Triboelectrification of Granular Plastic Wastes in Vibrated Zigzag Shaped Square Pipes in View of Electrostatic Separation

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***Abstract*—The paper presents an original device for the electrification of granular mixtures in vibrated zigzag-shaped tubes. Spatial movement of the granules introduced in the tubes is controlled by varying the oscillation amplitude and frequency of a slider-crank mechanism. In a first set of experiments, two sorts of granular plastics (ABS and HIPS) were separately processed through the vibratory tribo-charging device. Both ABS and HIPS charged negatively in contact with the aluminum tubes. The absolute value of charge/mass ratio increased with the amplitude and frequency of the vibratory movements, to attain a maximum of 26 nC/g for the HIPS particles. In the second set of experiments, 100 g samples of 50% ABS +50% HIPS were tribo-charged, than introduced in a free-fall electrostatic separator. A composite experimental design was performed for modelling the process. The output variable was the extraction of ABS, while the speed and length of the crank were with the applied voltage the three control variables under investigation. ABS extractions higher than 85% were obtained for optimally chosen values of the control variables.**

***Index Terms*—electrostatic separation, electric charge, granular plastics, triboelectricity**

I. Introduction

TRIBOELECTROSTATIC separation of granular materials represents a technology with large perspectives of application in the recycling industry [1]-[4] .

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Fig. 1. Zigzag-shaped channels employed as active elements of the tribocharging device. The channels are covered by plate bands of same material, in order to form square cross-section pipes.

The electric field forces perform the selective sorting of the particles that get charges of opposite signs in custom-designed tribocharging devices. The successful implementation of this technology is intimately co-related to the effective triboelectrification of the constituents of the granular mixture to be sorted.

Each of the tribocharging devices described in the technical literature has its own advantages and drawbacks [5], [6]. However, their claimed efficiency is likely to be strongly related to the nature, size and shape of the particles processed in the device. As no general rule can be formulated, experimental studies must precede any new industry application of the triboelectrostatic separation technology.

The aim of this paper is to evaluate an original tribocharging device consisting in a set of vibrated zigzag-shaped metallic pipes. The experiments were carried out on two types of plastics (ABS and HIPS) originating from the processing of information technology wastes. A free-fall electrostatic separator was then employed for the selective sorting of the two tribocharged plastics.

II. Experimental Procedure

A. *Vibratory Tribocharging Device*

The active elements of the Vibratory Tribocharging Device [7] are zigzag-shaped square cross-sections pipes, obtained by assembling straight segments of aluminum or PVC plate bands on a common metallic plate (Fig. 1).

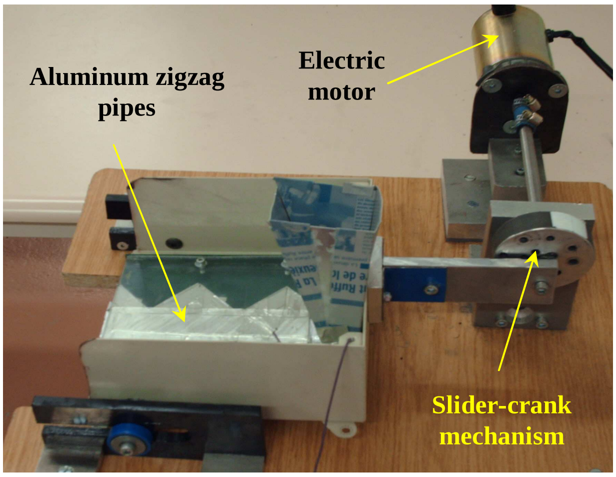

Fig. 2. Vibratory Tribocharging Device.

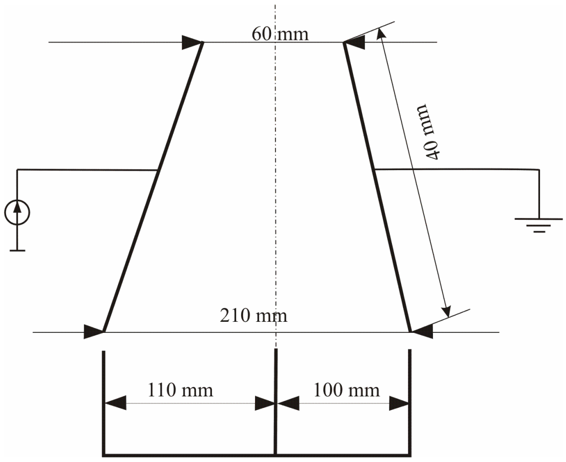

Fig. 3. Configuration of the electrode system.

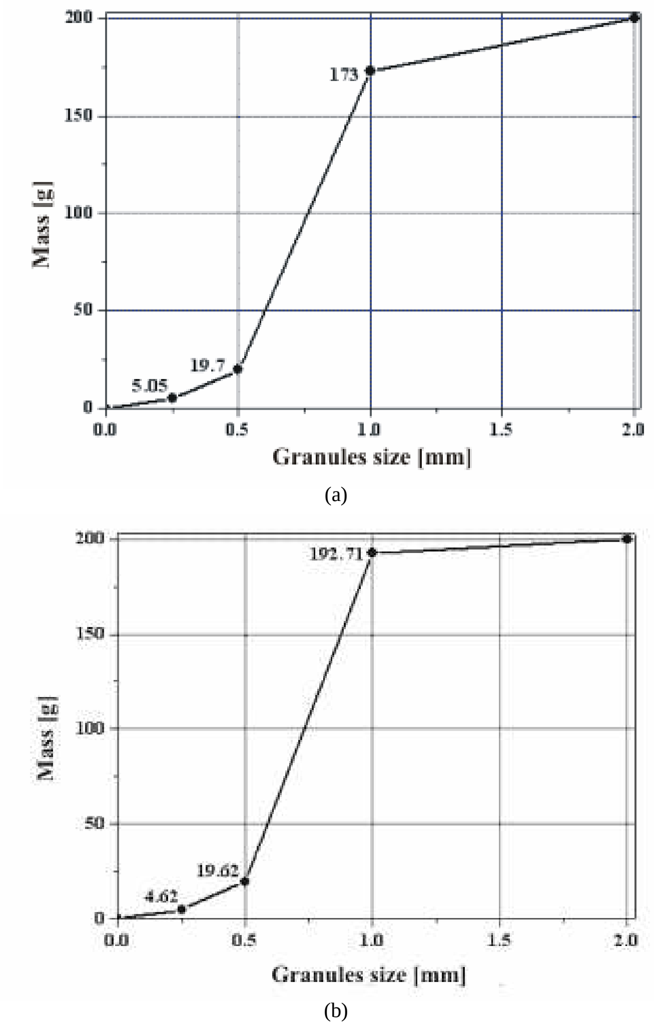

Fig. 4. Size distribution of ABS (a) and HIPS (b) granular materials extracted from IT wastes.

A DC motor driven slider-crank mechanism makes the plate and the tubes move in OY and OZ directions (Fig. 2). The particles inside the zigzag shaped tubes will move also in the OX direction. This 3-D motion of the particles can be controlled in two ways: (i) by continuously varying the speed of the DC motor; (ii) by five-step modification of eccentric radius *R* (crank length). Thus, both the frequency and the amplitude of the vibrations imposed to the zigzag shaped tubes are varied. The device has been designed so that it can be operated either as an “independent” unit, for the experimental study of tribocharging process, or as an “integrated” module of a free-fall electrostatic separator.

B. Experimental Set-up

The experimental set-up consists of the Vibratory Tribocharging Device, and a free fall electrostatic separator, energized from a high voltage supply (50 kV, 0.3 mA). The configuration of the electrodes is represented in Fig. 3. All the experiments were performed at ambient atmospheric conditions (temperature 22°C ± 1°C, relative humidity 44 % ± 2°%).

C. Materials

The study was focused on two granular plastic materials, originating from the processing of information technology wastes, provided by the APR2, Bonnières sur Seine, France: ABS (light grey) and HIPS (black). The granule size for both materials ranged between 0.25 and 2 mm (Fig. 4). The experiments were carried out on 10 g samples of these materials, after shieving to eliminate all particles of less than 0.5 mm in size.

D. Method

Experimental design methodology [8]-[10], was employed for the determination of a quadratic model of the tribocharging process:

$$y = f(x_i) = a_0 + a_1 x_1 + a_2 x_2 + a_{11} x_1^2 + a_{22} x_2^2 + a_{12} x_1 x_2 \; ; \quad (1)$$

where y is the response function (i.e., the charge/mass ratio of the particles collected at the output of the vibratory tribocharging device) and x_i is the normalized centered value for each factor u_i:

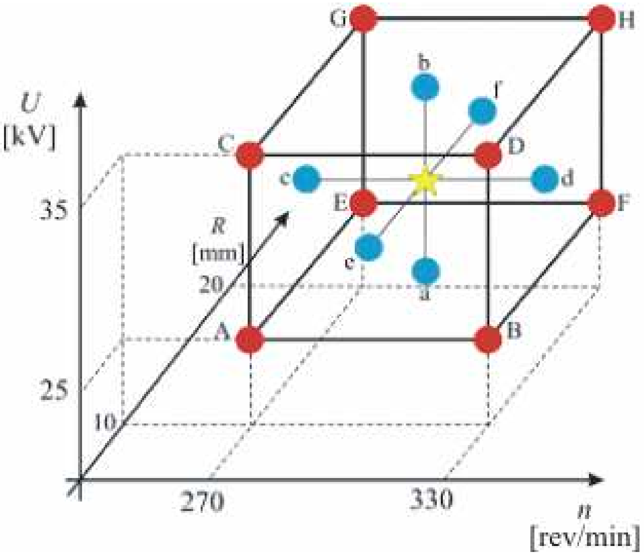

Fig. 5. Composite experimental design for the study of the triboelectrostatic separation of granular plastic mixtures.

$$x_i = (u_i - u_{ic})/\Delta u_i = u_i^*, \quad (2)$$

with

$$u_{ic}=(u_{imax}+u_{imin})/2; \ \Delta u_i = (u_{imax} - u_{imin})/2 \quad (3)$$

For the factors considered in the present study, i.e. the crank length R (10 to 20 mm), and the oscillation frequency of the triboelectrification pipes n (180 to 360 min^{-1}), the quadratic model of the response Q/M will take the following form:

$$Q/M = a_0 + a_1R^* + a_2\, n^* + a_{12}\, R^*n^* + a_{11}\, R^{*2} + a_{22}\, n^{*2} \quad (4)$$

In the present study, the model was obtained with a two-variable composite experimental design, as recommended in [11], [12].

In order to optimize the output of the electrostatic separator (i.e., maximize the ABS recovery *y*), the voltage applied to the plate electrodes *U* (domain of variation: 25 to 35 kV), the crank length *R* (10 to 20 mm), and the oscillation frequency of the tribo-electrification pipes *n* (180 to 360 min^{-1}) were the three variables of the composite experimental design that was adopted (Fig. 5). The analysis of the data for this and the other above-mentioned experiments were performed with the assistance of commercial software of experimental modeling (MODDE 5.0., developed by Umetrics, Sweden).

III. Tribocharging Experiments

Based on the *Q/M* results of a first composite experimental designs carried out on ABS and HIPS samples (Tables 1 and 2), contour plots (Fig. 6 a and b) and predicted response graphs (Fig. 7 a to d) were drawn, using the commercial software MODDE 5.0. For both tested plastics, the best charge-to-mass ratio was obtained for n = 360 rev/min and R = 20 mm. The HIPS charged better than ABS in contact with the aluminum pipes.

TABLE I
Results of the ABS tribocharging experiment

n [min^{-1}]	*R* [mm]	*Q* [nC]	*M* [g]	*Q/M* [nC/g]
270	10	-9	10	-0.90
330	10	-22.5	10	-2.25
270	20	-44	9.4	-4.68
330	20	-60	5.1	-11.76
270	15	-19.5	9.2	-2.12
330	15	-56.5	8.4	-6.73
300	10	-14	10	-1.40
300	20	-60	6.4	-9.38
300	15	-40	9.5	-4.21
300	15	-38	9.2	-4.13
300	15	-38	9.1	-4.18

TABLE II
Results of the HIPS tribocharging experiment

n [min^{-1}]	*R* [mm]	*Q* [nC]	*M* [g]	*Q/M* [nC/g]
270	10	-70	10	-7.00
330	10	-95	10	-9.50
270	20	-110	9.2	-11.96
330	20	-195.4	7.6	-25.71
270	15	-86	9.3	-9.25
330	15	-170	9.8	-17.35
300	10	-85	10	-8.50
300	20	-200	9	-22.22
300	15	-90	9.5	-9.47
300	15	-120	9.9	-12.12
300	15	-117	9.6	-12.19

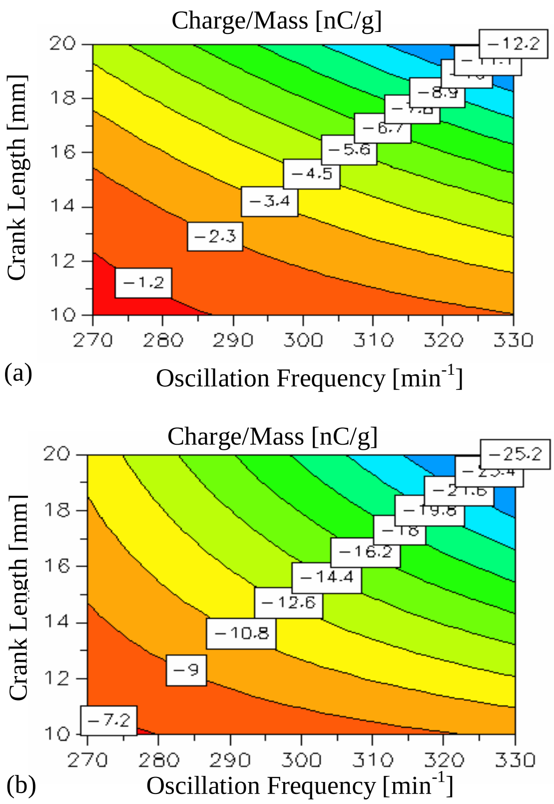

Fig. 6. Contour plots of the charge/mass ratio of ABS (a) and HIPS (b) granular samples, as function of the oscillation frequency *n* and the crank length *R*.

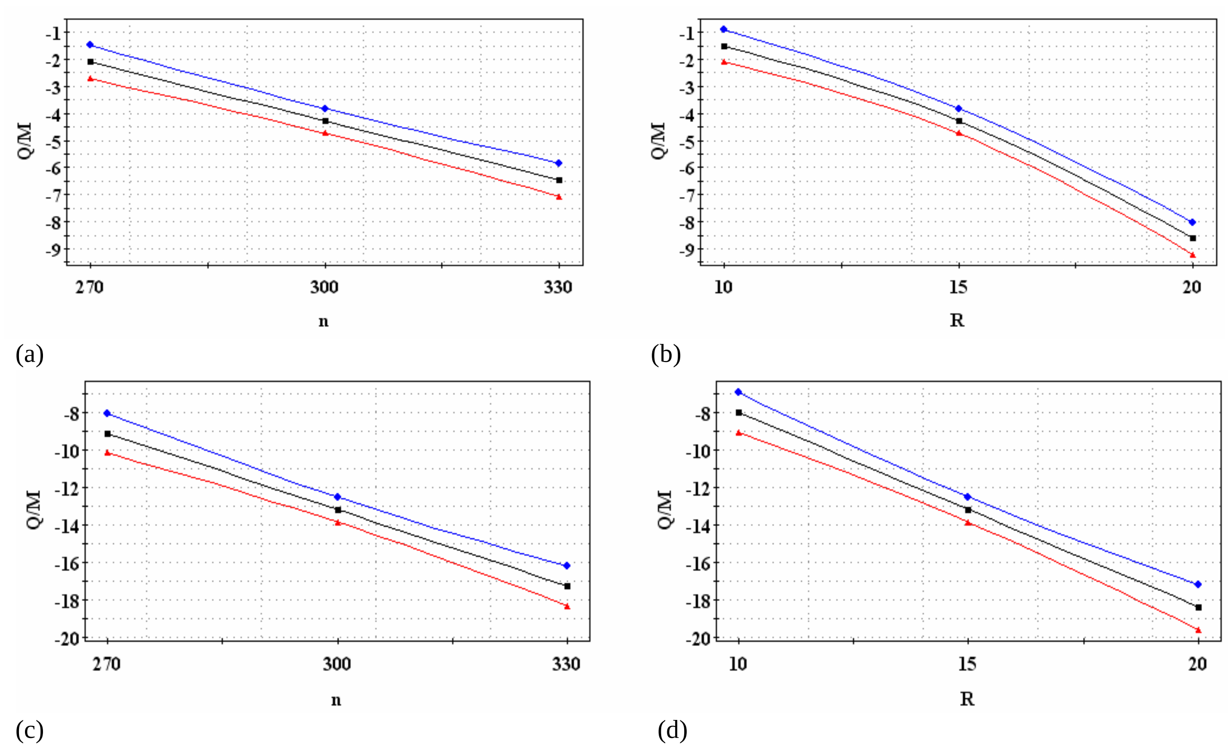

Fig. 7. Predicted charge/mass of ABS (a and b) and HIPS (c and d) granular samples, as function of the oscillation frequency n [min^{-1}], for a crank length R = 15 mm (a and c), or as function of the length crank R [mm], for an oscillation frequency n = 300 min^{-1} (b and d).

The response function Q/M computed with MODDE 5.0 based on the results of the ABS experiments was:

$$Q/M = -4.274-2.173\, n^*-3.545\, R^*-1.4325\, R^*\, n^*-0.787\, R^{*2} \quad (5)$$

A slightly different plynomial model is found for HIPS (the coefficient of the R^{*2} term was not statistically significant and could be removed from the model) :

$$Q/M = -13.194-4.058n^*-5.172R^*-2.8125R^*n^* \quad (6)$$

In both cases the charge per mass ratio Q/M increases (in absolute value) with both the crank length R and the oscillation frequency n. Due to the interaction between the two factors, Q/M increases more (in absolute value) with the increase of R for higher values of n.

III. Triboelectrostatic Separation Experiments

The results of the composite experimental design carried out on the 50% ABS – 50% HIPS samples are given in Table III. In all the essays, more than 70% of the ABS in the feed was recovered in the final product with 100% purity.

The response function y (i.e., ABS recovery, expressed in [%]) computed with MODDE 5.0, is:

$$y = 82.83 -2.758\, n^*-2.998\, R^*- 3.002\, U^* + 1.648\, n^*\, R^*- 1.598\, n^*\, U^*- 2.348\, R^*\, U^* \quad (7)$$

TABLE III
Results of the ABS/HIPS Triboelectrostatic Separation Experiment

n [min^{-1}]	R [mm]	U [kV]	y [%]
270	10	25	88.8
330	10	25	84.0
270	20	25	85.0
330	20	25	85.6
270	10	35	85.4
330	10	35	78.8
270	20	35	76.8
330	20	35	72.2
270	15	30	86.0
330	15	30	79.6
300	10	30	85.6
300	20	30	78.8
300	15	25	86.4
300	15	35	80.8
300	15	30	81.8
300	15	30	82.4
300	15	30	83.4

The predicted response graphs in Fig. 8 point out a quite surprising effect: in the conditions of the experiments, the best results were obtained for the lower levels of the three factors under investigation. As a matter of fact, the particles get very well charged even at low oscillation frequency n and crank length R, so that a very good separation can be achieved without using a very high applied voltage U. With higher n and R, the charged particles impact the electrodes of opposite polarities and are deviated to the wrong collecting box.

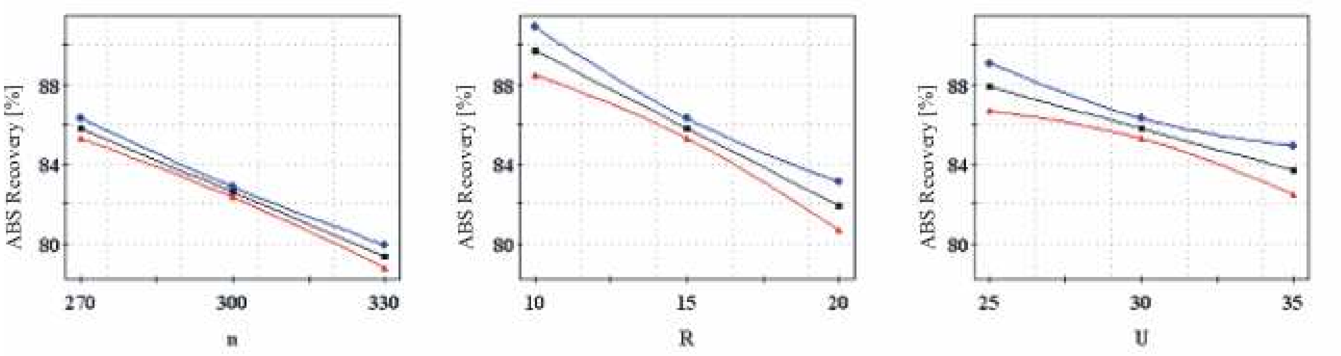

Fig. 8. ABS recovery [%] predicted by MODDE 5.0, as function of the oscillation frequency n [min^{-1}], crank length R [mm] and applied high voltage U [kV].

V. Conclusions

The vibratory tribocharging device, characterised by zigzag-shaped metallic tubes and spatial 3D movement imposed to multi-component granular mixtures of insulating materials, represents an effective solution for extending the triboelectrostatic separation applications in the recycling industry. The design of the device facilitates the setting of the control variables (oscillation frequency and crank length), as well as the integrated operation with a free-fall electrostatic separator.

The movement of the plastic particles in the vibratory tribocharging device implies multiple particle-to-wall and particle-to-particle collisions. Future researches have to evaluate the influence of the two mechanisms on the tribocharging process in order to improve the efficiency of plastics recycling by triboelectrostatic separation.

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