Electrostatic separator for micronized mixtures of metals and plastics originating from waste electric and electronic equipment

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Abstract. In spite of their extensive use for processing mixtures of granules exceeding 1 mm in size, very few industrial electrostatic separators are capable of handling micronized metals and plastics originating from waste electric and electronic equipment. The aim of the present work is to validate the possibility of using a novel belt-type electrostatic separator for the selective sorting of such particulate mixtures, the dimensions of which are in the order of 0.1 mm. In this type of separator, the metal particles get charged by electrostatic induction in contact with the grounded metal belt electrode, while the plastics remain uncharged in the electric field and are collected separately. The experiments are performed with 2-g samples of a mixture composed in equal proportions (50% - 50%) of Aluminium and Acrylonitrile Butadiene Styrene (ABS) particles of average diameter ranging between 125 µm and 250 µm. They enabled the evaluation of the effects and the interaction of two control variables of the process: the angle of inclination of the roll-type electrode and the high voltage applied to it.

1. Introduction
Electrostatic separation is a method extensively employed in industry for processing mixtures of granules typically exceeding 1 mm in size [1]-[3]. However, very few electrostatic separators are capable of handling smaller sized particulate mixtures [4]-[7]. The micronized mixtures of metals and plastics originating from waste electric and electronic equipment (WEEE) are characterized by dimensions in the order of 0.1 to 0.5 mm.

The aim of the present paper is to demonstrate the feasibility of the electrostatic sorting of such mixtures, using a novel multifunctional belt-type electrostatic separator. The experiments are carried out with micronized mixtures of Al and ABS, two materials frequently encountered in the composition of WEEE. The study is performed according to a full factorial experimental design [8], [9] that enables the evaluation of the effects of the two major control variables of the process.

2. Experimental set up
The novel belt-type electrostatic separator (figure 1), designed by the PPRIME Institute in Poitiers, France, is a multifunctional equipment that is able to sort granular or micronized materials through the use of three different physical mechanisms of electrical charging: (1) triboelectric effect [10]-[13] involving the charge transfer at the impact and/or friction of the particles between themselves or against the walls of dedicated devices; (2) DC corona discharge [14], [15]; (3) electrostatic induction [16]-[18]. The particles are disposed as a monolayer onto the surface of a metallic belt-type conveyor (6) (length: 700 mm; width: 70 mm), which is connected to the ground and entrained by a variable speed drive (5).
The primary vibratory feeder (8) (model PDB 4/30, VIBRA France) may be used in association with a custom-designed particle-dispersion device and has a dedicated control unit. The speed of the particles at the surface of this tray can be thus correlated with the speed of the metallic conveyor belt. A secondary vibratory feeder (7) (model DR 100, RETSCH) is employed for adjusting the mass of material processed in a time unit. The trays of both vibratory feeders are connected to the ground.

A roll electrode (4) (stainless steel; diameter: 30 mm; length: 70 mm) is connected to a reversible (positive or negative) high voltage power supply (not shown in figure 1; model SPL 300, 100 kV; 3 mA; SPELLMAN). A zone of intense electric field is generated between this electrode and the grounded metallic belt-conveyor. The uncharged insulating particles are not affected by this electric field, and are collected in the box (1). The conductive particles charge by conductive induction in contact with the grounded belt (6) and are attracted to the roll electrode of opposite polarity. Most of them are collected in the box (2). Some of the conductive particles attracted to the roll electrode bounce back after contact with it and end up in the box (3) of the collector.

The distance between the roll electrode and the surface of the metallic belt conveyor is 25 mm. Its angular position is expressed by the angle $\alpha$ [$^\circ$] between the vertical direction and the plan defined by the axes of the roll and of the conveyor drum. This angle can be set in the range from 0$^\circ$ to 90$^\circ$, by increments of 15$^\circ$.

### 3. Materials and method

The experiments are carried out on a 50% Al + 50% ABS mixture of particles originating from WEEE. The average diameter of the particles of the mixture ranges between 125 µm and 250 µm.

Based on the results of a preliminary electrostatic separation test, the angular position $\alpha$ [$^\circ$] of the roll electrode and the high-voltage $U$ [kV] applied to it have been designated as the most significant factors of the electrostatic separation process and their domain of variation has been fixed as shown in Table 1.

**Table 1.** The domain of variation of the control variables: angle $\alpha$ and high-voltage $U$.

|          | Minimum | Maximum |
|----------|---------|---------|
| $\alpha$ [$^\circ$] | 15      | 45      |
| $U$ [kV]   | 14      | 20      |
A full-factorial experimental design is adopted for the present study, as it enables the evaluation of the effects of these two control variables and the interaction between them. These experiments are all made in stable climatic conditions of temperature (between 23.9 ° and 25.6 °) and relative humidity (between 56.2 % and 62.4 %). Each of the 2² experiments is duplicated, to make possible the estimate of the experimental error.

The masses collected in the three boxes (figure 2) are measured with a precision electronic scale (resolution: 0.01 g). The values recorded for the boxes 2 and 3 are summed up to give the total mass of the conductor product. The roll electrode and the conveyor belt are cleaned after each experiment. The data are analysed with commercial software (MODDE 5.0, Umetrics, Sweden).

Figure 2. Schematic of the collecting system.

4. Results and discussion

The results of the eight experiments are given in Table 2, where \( m_{\text{Al}} \) and \( m_{\text{ABS}} \) are respectively the masses of the conducting and insulating separated products, expressed in percentage of the feed.

| Run | \( U \) [kV] | \( \alpha \) [°] | \( m_{\text{Al}} \) [%] | \( m_{\text{ABS}} \) [%] | Loss [%] |
|-----|--------------|----------------|-----------------|-----------------|--------|
| 1   | 14           | 15             | 53.27           | 44.86           | 1.87   |
| 2   | 20           | 15             | 58.06           | 40.32           | 1.61   |
| 3   | 14           | 45             | 33.17           | 66.35           | 0.48   |
| 4   | 20           | 45             | 49.72           | 49.73           | 0.55   |
| 5   | 14           | 15             | 47.32           | 51.71           | 0.98   |
| 6   | 20           | 15             | 60.99           | 38.46           | 0.55   |
| 7   | 14           | 45             | 36.04           | 62.94           | 1.02   |
| 8   | 20           | 45             | 42.42           | 57.07           | 0.51   |

The material losses for these experiments are negligible because they represent less than 2% of the feed (an average of 0.94%). Using MODDE 5.0, a linear model is obtained for each of the output variables (responses) \( m_{\text{Al}} \) and \( m_{\text{ABS}} \), in function of the normalized centred values \( U^* \) and \( \alpha^* \) of the two control variables (figure 3):

\[
m_{\text{Al}} = 47.62 + 5.17 U^* - 7.28 \alpha^* \tag{1}
\]

\[
m_{\text{ABS}} = 51.43 - 5.03 U^* + 7.59 \alpha^* \tag{2}
\]

The average mass of the conductive product \( m_{\text{Al}} \) collected in boxes 2 and 3 increases from about 42% at an applied high voltage \( U = 14 \text{ kV} \) (which means that the electric is too weak for all the Al particles to be attracted to the roll electrode), to roughly 52% at \( U = 20 \text{ kV} \). Indeed, by increasing the high voltage, the electric field becomes strong enough to drive to the roll electrode not only the 50 g of Al, but also some of the ABS particles that carry a positive charge, acquired by tribocharging effect during transportation. Neutralization of the materials prior to electrostatic separation might solve this problem.

The angular position \( \alpha \) of the roll electrode has also a significant effect on the mass of conductive product. The average mass collected with the roll electrode at \( \alpha = 15^\circ \) represents more than 55% of the feed, which means that the electric field drives to the boxes 2 and 3 not only the Al particles, but also a relatively large percentage of insulating particles. This is due to both the Coulomb force acting on the insulating particles carrying a residual positive tribo-charge, and the dielectrophoretic force that acts on neutral, but polarized ABS particles. At \( \alpha = 45^\circ \), the mechanical forces (centrifugal and gravitational) have a stronger influence on both Al and ABS particles, and the average mass of the conductive product represents only 35% of the feed, if \( U = 14 \text{ kV} \). According to the linear model (1), the best results (i.e., \( m_{\text{Al}} = 50\% \)) are expected to be obtained at \( U^* = 1 \) (i.e., \( U = 20 \text{ kV} \)) and \( \alpha^* = 0.4 \) (i.e., \( \alpha = 33^\circ \)).
Figure 3. MODDE 5.0- predicted variation of the collected mass of aluminum, expressed in [%] of the total mass of the particulate mixture fed to the separator, as function of the applied voltage $U$ [kV] (a), and of the angle $\alpha$ [°] (b). The upper and lower curves indicate the limits of the confidence interval.

However, a composite factorial experimental design should be performed in order to rigorously establish the optimal operating conditions. An appropriate technique for evaluating the purity of the products would be necessary for validating that optimum.

5. Conclusions

The belt-type electrostatic separator presented described in this paper can successfully perform the selective sorting of metallic and insulating particles from micronized WEEE. Within the limits of the experimental domain considered in the present study, the mass of the particles recovered as conductive product increases with the applied high-voltage and decreases with the angle that gives the position of the axis of the high-voltage electrode.

Further research is needed for a more accurate modelling and optimization of the separation process, as well as for analyzing the purity of the products.

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