Roll-type versus Free-fall Electrostatic Separation of Tribocharged Plastic Particles

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***Abstract*— Tribocharged mixed granular materials are commonly separated in the electrostatic field generated between two vertical plate electrodes. However, the existing technologies are not appropriate for sorting coarse granules (size > 2 mm) for which the effect of gravity is stronger than the Coulomb forces. The aim of the experiments reported in this paper was to show that particle sorting is more efficient when done in a roll-type electrostatic separator. The granular materials to be separated, a mixture of 50% low-density polyethylene (LDPE) and 50% high-density polyethylene (HDPE) were charged by particle-to-particle and particle-to-wall collisions taking place inside the rotating tube of a custom-designed tribocharging device. The study was performed with charging tubes made of four different materials: steel, aluminium, polyvinyl chloride and polyethylene. Under optimal operating conditions, more than 97% of the LDPE (purity: 97,83%) and 92% of the HDPE (purity: 92,45%) were recovered in the collector of the roll-type electrostatic separator, as compared to only about 60% and 75%, respectively, in the case of a standard free-fall separator.**

Index Terms— **electrostatic separation, granular plastics, insulating materials, tribocharging**

I. Introduction

Electrostatic separation is a generic term given to a significant class of material processing technologies, commonly used for the sorting of granular mixtures by means of electrical forces acting on charged or polarized particles [1-6]. A major application of these technologies is the recycling of metals and plastics from industrial wastes [7-9]. The quality of the recycled materials is better than with other conventional methods of waste processing and the overall efficiency of the electrostatic separation is higher.

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At present, the research and development efforts are focused on the development of effective dry technologies for separating granular plastic wastes [10-12], in order to contribute to the protection of the environment, by more effective use of primary resources and reduction of the amount of non-biodegradable litter in the landfills. Triboelectrostatic separation is such a technology, as demonstrated by several technical reports on successful industrial applications [13].

Most if not all of the existing triboelectrostatic separators had been initially developed for mineral ores beneficiation [14-18]. Such separators comprise a tribocharging unit, an electrostatic field zone, and several collecting bins for the pure and middling products (Fig. 1). The granular materials to be separated are introduced in the tribocharging device, where they acquire either positive or negative charge, due to numerous particle-to-particle and particle-to-wall collisions. The positively and negatively charged fractions are then sorted by the Coulomb forces, while falling freely in a horizontal electric field, created between two vertical plate electrodes, connected to two DC high voltage power supplies, of opposite polarities. The particles that have not been sufficiently charged are collected in the central area of the collector. They are referred to as "middling" and can be reprocessed.

The effectiveness of the separation primarily relies on the ability to control particle tribocharging, a process which still defies the true test of scientific understanding, i.e., predictability of outcome [19-26].

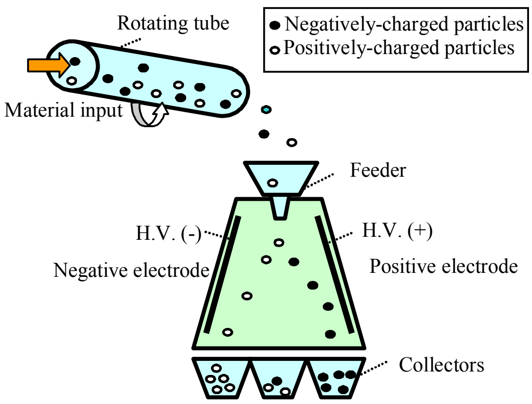

Fig.1. Schematic representation of the free-fall triboelectric separation process

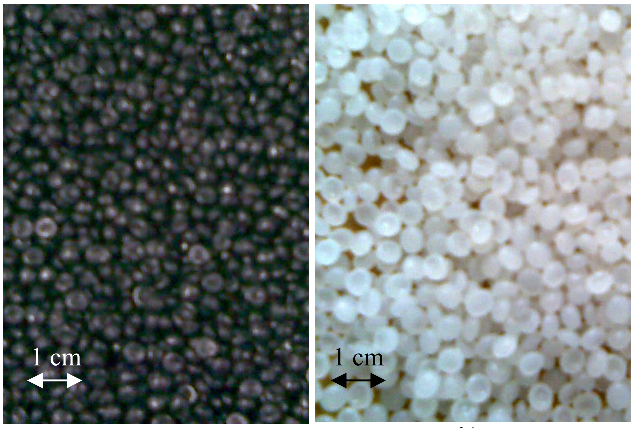

Fig. 2. HDPE (a) and LDPE (b) particles

In a previous study, the authors demonstrated the versatility of a custom-designed free-fall electrostatic separator to perform the selective sorting of certain granular mixtures. However, this equipment is unlikely to be efficient for coarse particles (size > 2 mm), where the Coulomb forces are surpassed by the gravity effect.

The aim of the experiments reported in this paper was to show that particle sorting is more efficient when done in a roll-type electrostatic separator. For the sake of this work, the authors modified a roll-type separator they had previously developed for metal/insulation separations [27].

II. Materials and Methods

The 200-g samples of granular materials were composed of 50% low-density polyethylene (LDPE) and 50% high-density polyethylene (HDPE). The typical shape and size of the plastic granules can be examined in Fig. 2.

Each sample was first processed in a custom-designed tribocharging device, as the one displayed in Fig. 3. The device consisted in a 10 cm diameter, 120 cm long PVC rotating cylinder, inclined at 10° to the horizontal. The residence time in the tribocharging device was 1 min. Part of the charge acquired by the particles is due to their impacts with the walls of the device. Therefore, the study was performed with charging tubes of four different materials: steel, aluminium, polyvinyl chloride and polyethylene.

In a first set of experiments, the charged granules were then separated in the electrical field generated by two vertical plate electrodes (dimensions: 30 × 65 cm) spaced at 20 cm and inclined at 30°, and collected in three compartments: two for the "pure" products and one for the "middling" (Fig. 3).

In the other experiments, the selective sorting of the charged particles was performed in a roll-type electrostatic separator (Fig. 4). According to their sign, the charged particles either are pinned to the surface of the roll-electrode or attracted to the static electrode connected to the HV supply.

The mass of the product collected in each compartment was measured using a digital balance (precision = 0.01 g). The purity of a product was calculated as:

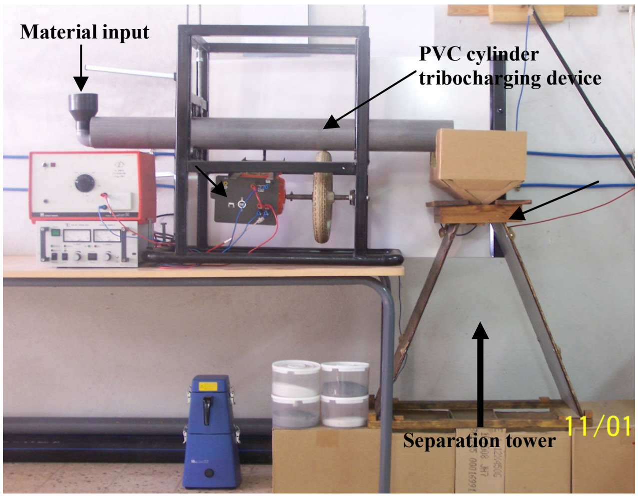

Fig. 3. Experimental device for the study of the free-fall triboelectrostatic separation process

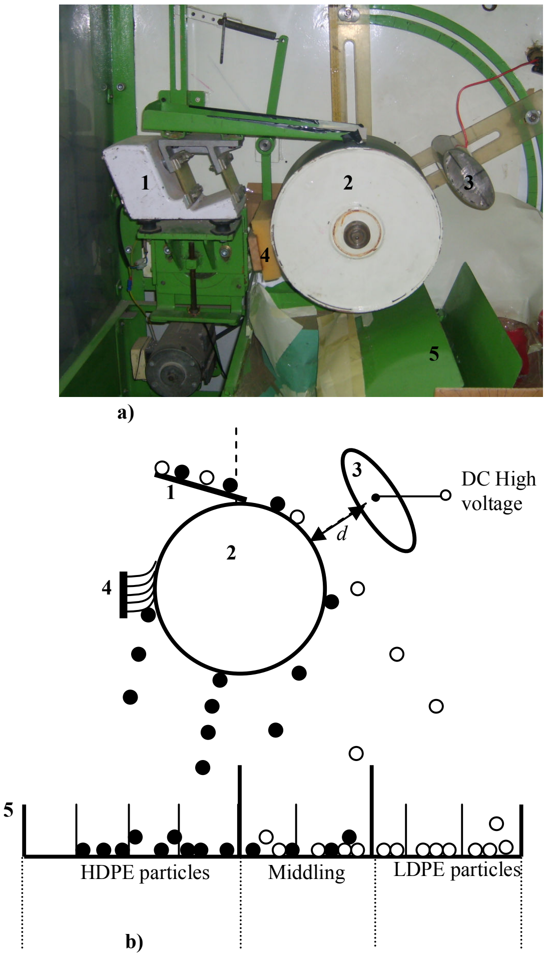

Fig. 4. Photograph (a) and schematic representation (b) of the roll-type triboelectrostatic separator

1- Vibratory feeder ; 2- Grounded rotating roll electrode; 3- HV static electrode; 4- Brush; 5- Collecting compartments

$$Pur(\%) = \frac{m_{ic}}{m_{tc}} 100 \qquad (1)$$

with m_{ic}: quantity of the product i collected in the compartment reserved for it; m_{tc}: total mass (both products) collected in the same compartment. The recovery represents the ratio of m_{ic} to the total mass m_{it} of the product i in the feed:

$$Rec(\%) = \frac{m_{ic}}{m_{it}} 100 \qquad (2)$$

Separation performances depend on two groups of factors. The first group includes tube material and the control variables of the tribocharging device: residence time t, tube rotation speed N_t and sample mass m. The second group is composed of the control variables of the separator: voltage U, inter-electrode spacing d, roll speed N_c and angular position α of the HV electrode (Fig. 4).

A set of experiments were done with four types of tribo-charging tubes (PVC, HDPE, Al, and steel), for otherwise identical operating conditions: t = 60 s, N_t = 300 rpm, m = 200 g, N_c = 60 rpm, U = 30 kV and d = 5 cm. In order to investigate the effects of the group of factors related to the tribocharging device, another set of experiments were performed with the control variables of the separator maintained at fixed values: N_c = 60 rpm, U = 30 kV, d = 5 cm and α = 35°. Another set of experiments were carried out at fixed values of the tribocharging control variables: t = 60 s, N_t = 300 rpm and m = 200 g for several values of the control variables of the separator. All experiments were performed at 23±2°C, RH = 40±5%.

III. Results and Discussion

A. Free-fall electrostatic separation experiments

In spite of many experiments carried out under various operating conditions (speed N_t of the rotating tube, high voltage U applied to the electrodes), the best separation results given in Table I are far from being satisfactory. These results, obtained with the PVC tube, clearly point out that free-fall electrostatic separation could not be employed to process this type of plastic particles. Even at highest attainable electric field intensity, corresponding to an applied voltage U = 50 kV, the gravitational force surpasses the electrostatic force acting on the processed particles. In a previous paper [28], the same free-fall tribo-electrostatic separator had been successfully employed to separate a PVC/LDPE mixture. Purities higher than 95% were obtained in that case, which can be explained by the better tribo-charging of LDPE particles in contact with PVC than with HDPE particles.

TABLE I: BEST FREE-FALL ELECTROSTATIC SEPARATION RESULTS FOR A 50/50 % HDPE/LDPE SAMPLE, m = 200 g, U = 50 kV

HDPE box	**LDPE box**	**Middling** [g]
70.52 g ≈ 75% HDPE ≈ 25% LDPE	**82.78** ≈ 60% LDPE ≈ 40% HDPE	**46.7**

B. Choice of the best material for the tribocharging tube

Best results in terms of recovery and purity of the products collected in he HDPE and LDPE compartments were obtained with the PVC charging tube (Table II). This device was adopted for all the other experiments.

TABLE II: INFLUENCE OF CHARGING TUBE MATERIAL ON SEPARATION RESULTS

Tube Material	HDPE		LDPE	
	Rec [%]	*Pur* [%]	*Rec* [%]	*Pur* [%]
PVC	91.11	97.87	98.02	91.68
HDPE	83.87	93.64	94.3	85.39
Al	86.88	99.72	99.76	88.38
Steel	78.74	99.92	99.94	82.46

C. Tribocharging experiments

According to experimental data summarized in Table III, the efficiency of the separator depends significantly on time t the particles spend in the tribocharging device. Best HDPE and LDPE recovery and purity were obtained when t =90 s. For longer residence time in the tribocharging tube, particles of opposite charge may agglomerate and the efficiency of the separation is compromised.

The results of the experiments done at various values of the tube rotation speed N_t show that this factor has great influence on the performances of the separator. Best results were obtained at around N_t = 300 rpm. The efficiency of the process decreases at high values of tube speed, because the centrifugal force that stick the granules to the walls of the tube. The particles do not undergo more collisions, and therefore did not acquire enough charge to be well separated.

Finally, it should be noted that the mass m affects also the efficiency of the process. When processing larger quantities of materials, the efficiency is better, because there are more collisions and hence, the amount of charge increases.

TABLE III: ELECTROSTATIC SEPARATION RESULTS AT DIFFERENT VALUES OF THE VARIABLES THAT INFLUENCE THE TRIBOCHARGING OF 50/50 % HDPE/LDPE SAMPLES

	HDPE		LDPE	
	Rec [%]	*Pur* [%]	*Rec* [%]	*Pur* [%]
***t*(s)**	N_t=100 rpm and m =200 g			
20	87.63	68.14	59.04	82.67
90	93.40	86.64	85.60	92.84
180	92.14	85.71	84.63	91.51
N_t (rpm)	t =60 s and m=200 g			
100	89.40	97.38	97.60	90.20
300	90.64	97.42	97.60	91.24
500	88.93	96.92	97.18	89.77
***m* (g)**	N_t=100 rpm and t =60 s			
200	93.54	98.17	98.26	93.83
120	93.73	96.49	96.60	93.90
40	72.85	95.47	96.55	78.05

D. Roll-type electrostatic separation experiments

The results of this final set of experiments can be examined in Table IV. They point out the fact that the roll speed significantly affects the performance of the separator, i.e. the recovery and the purity of the products. Indeed, at higher roll speed, the centrifugal forces surpass the electric forces; consequently, the particles will lift-off from the roll electrode, no matter what is the sign of the electric charge they carry. Lower roll speed values lead to better results and are recommended in this case.

Unsurprisingly, at fixed applied voltage $U = 30$ kV, the best results were obtained for the inter-electrode spacing $d = 3$ cm, which provides a stronger electrostatic field in the active zone of the separator. At $d < 3$ cm, the breakdown of the air gap may occur.

By adjusting the angular position α of the HV electrode, it is possible to modify the configuration of the electric field and control the particle trajectories. The recommended value of α is 45°.

TABLE IV: ELECTROSTATIC SEPARATION RESULTS AT DIFFERENT VALUES OF THE VARIABLES THAT INFLUENCE THE TRIBOCHARGING OF A 50/50 % HDPE/LDPE SAMPLE, $m = 200$ g, $U = 30$ kV

	HDPE		LDPE	
	Rec [%]	*Pur* [%]	*Rec* [%]	*Pur* [%]
N_c (rpm)	$d = 7$ cm and $\alpha = 35°$			
40	84.4	89.78	90.41	85.28
80	49.2	80.39	88.01	63.40
120	Very poor separation			
α (°)	$d = 7$ cm and $N_c = 40$ rpm			
25	66.87	93.65	94.47	74.23
35	84.88	95.60	96.1	86.40
45	92.02	97.83	97.96	92.49
***d* (cm)**	$N_c = 40$ rpm and $\alpha = 25°$			
3	89.93	94.68	94.95	90.41
7	71.7	90.87	92.8	76.63

IV. CONCLUSIONS

The efficiency of conventional free-fall tribo-electrostatic separators is very poor when processing coarse granular mixtures of insulating materials with particle sizes > 2 mm, as gravity surpasses the action of Coulomb forces. In this particular situation, the roll-type tribo-electrostatic separation methods are more appropriate. Separated product purities and recoveries beyond 90% can be obtained by appropriately controlling the centrifugal forces (the roll speed n) and the configuration of the electric field (the angular position α of the HV electrode). The main limitation of this technique is the lower through-puts as compared with the free-fall separation, due to the fact that the materials to be separated should be processed as mono-layers of particles at the surface of low-speed rotating roll electrodes.

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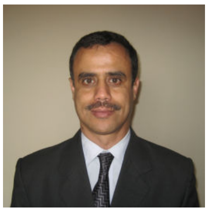

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