Factors that influence the efficiency of a fluidized-bed-type tribo-electrostatic separator for mixed granular plastics

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Abstract. Fluidized bed devices have already been used as tribochargers for various industrial electrostatic separation processes. In the present paper, the authors investigate the behaviour of polyamide - polycarbonate granular plastic mixtures in a parallelepiped bed, the height of which is roughly 2 times its length or width, so that the collisions between granules become the prevailing tribocharging mechanism. Two of the opposite walls of the tribocharging chamber consist of metallic plates connected to two DC high-voltage supplies of opposite polarities, so that the charged particles are attracted to the electrodes and separated while still in the fluidized state. The collecting hoppers are designed as Faraday cups connected to two electrometers, thus allowing the instantaneous measurement of the charge carried by the separated particles. Experimental design methodology was employed for the optimization of the tribo-aero-electrostatic separation process, the input variables being the high-voltage applied to the electrodes and the duration of the tribocharging. Higher voltages applied to the electrode system do not necessarily lead to larger quantities of collected products but improve the purity of the concentrates. The composition of the mixture influences the outcome of the process.

1. Introduction
A wide range of applications in the chemical industry and in powder processing take advantage of the tribo-charging effects occurring in fluidized bed reactors [1-4]. The size of solid particles processed in standard reactors ranges from less than 1 \( \mu \)m to 6 cm [5-9]. In any fluidized bed, the granules become electrically charged by contacts between each other or with the walls of the tribocharger [1, 10].

In a previous paper, the authors have studied a cylindrical fluidized bed device, characterized by elevated air velocities and height/diameter ratios, which favor more frequent granule-to-wall collisions [11]. By choosing wall materials in accordance with the triboelectric series [12-14], the two classes of particles to be separated charge with opposite polarities [15] and are sorted by the electric forces exerted on them while falling freely in the electric field generated between vertical plate electrodes.

The present paper is aimed at experimental modelling of the tribo-electrostatic separation process in a parallelepiped fluidized bed, the height of which is roughly 2 times its length or width, so that the collisions between granules become the prevailing tribocharging mechanism. The peculiar advantage of this configuration in comparison with the “standard” cylindrical one is that an electric field can be easily generated inside the fluidized bed by the metallization of two of the opposite walls of the tribocharging chamber and connecting them to two DC high-voltage supplies of opposite polarities. The charged particles will be attracted to the electrodes and separated while still in the fluidized state.

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2. Experimental set-up
The fluidized bed built for this experiment is a rectangular prism (115 mm x 85 mm x 400 mm), with two opposite vertical walls made of polycarbonate, the other two consisting of aluminium plates connected to two adjustable DC high-voltage supplies of positive and negative polarity (Fig. 1).

The granular material is deposited on the screen type air distributor and is maintained in the fluidized bed state generated by the ascending air. The charged granules are attracted to the electrodes of opposite polarity and fall into the two collecting hoppers, designed as Faraday cups connected to two electrometers that measure the charge carried by the separated particles.

3. Material and methods
The tribo-electrostatic separation experiments were performed on blue virgin polyamide (PA) and orange polycarbonate (PC) granules, used in the plastics industry (characteristic size: 2 mm). Two types of samples (mass of a sample: 100 g) were prepared as binary mixtures with different compositions. The experiments were carried out under relatively stable ambient conditions: temperature $T = 17 - 22^\circ C$, relative humidity $RH = 44 - 60\%$, and at given air velocity $v = 6$ m/s, measured with a miniature cup-type anemometer in the absence of particles. The charge measurement data acquired by the electrometers (model 6514, Keithley Instruments) during the steady-state operation of the tribocharger were processed by a virtual instrument (VI) developed in the LabView environment.
The high voltage U applied to the electrodes and the duration t of the tribocharging were the two process variables investigated. The effects of each variable on the output of the process (i.e. the charge/mass ratio of the granules collected at the electrodes), were evaluated for two classes of binary granular mixtures: 50% PA – 50% PC; 75% PA – 25% PC.

In order to obtain a quadratic polynomial model of the tribo-aero-electrostatic separation process, the composite factorial experimental design [34] was employed for the present study. The domain of variation of the high voltage provided by each supply \( U_{\text{min}} = 6 \text{ kV} \); \( U_{\text{max}} = 18 \text{ kV} \) and of the tribocharging duration \( t_{\text{min}} = 30 \text{ s} \); \( t_{\text{max}} = 120 \text{ s} \), were established based on the results of preliminary experiments. The data were processed using commercial software, MODDE 5.0, developed by Umetrics [17]. The program calculates the coefficients of the mathematical model, evaluates their statistical significance, as well as two statistical criteria (the goodness of fit \( R^2 \), and the goodness of prediction \( Q^2 \)), and identifies the best adjustments of the input variables for optimizing the process.

4. Results and discussion
The results of the composite factorial experimental design carried out for the two classes of samples characterized by different percentages of PA and PC granules are summarized in Table 1. The corresponding mathematical models calculated by MODDE 5.0 are given in Table 2. The statistics \( R^2 \) and \( Q^2 \) of these models, listed in the same table, are excellent.

The equal-charge curves plotted in figure 2 for the 50 g PA + 50 g PC granular mixture illustrate the effects of the two factors under study. Optimum operation is achieved at \( U = 10.4 \text{ kV} \); \( t = 120 \text{ s} \).

Table 1. Charge of the PA and PC products obtained by tribo-aero-electrostatic separation of two classes of granular mixtures

| Run No. | \( U \) [kV] | \( t \) [s] | 50 g PA + 50 g | 75 g PA + 25 g |
|---------|-------------|-------------|---------------|---------------|
|         |             |             | \( Q_{PA} \) [nC] | \( Q_{PC} \) [nC] | \( Q_{PA} \) [nC] | \( Q_{PC} \) [nC] |
| 1       | 6           | 30          | 24.2          | -44.1         | 18.1           | -31.8          |
| 2       | 18          | 30          | 81.7          | -92.4         | 61.5           | -82.5          |
| 3       | 6           | 120         | 319           | -350          | 190            | -110           |
| 4       | 18          | 120         | 217           | -282          | 188            | -164           |
| 5       | 6           | 75          | 181           | -237          | 90             | -82.7          |
| 6       | 18          | 75          | 174           | -214          | 145            | -156           |
| 7       | 12          | 30          | 91.6          | -98           | 38.3           | -57.2          |
| 8       | 12          | 120         | 363           | -389          | 246            | -156           |
| 9       | 12          | 75          | 288           | -293          | 117            | -132           |
| 10      | 12         | 75          | 298           | -303          | 124            | -134           |
| 11      | 12         | 75          | 305           | -313          | 132            | -137           |

Table 2. Quadratic models of \( Q_{PA} \) [nC] and \( Q_{PC} \) [nC] calculated by MODDE 5.0 from the data in Table 1, for the two classes of granular mixtures

| Class | Model                                      | Statistics |
|-------|--------------------------------------------|------------|
| 50 g  | \( Q_{PA} = 293.5 - 8.58 U^{*2} + 105 t^{*} \) + 111 U^{*2} - 25 t^{*2} - 39.9 U^{*} t^{*} | \( R^2 = 0.996 \); \( Q^2 = 0.952 \) |
| PA    | \( Q_{PC} = -297.5 + 7.11 U^{*2} - 63.7 U^{*2} - 45.7 t^{*2} - 29.1 U^{*} t^{*} \) | \( R^2 = 0.999 \); \( Q^2 = 0.999 \) |
| 75 g  | \( Q_{PA} = 123.9 + 31.2 U^{*2} + 99.5 t^{*} \) - 5.86 U^{*2} + 18.8 t^{*2} + 11.4 U^{*} t^{*} | \( R^2 = 0.995 \); \( Q^2 = 0.952 \) |
| PC    | \( Q_{PC} = -133.2 - 29.7 U^{*2} - 132 t^{*2} - 121.4 U^{*} t^{*} \) + 12.1 U^{*2} + 24.9 t^{*2} | \( R^2 = 0.984 \); \( Q^2 = 0.934 \) |

Figure 2. MODDE 5.0 predicted equal-charge \( q \) [nC] contours for PC and PA particles separated from a 50 g PA + 50 g PC granular mixture, as a function of the voltage \( U \) [kV] and the duration \( t \) [s].
Figure 3. MODDE 5.0 predicted charge $q$ [nC] of PC and PA particles separated from a 75 g PA + 25 g PC granular mixture, as function of the high-voltage $U$ [kV] (a) and the tribocharging duration $t$ [s] (b). The upper and the lower curves on each graph indicate the limits of the 95% confidence interval.

In the case of the 75 g PA + 25 g PC granular mixture, better results are obtained at higher applied voltages and longer tribocharging durations (figure 3).

The PA-PC granular mixtures of various compositions can be successfully tribocharged and separated in the electric field of a fluidized bed. As one sort of particles may be collected faster than the others, the composition of the mixture in the fluidized bed may vary in time. This may impose severe constraints on the integration of fluidized bed devices into a continuous industrial process.

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