191, 2009.

[8] L. Dascalescu, R.Morar, A. Iuga, A. Samuila, and V. Neamtu, “Electrostatic separation of insulating and conductive particles from granular mixes,” *Particulate Sci. Technol.*, vol. 16, no. 1, pp. 25–42, 1998.

[9] G. Dodbiba, A. Shibayama, T. Miazaki, and T. Fujita, “Triboelectrostatic separation of ABS, PS and PP plastic mixture,” *Mater. Trans.*, vol. 44, no. 1, pp. 161–166, 2003

[10] L. Dascalescu, A. Tilmatine, F. Aman, and M. Mihailescu, “Optimisation of electrostatic separation processes using response surface modeling,” *IEEE Trans. Ind. Appl.*, vol. 40, no. 1, pp. 53–59, 2004.

[11] K. Medles, A.Tilmatine, F. Miloua, A. Bendaoud, M. Younes, M. Rahli, and L. Dascalescu., “Set point identification and robustness testing of electrostatic separation processes,” *IEEE Trans. Ind. Appl*, vol. 43, no. 3, pp. 618–626, 2007.

[12] C. Park, H. Jeon, and J. Park, “PVC removal from mixed plastics by triboelectrostatic separation,” J. *Hazard. Mater.*, vol. 144, pp. 470–476, 2007.