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Factors Influencing the Triboelectric Charging of Granular Plastics in a Rotating-cylinder-type Tribocharger

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Abstract. The electric charging of granular plastics in view of their electrostatic separation is one of the major industrial applications of the triboelectric phenomenon. The granules get charged by collisions and frictions with each-others and with the walls of the tribocharging device. In electrostatic separation applications, the granules of a mixture must be sufficiently charged to be attracted by electrodes of opposite polarity for their separation by type of material. The objective of the present work is to study the effects of three factors that influence the triboelectric charging of polycarbonate granules (size: 2 mm to 5 mm) originating from waste electric and electronic equipment in a rotating-cylinder-type device: particle residence time, cylinder inclination and its rotation speed. The performance of the triboelectric charger was evaluated by measuring the charge per mass ratio of the granules collected at the outlet of the device.

1. Introduction

Waste electrical and electronic equipment is composed of a wide variety of conducting and insulating materials [1]. The electrostatic separation of the latter [2] requires their charging by triboelectric effect [3]. Triboelectric charging occurs when two materials of different nature collide [4]: an electric charge is transferred from one to the other; this phenomenon is also called contact charging [5]. The higher the electric charge acquired by the particles, the more effective is the electrostatic separation.

Besides electrostatic separation [6, 7], triboelectricity is the basis for many other important technologies like electro-photography [8, 9], electrostatic precipitation [10, 11], triboelectric energy harvesting [12, 13] There are many different tribocharging devices [14], including rotary cylinders [15], fluidized beds [16], vibrating plates [17], fan-or propeller-type units and tribo-cyclones [18].

The objective of this work was to optimize the operation of a new triboelectric charging device designed by the authors and manufactured by CITF Company, in view of its utilization for the electrostatic separation granular plastics mixtures originating from waste electric and electronic equipment. The polycarbonate (PC) granules used in this study had sizes between 2 mm and 5 mm, which are typical for the considered application.

Modelling and optimization of triboelectric charging process were carried out using the design of experiments methodology [19] with respect to three factors, namely: the rotation speed of the outer cylinder, as well as its inclination angle and the residence time of the particles in the device.

2. Experimental setup

In this device (Figure 1), the particles to be tribocharged are introduced into a funnel (1). A valve (2) is used to regulate the particle flow entering into the hollow cylinder (3) which allows their triboelectric charging. This cylinder is entrained by an electrical motor (4). The rotational speed of the hollow cylinder is variable up to 120 rpm. The hollow cylinder is made of PVC, its length is adjustable (200 mm, 400 mm or 600 mm) and three or six blades of 10 mm or 15 mm height can be attached to its inner wall. Its inclination angle can also be changed between 0° (horizontal) and 45° (5). The flow rate of material entering the tube is controlled by a trapdoor. When it is closed, the particles remain inside the device. This allows the increase of the residence time of the particles in the device, which might be beneficial for the triboelectrical charging process. An exit hopper (6) prevents the projection of the particles and allows their recovery. Moreover, a control cabinet (7) is used for adjusting the speed the cylinder. At the outlet of this device, the particles can be recovered in a Faraday cage if it is desired to measure their charge or directly introduced in an electrostatic separator.

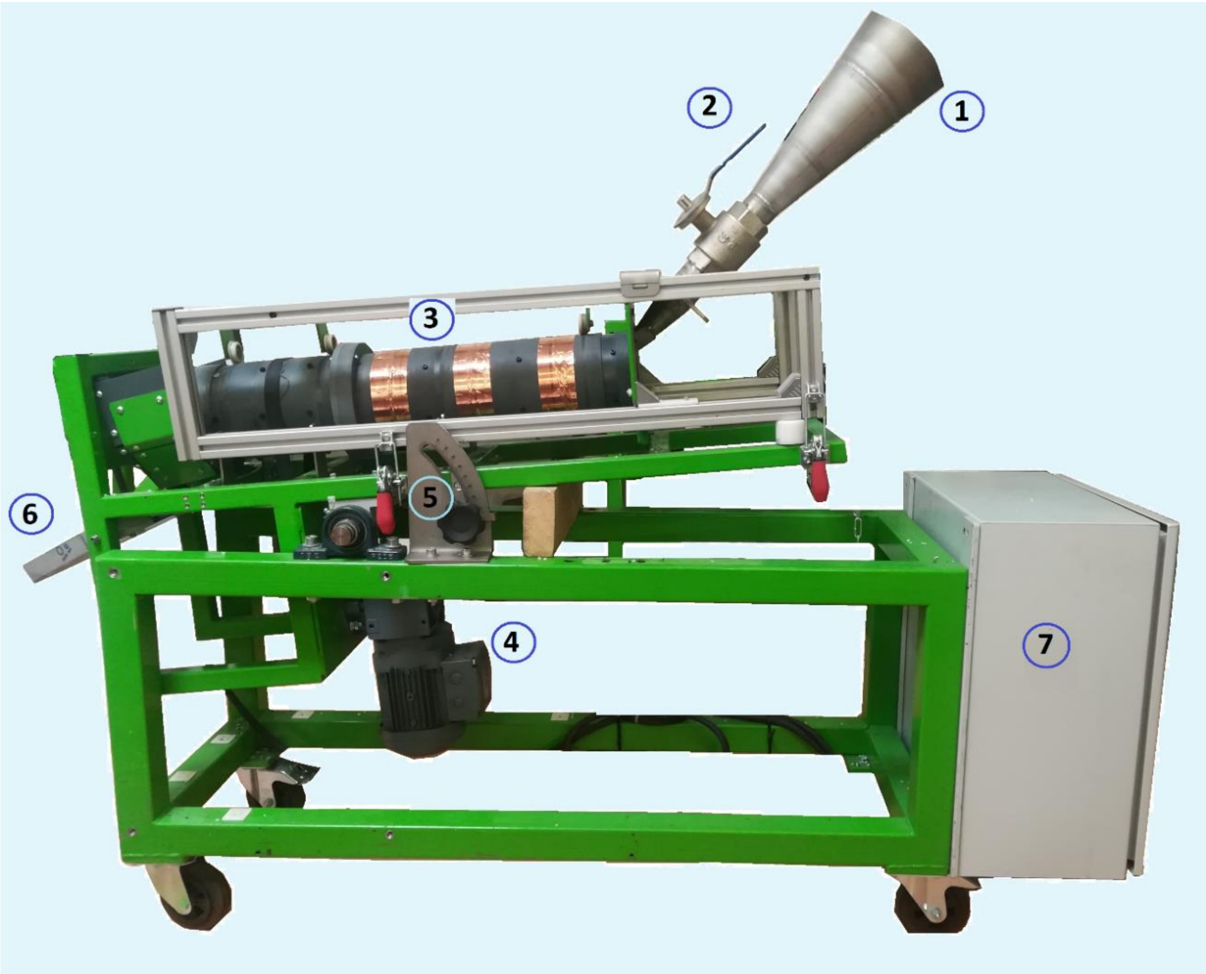

Figure 1. Charging device with rotating cylinders. (1) Funnel; (2) Valve; (3) Hollow cylinder; (4) Motor; (5) Inclination adjustment system; (6) Output hopper; (7) Electrical control cabinet.

3. Materials and method

The granular plastic waste used in the present study was white PC (Figure 2). The size of the particle was typically between 2 mm and 5 mm. The experiments were all duplicated and performed by the same operators, using similar samples and under almost constant climatic conditions: room temperature 18.3°C to 19.0°C and relative humidity of the air 40.2% to 55.7%.

In each experiment, 100 g of particles were used.

Figure 2. Aspect and size of PC particle.

Note that, according to the positioning in the triboelectric series, PC should get positively charged in contact with PVC.

For each test, an experimental procedure was elaborated and scrupulously respected:

- close the trapdoor of the cylinder;
- deposit the particle mixture in the funnel;
- adjust the angle of inclination;
- adjust the cylinder rotation speed;
- start the cylinder rotation motion;
- open the valve and at the same time measure the particles residence time in the cylinder;
- stop the rotation;
- open the trapdoor;
- recover the product in a Faraday cage connected to an electrometer to measure its electrical charge and placed on a precision electronic scale (KERN, resolution: 0,01 g) to measure its mass.

The experimental design method is used to identify the optimum operating point of the tribocharging device. This method determines the number of experiments to be performed in order to achieve a predetermined goal and predicts the behavior of the process in the domain of definition of several factors that may vary simultaneously.

In addition, it enables the evaluation of the significance of the effects of these factors and of their interactions. In the industrial field, this method is of great interest because it allows the evaluation of the influencing factors and the optimization of a process while performing a minimum number of tests.

The response y of the process can be expressed a function of several factors (the input variables u_i). Most often, the answer is expressed as a polynomial of the first or second degree:

$$y = c_0 + \sum c_{ij} u_i u_j + \sum c_{ij} u_i^2 \quad (1)$$

In the case of what is called a factorial composite design, the total number of tests N, for k factors, at two levels (LOW and HIGH) is written as follows:

$$N = 2^k + 2 * k + 3 \quad (2)$$

4. Results and discussion

4.1. Determination and modeling of the experimental domain

The domain of variation of three control variables of the process was established as follows, after preliminary tests:

- Inclination angle α [°] = [3, 7];

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- Rotation speed n [rpm] = [50, 90];
- Residence time of the particles in cylinder t [min] = [1, 3].

The analysis of the experimental results given in Table 1was carried out with MODDE 5.0 program [19], which calculates the coefficients a_{ij} of the mathematical model, draws the response contours, and identifies the best adjustments of the parameters for optimizing the process.

Table 1. Charge/mass ratio (*Q/m*) of PC tribocharged particles, for the 17 runs of the composite factorial experimental design.

N	Inclination angle α [°]	Rotation speed n [rpm]	Residence time t [min]	Charge to mass ratio Q/m[nC/g]
1	3	50	1	5.83
2	7	50	1	3.47
3	3	90	1	6.14
4	7	90	1	4..31
5	3	50	3	7.12
6	7	50	3	3.26
7	3	90	3	7.06
8	7	90	3	4.00
9	3	70	2	7.08
10	7	70	2	4.20
11	5	50	2	5.46
12	5	90	2	5.81
13	5	70	1	5.59
14	5	70	3	6.11
15	5	70	2	6.32
16	5	70	2	6.26
17	5	70	2	6.25

4.2. Descriptive quality of the model

The evaluation of the effects of the control factors reveals the inclination angle of tribocharger as the most important. The mathematical model of the response (i.e., the charge to mass ratio) is given by:

$$Q/_{m} = 6.14 - 1.4 * \alpha + 0.22 * n + 0.22 * t - 0.41 * \alpha^2 - 0.41 * n^2 - 0.20 * t^2 + 0.16 * \alpha * n - 0.34 * \alpha * t - 0.06 * n * t \quad (3)$$

The statistical indicators obtained for this experiment design R^2= 0.9945 and Q^2= 0.9694, which characterize the quality of the regression and prediction, respectively, are close to 1.0, indicating that the obtained model can be confidently used for optimizing the triboelectric charging process.

4.3. Influence of selected factors on responses

From the mathematical model (1), the MODDE 5.0 software plotted the variation of the response according to each of the chosen factors(Figure 3).The results show a decrease in the charge of the entrained particles with the increase of the inclination angle of the rotating cylinder as shown in figure 3.a.When the inclination is small, the particles are more spread out along the cylinder length and less in contact with each other, which increase the number of impacts and enhance the friction between particles and wall, facilitating the transfer of electric charges.

At first, the charge increases with the rotational speed of the cylinder, then saturates for values higher than 70 rpm (Figure 3.b). This can be explained by the peculiarities of the relative sliding motion between the particles and the wall of the cylinder.

The charge is quasi-proportional to the residence time as illustrated in Figure 3.c. The increase of charge is due to the higher number of impacts and the longer time of contact between the particles and the wall.

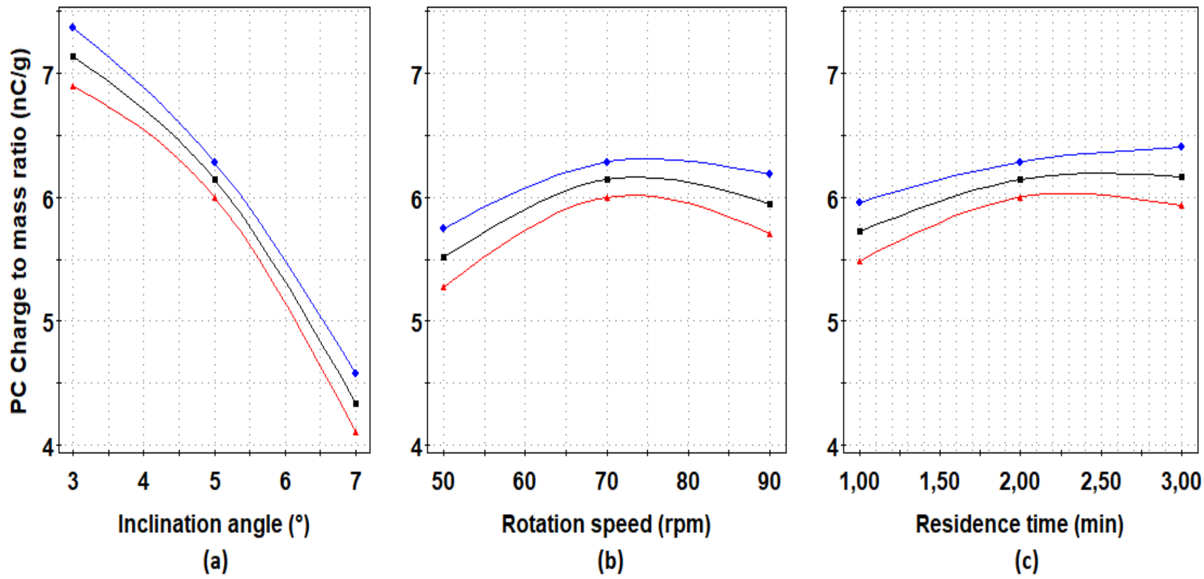

Figure 3. Charge to mass ratio predicted by MODDE 5.0, as function of: (a) inclination angle α, at *n*= 70 rpm, *t*= 2 min; (b) rotation speed *n*, at α=5°,*t*= 2 min; (c) residence time *t*, at α= 5°, *n*= 70 rpm.

4.4. Determination of optimal operating point

MODDE 5.0 software proposes graphic representations of the predicted response *Q/m* according to the studied factors (Figure 4).

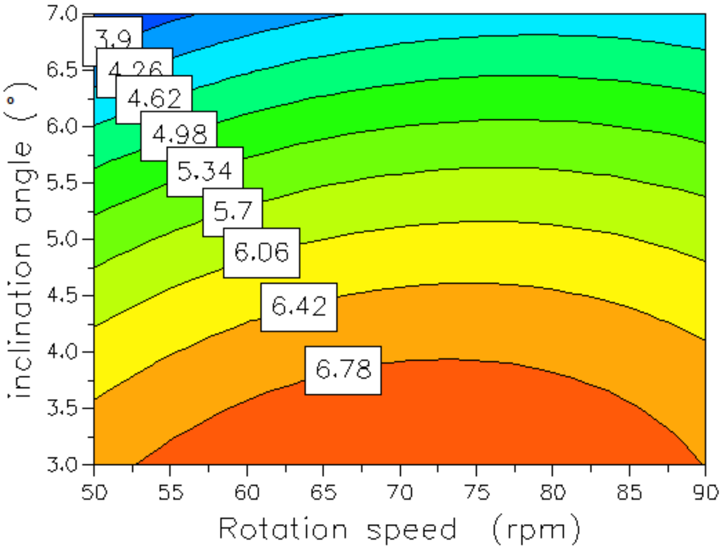

Figure 4. MODDE-predicted charge to mass ratio contours for tribocharged granular PC, depending on the control variables (rotation speed, inclination angle), for a residence time t = 2 min.

According to the predictions made by MODDE 5.0 software, the best tribocharging is obtained when the control factors are adjusted at the values given in Table 2. Two additional experiments were done for a minimum and a maximum residence time of particles. They were in good agreement with the theoretical predictions.

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Table 2. Comparison between MODDE 5.0-predicted and experimentally obtained results.

Results	Inclination angle α [°]	Rotation speed *n* [rpm]	Residence time *t* [min]	Charge to Mass ratio[nC/g]
Predicted	5.5	50	1	4.68
Experimental				4.82
Predicted	4.3	90	3	6.36
Experimental				5.88

5. Conclusion

The results of the experimental study performed on mm-size PC granules authorize the following conclusions:

(1) Tribocharging device presented in this paper proved its efficiency in processing granular polymers;
(2) The experimental design methodology enables the modelling and optimization of the triboelectric charging process. The obtained mathematical models can then be used for the determination of the optimal values of the different control factors of the triboelectric charging process.
(3) The outcome of the triboelectric charging process depends on the inclination angle and the rotation speed of the cylinder, as well as on the residence time of the particles inside the tribocharger.
(4) In 1 min, PC granules can acquire a maximum charge/mass ratio Q/m= 4.68 nC/g with the rotating cylinder inclined at an angle α=5.5° and rotating at a speed n=50 rpm. Higher charge/mass ratios, close to 6.5 nC/g, can be obtained for a longer residence time (3 min).

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