Electrostatic separation of HIPS/ABS and HIPS/ABS-PC plastic mixtures from IT equipment using fluidized bed tribocharging

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ABSTRACT. The paper presents an experimental study of the triboelectrostatic separation feasibility of two plastic mixtures, HIPS/ABS and HIPS/ABS-PC from IT waste, with balanced composition, 50% component A / 50% component B, as well as unbalanced compositions such as 10% A / 90% B and 90% A / 10% B. Samples of (1 - 2) mm granular mixture were provided by a WEEE recycler. The laboratory set-up consists in a free fall electrostatic separator equipped with a fluidized bed tribocharging device, characterized by interchangeable tribocharging chambers. Preliminary tests were carried out in order to establish the optimal material for the tribocharging chamber and the duration of the charging process. Samples of the granular mixture were subjected to the tribocharging process, then introduced into the free-fall electrostatic separator. The analysis of the seven collecting boxes contents shows a recovery rate of approximately 90% and a purity of about 99% for both components of the granular mixture. These results put in evidence the feasibility and the high efficiency of the triboelectrostatic separation of balanced and as well as heavily unbalanced composition mixtures of HIPS/ABS and HIPS/ABS-PC, using the fluidized bed for the tribocharging device.

KEYWORDS: triboelectrostatic separation, weee recycling, granular plastic mixtures, free-fall electrostatic separator, tribocharging device.

1. Introduction

Around 25.8 million tons of plastic waste are generated in the European Union every year. Less than 30% of such waste is collected for recycling, a significant part being treated in third countries (Communication 2018). Plastics from waste electric and electronic equipment (WEEE) represent 8% of this quantity, are more highly engineered, and include additives. IT equipment is characterized by the presence of more than one type of polymer in one product and the plastics are bounded with more complex products. Because of their chemical structure, different types of polymers should not be mixed together in the recycling process. According to Takatori (2018) even at low content of impurities, the mechanical properties of the recycled plastic often are significantly worsened. This requires that the mixed WEEE plastics be efficiently sorted on polymer types.

Different technologies are used for mixed plastic separation, including wet separation techniques - froth flotation (Burat, Güney and Olgaç Kangal 2009; Wang et al. 2015), density (sink-float) separation (Wang et al. 2015), magnetic density separation (Bakker, Rem and Fraunholcz 2009; Serranti et al. 2015), hydrocyclones (Pascoe 2005; Yuan et al. 2015), and dry separation techniques - automatic sorting systems based on near-infrared spectroscopic analysis (Serranti, Gargiulo and Bonifazi 2012), infrared and Raman spectrometry (Sommer and Rich 1997; Allen, Kalivas and Rodriguez 1999), infrared absorption using laser diodes, vertical air classifiers, air table, triboelectrostatic separation (Dascalescu et al. 1998, Dascalescu, Zeghloul and Iuga 2016, Dodbiba and Fujita 2004). Among the technologies currently employed for waste plastic sorting, the triboelectrostatic separation already proved its efficiency (Bilici et al. 2011; Dascalescu et al. 2011; Dodbiba et al. 2003a, 2003b; Li, Wu, and Xu 2015; Park, Jeon, and Park, J. 2007), and it’s distinguished as a clean and environmentally friendly technology that has the advantage of low energy consumption, simplicity and moderate cost maintenance. The method consists in charging the components of the granular mixture with opposite polarity charge using a tribocharging device, then feeding the charged material in the high intensity electric field of a free fall electrostatic separator where the granules trajectories are deflected by the electric field force in accordance with the charge magnitude and polarity (Fig. 1.a). One of the most efficient tribocharging device uses the fluidized bed to charge the granular mixture (Boukhoulda et al 2017; Calin et al. 2008a, 2008b; Bilici et al. 2011; Dascalescu et al. 2011, Iuga et al 2016) and consists of a fluidized air chamber, an input/output module for the granular material, and a tribocharging chamber (Fig. 1.b).

Figure 1. Here.

WEEE, and in particular IT waste, contains a large number of engineering plastics whose value is much higher than other plastics used in packaging, agriculture, or construction. ABS and HIPS represent more than 50 % of these plastics, ABS-PC being also frequently used in IT equipment (European Electronics Recyclers Asssociation 2017; Makenji and Savage 2012; WRAP 2009). The value of recycled plastics from IT waste is much higher if ABS and ABS-PC can be separated from HIPS.

The aim of this experimental study is to evaluate the possibility of separating HIPS/ABS-PC and HIPS/ABS mixtures originating from IT waste, with interest in balanced mixture compositions (50% component A / 50% component B), as well as heavily unbalanced compositions (10% A / 90% B and 90% A / 10% B).

2. Materials

Granular samples of ABS-PC, ABS, and HIPS used in our experiments originate from a company that specializes in recycling IT wastes.

Preliminary tests done with binary mixtures of these raw material samples showed poor quality separations for the main separation indicators such as recovery rate and purity. It was concluded empirically that when charging granules in a fluidized bed tribocharging process, the fine granules (fractions smaller than 1 mm) charge after approximately 30 seconds. Then they get stuck either on the interior surface of the tribocharging chamber, or on larger granules (fractions larger than 1 mm), that leads to a lower net granular charge and poor separation results. Previous experimental runs showed that the triboelectrostatic separation process is optimal when the granular fraction is between 1 mm and 5 mm with the ratio of the maximum and minimum granule size d_{max} / d_{min} = 1…2.5 (Calin et al., 2008b).

In order to prepare the samples for separation, the granular material underwent a gradation test and its granular fraction composition is shown in Fig. 2.

Figure 2. Here.

For each of the three materials, the fractions smaller than 1 mm were eliminated and the remaining two larger fractions were used in further experiments. In each case these larger fractions represent about 90% of the total weight of the primary sample, while the d_{max} / d_{min} ratio is approximately 2. Each material has a different color, that facilitates the evaluation of the separation results.

3. Experimental set-up and method

3.1 Experimental set-up

The experimental set-up that was used to conduct the separation experiments on HIPS/ABS and HIPS/ABS-PC granular mixtures is composed of a fluidized bed tribocharging device and free-fall electrostatic separator (Fig. 3). The plate electrodes of the separator (1250 mm x 550 mm) are positioned with a 300 mm gap at their tops (to concentrate a higher field in this region) and a 600 mm gap at their base (to allow a larger spread of granules). The high intensity electric field was generated by connecting these electrodes to two high voltage supplies of positive and negative polarity. The fluidizing air was supplied from a compressor at constant pressure, (p = 0.5 bar), temperature (T = 18°C), and humidity (RH = 6%).

Figure 3. Here.

A typical separation experiment is conducted by charging the granular sample to be separated in the fluidized bed tribocharging device for a set amount of time, in order to acquire sufficient charge on the granules surface with opposite polarity for the two components of the granular mixture. Then the material is fed into the separator and as it falls free between the electrodes, each granules' individual trajectory is deviated by the force exerted by the high intensity electric field, then collected in the seven boxes placed at the base of the separator.

3.2 Choosing the tribocharging chamber material

The main tribocharging mechanism in fluidized bed devices (Fig. 4) is the granule-granule collision (cases B and C), but granule-wall collisions (case A) might amplify or diminish the net surface charge of the granules (Messafeur et al. 2019). An efficient triboelectrification is obtained when the chamber's walls give the granules the same charge polarity that granules obtain after colliding with each other, as in case B (Calin et al. 2007).

Figure 4. Here.

In order to choose the optimal material for the tribocharging chamber, three chambers of identical geometry, but different available materials – aluminum (Al), polypropylene (PP), and polyethylene terephthalate (PET) were constructed. Two minutes long tribocharging runs were conducted with each of the three chambers and the polarity of the charge acquired on the granules was recorded.

The aluminum walls of the chamber charge all types of granules with negative polarity, while polypropylene with charge of positive polarity. In contrast, the charge polarity acquired by the granules in the PET chamber is negative for HIPS granules and positive for ABS and ABS-PC granules. This makes the PET chamber a charge amplifier for both considered material mixtures of HIPS/ABS and HIPS/ABS-PC, as HIPS charges negatively with both ABS and ABS-PC. In addition, PET is transparent and allows observation of the phenomena, making this material the obvious choice for the tribocharging chamber.

3.3 Setting the optimal tribocharging time

The charge acquired by the granules in the tribocharging process depends on the number of collisions and consequently on the charging time. For each material, the optimal time was evaluated by running a set of five successive runs of 1, 2, 3, 4, and 5 minutes with samples of 30g.

The PET tribocharging chamber was screened with aluminum tape and grounded in order to allow the charge transfer, while the parameters of the fluidizing air were kept constant at p = 0.8 bar, T = (18…20) °C, and RH = (4…6) %. Each set of five runs was repeated four times, with the average charge values of the granules (measured with a Faraday pail and a Keithley 6415 electrometer) plotted on Fig. 5.

Figure 5. Here.

The charge/mass ratio - time characteristic from Fig. 5 shows a non-linear dependence of the charge accumulated by every of the three types of granules and a saturation tendency for charging times longer than 4 minutes. Looking at HIPS, the charge/mass maximum value is 17.9 nC/g, obtained at a charging time of 4 minutes, wile for a charging time of 5 minutes a decay is recorded, the measured average being 15.2 nC/g. This could be due in principal to charge transfers towards the walls of the chamber from granules that stick and then fall off of the walls' surface. Taking into account that granule-granule collisions represent the main charging mechanism in the fluidized bed, and in order to avoid material getting stuck on the walls of the tribocharging chamber, a charging time of two minutes was considered sufficient for all future experimental runs.

3.4 Binary mixture separation methodology

The separation of HIPS/ABS-PC and HIPS/ABS mixtures was done with a balanced mixture composition made of 50% component A and 50% component B (50%-50%), as well as heavily unbalanced compositions made of 10% component A / 90% component B (10%-90%) or 90% component A / 10% component B (90%-10%).

These three types of mixtures were made with white HIPS granules, green ABS-PC granules, and black ABS granules of fraction larger than 1 mm, in samples of 100g. The charging time was set at 2 minutes for all HIPS/ABS-PC mixtures and 1 minute for HIPS/ABS mixtures (which is more susceptible to getting stuck on the walls of the chamber). The electrodes of the free-fall electrostatic separator were supplied at ±40 kV for HIPS/ABS-PC samples and at ±35 kV for HIPS/ABS samples.

The contents of the seven collecting boxes was analyzed in order to determine the separation quality, so the following two indicators were defined for each composing material: *recovery rate* = ratio of recovered material weight to material weight in sample, and *purity* = ratio of recovered material weight to separated fraction weight.

4. Results and discussion

The separation fractions were established by considering the contents of a number of collecting boxes closest to the electrodes towards each material type was deviated. In the case of balanced mixtures, one fraction would consist of the contents of boxes 1 and 2 (leftmost two boxes), while the other fraction would be the contents of boxes 6 and 7 (rightmost two boxes). For heavily unbalanced mixtures, the separated fraction of the majority component in the initial sample consists of 4 boxes, while the fraction of the component in minority in the initial sample would consist of two boxes.

4.1 HIPS/ABS-PC separation experiments

4.1.1 50% HIPS / 50% ABS-PC

Separation experiments were carried out by doing three successive runs with a balanced mixture composed of 50g HIPS and 50g ABS-PC. The charge polarity acquired by HIPS granules after collisions with ABS-PC granules and the PET walls of the tribocharging chamber is negative, so the separated fractions are collected towards the positive electrode of the free-fall separator, the vast majority in boxes 1 and 2 (Fig. 6.a). ABS-PC granules charge positively in the fluidization bed and are collected towards the negative electrode, mostly in boxes 6 and 7. ABS-PC and HIPS separated fractions are similarly distributed in the collected boxes which hints to an efficient separation, a consequence of the sample containing equal ratios of ABS-PC and HIPS. The quality of the fractions is underlined as well by the very high purities and recovery rates (Fig. 6.b).

Figure 6. Here

The fluidized bed tribocharging process is characterized by three main types of charge exchange by contact (Fig. 4): granule-granule collisions of different materials (case B), granule-wall collisions (case A), and granule-granule collisions of the same material (case C). While the first two mechanisms give, in this case, net positive charge on ABS-PC granules and net negative charge on HIPS granules, the last mechanism charges granules of same material both positively and negatively. However, this last mechanism has low occurrence so in the cases where this mechanism is most responsible how the charge was acquired by a granule, a very low percentage of HIPS granules charged positively (as opposed to most HIPS granules that charged negatively) and ended up being collected with ABS-PC granules, representing the impurities of that fraction. In a similar fashion, some ABS-PC granules charge negatively and represent impurities in the HIPS fraction.

4.1.2 10% HIPS / 90% ABS-PC

A single sample containing 10g HIPS and 90g ABS-PC was charged in the fluidized bed tribocharging device and then separated. Two more runs were made and their separated fractions let to accumulate so that two separation products were obtained (Fig. 7). The minority component (HIPS) acquires a strongly negative charge, because each HIPS granule gets its charge from ABS-PC granules (1 to 9 ratio) and the PET wall of the device. Consequently, most HIPS granules are deviated towards boxes 1 and 2 in the vicinity of the positive electrode.

ABS-PC granules, that are in majority, charge with a weak positive charge because most contacts are with other ABS-PC granules where some charge positively and some negatively (Fig. 4, case C). As consequence, the net charge is low and ABS-PC granules get distributed throughout the seven collecting boxes. Most are found in boxes 4-7 with a maximum in box 5. For this reason, the concentrate HIPS fraction was collected from boxes 1 and 2 and the ABS-PC concentrate from boxes 4-7.

Figure 7. Here.

4.1.3 90% HIPS / 10% ABS-PC

Next experiment focuses on separating heavily unbalanced samples composed of 90g HIPS and 10g ABS-PC. As in the previous case with the other unbalanced mixture, this sample is difficult to separate because the component in minority (ABS-PC) acquires a high positive charge, while the component in majority (HIPS) charges in this case, with charge of both polarities. ABS-PC granules are collected in boxes closest to the negative electrode, while HIPS granules get distributed throughout the seven collecting boxes, with some affecting the purity of the ABS-PC concentrate. The analysis of the separation products (purity and recovery rate) was made for concentrates from boxes 1-4 representing HIPS and boxes 6-7 representing ABS-PC (Fig. 8.a).

Figure 8. Here.

After analyzing the separation products, the recovery rate and purity for HIPS were measured at 95% and 99% respectively, while for ABS-PC at 84.5% and 82.5% respectively. In order to improve the quality indicators, the contents of boxes 4-7, representing an almost balanced mixture of 32.8g HIPS and 29g ABS-PC was collected and run again, first through the tribocharging device, then through the separator. In this case the granular mixture behaved like a balanced sample, with most HIPS charging negatively and being separated in boxes 1 and 2 and ABS-PC charging positively and collecting in boxes 5-7 (Fig. 8.b).

After the two-step separation the final HIPS concentrate is 99.6% pure and has a recovery rate of 99.6%, while the ABS-PC concentrate has a recovery rate of 89% and 99.6% purity (Fig. 9).

Figure 9. Here.

4.2 HIPS/ABS separation experiments

For all HIPS/ABS granular mixtures the tribocharging time in the fluidized bed device was reduced to 60 seconds, because at larger time intervals strongly charged granules adhere to the PET wall of the tribocharging chamber. The voltage drop between the electrodes was reduced as well, to 70 kV by supplying the electrodes at ± 35 kV. This was done in order to avoid deviating the granules so much that they hit the electrodes and end up collecting towards the opposite electrode with the other material concentrate.

4.2.1 50% HIPS / 50% ABS

Four balanced samples of 50g HIPS and 50g ABS were used to carry out four successive runs of tribocharging and separation. Repeated contacts between ABS and HIPS granules represent the main charging mechanism and lead to equal, but opposing polarity charge/mass ratio for both materials.

HIPS granules charge negatively in contact with ABS granules or the PET wall of the tribocharging chamber and in the high intensity electric field of the separator, deviate towards the positive electrode, in boxes 1 and 2 (Fig. 10.a). Similarly, ABS-PC granules charge positively when in contact with HIPS granules or the PET walls and end up mostly in boxes 6 and 7.

The purity of ABS and HIPS concentrates was computed after four successive runs and shows values close to 100% for both materials. The recovery rates are somewhat lower, but close to 90% (Fig. 10.b). The larger quantity of unseparated fraction (middling) might be a result of both the reduction of the tribocharging time, and the weaker field between the electrodes of the free-fall electrostatic separator.

Figure 10. Here.

4.2.2 10% HIPS and 90% ABS

HIPS granules constitute in this case the minority component and they get heavily charged negatively after repeated collisions with ABS granules in the tribocharging process. In the meantime, the majority ABS granules acquire a weak positive charge causing a spread in all the seven boxes, with a maximum in box 6 (Fig. 11.a). Heavily charged ABS granules collide with the negative electrode and get collected in boxes 1 and 2 as impurities for the HIPS concentrate. Therefore, the HIPS fraction collected from boxes 1-2 has a recovery rate of 93.8% and purity of only 83.8%. On the other hand, the ABS concentrate has a purity of 99.7% and a recovery rate of 94.8% (Fig. 11.b).

Figure 11. Here.

4.2.3 90% HIPS and 10% ABS

The experimental results of the separation of this mixture is in conformity with the results obtained with other heavily unbalanced mixtures, with HIPS granules in majority getting a low charge, because the dominant charging mechanism is contacts between granules of the same material (Fig. 4, case C). HIPS granules deviate throughout the collecting boxes with a maximum in box 3, showing that most HIPS granules acquire a weak negative charge. Nonetheless, there are positively charged HIPS granules that were deviated towards the negative electrode and were collected in boxes 6 and 7 (Fig. 12. a). ABS granules in minority charge strongly with positive polarity, with the bulk collecting in boxes 6-7. The presence of a few ABS granules in boxes 2-4 is a result of strongly charged granules bouncing off of the negative electrode and being redirected towards the positive electrode. The analysis of the separation results was made on the HIPS concentrate collected from boxes 1-4 and the ABS concentrate from boxes 6-7, with recovery rates of 95.2% and 93.6% respectively (Fig. 12.b).

Figure 12. Here.

Separation tests results show that HIPS, ABS-PC, and ABS concentrates obtained from binary granular mixtures samples with balanced or heavily unbalanced composition, have high recovery rates and purities with rather close values for each of the studied case (Table 1).

Table 1. Here.

In the triboelectrostatic separation process the charge accumulated by the granules during the tribocharging process is a key factor. Fluidized bed tribocharging devices have the advantage that the main charging mechanism is granule-granule contacts from which the resultant charge is negative for one component of the granular mixture and positive for the other. The ratios of the two components of the binary mixture play a very important role as at equal ratio, most granules of one material type acquire charge of the same polarity. For this reason, the majority of the granules of both materials are collected in the boxes closest to the electrodes and the separation products have recovery rates between 88% and 94.1% and purities between 99.5% and 99.8%.

In the case of heavily unbalanced mixtures, granules from the material in majority charge with the same polarity when in contact with granules of the other material or with the walls of the tribocharging device. However, because there are a lot of contacts between granules of the same type (being in majority), some of them will have a net charge of the same polarity as the minority material charge and end up being collected with them, impurifying the concentrate of the minority material. The recovery rate of the majority material was between 94.8% and 97% with high purities ranging from 99% to 99.7%.

Granules from the minority material are strongly charged, more than the majority material granules, by contacts with granules from the majority material and the walls of the device, with charge of the same polarity. The high intensity electric field of the separator deviates these granules towards the boxes closes to the electrode of opposite polarity. A small number of them are so heavily deviated that they bounce off of the electrode and end up as impurities in the boxes that contain the majority material concentrate.

Consequently, the recovery rate of the minority component is inferior to the majority component and has values between 84.5% and 94.3% with relatively low purities between 82.6% and 92.9%. In some cases, a second separation is necessary in order to obtain higher recovery rates and purities. In the case of the mixture containing 90% HIPS and 10% ABS-PC a second separation run with the minority concentrate led to increased recovery rate and purity of both concentrates. Thus, the recovery rate for HIPS and ABS-PC increased from 95% to 99.6% and from 84.5% to 89% respectively, while the purity increased from 99% to 99.6% and from 82.6% to 99.6% respectively.

5. Conclusions

The results obtained after six triboelectrostatic separation experiments on binary mixtures of HIPS/ABS-PC and HIPS/ABS of balanced and heavily unbalanced proportions confirm the feasibility of the separation of HIPS, ABS-PC, and ABS originated from IT waste in the free-fall electrostatic separator, with prior tribocharging in a fluidized bed device.

The highest recovery rates and purities were obtained for balanced mixtures of the components in the granular samples. In the case of heavily unbalanced mixtures, after a first separation, the majority material concentrate is characterized by high recovery rate and purity close to 100%, while the minority material concentrate has low purity and moderate recovery rate. For heavily unbalanced mixtures, a second separation improves significantly the quality of the separation products.

ACKNOWLEDGMENTS

This work was supported within the research program PN-III-P1-1.2-PCCDI-2017-0652 [project NR. 84PCCDI - 01/03/2018 TRADE-IT].

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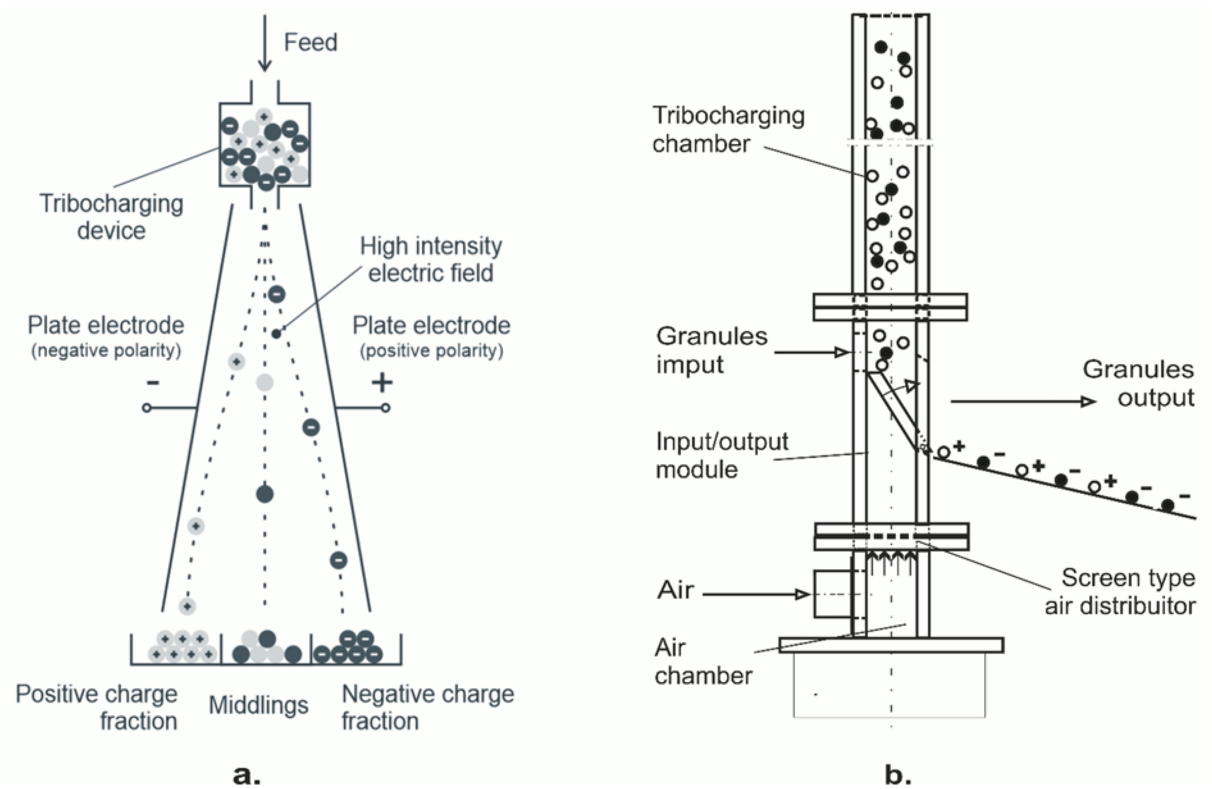

Figure 1. Principle of the triboelectrostatic separation (a) and of the fluidized bed tribocharging device for granular material mixtures (b)

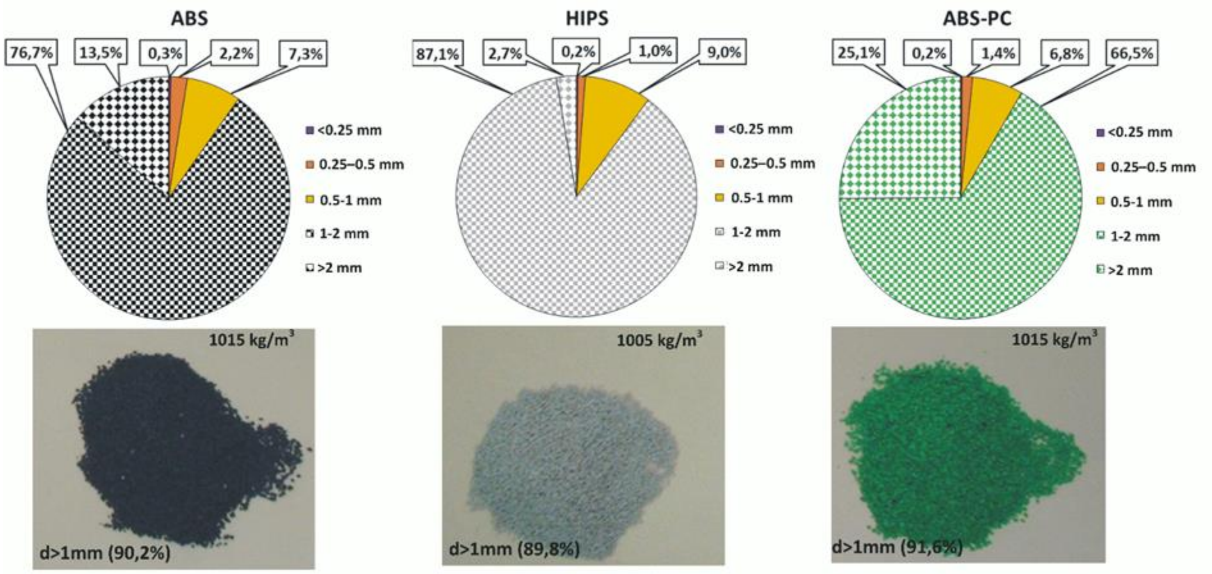

Figure 2. Granular fraction distribution and appearance for each of the three material samples (d>1 mm) used in the separation experiments. The distributions were obtained by sieving the material using a sieve stack containing 0.25, 0.5, 1, 2 mm mesh sizes

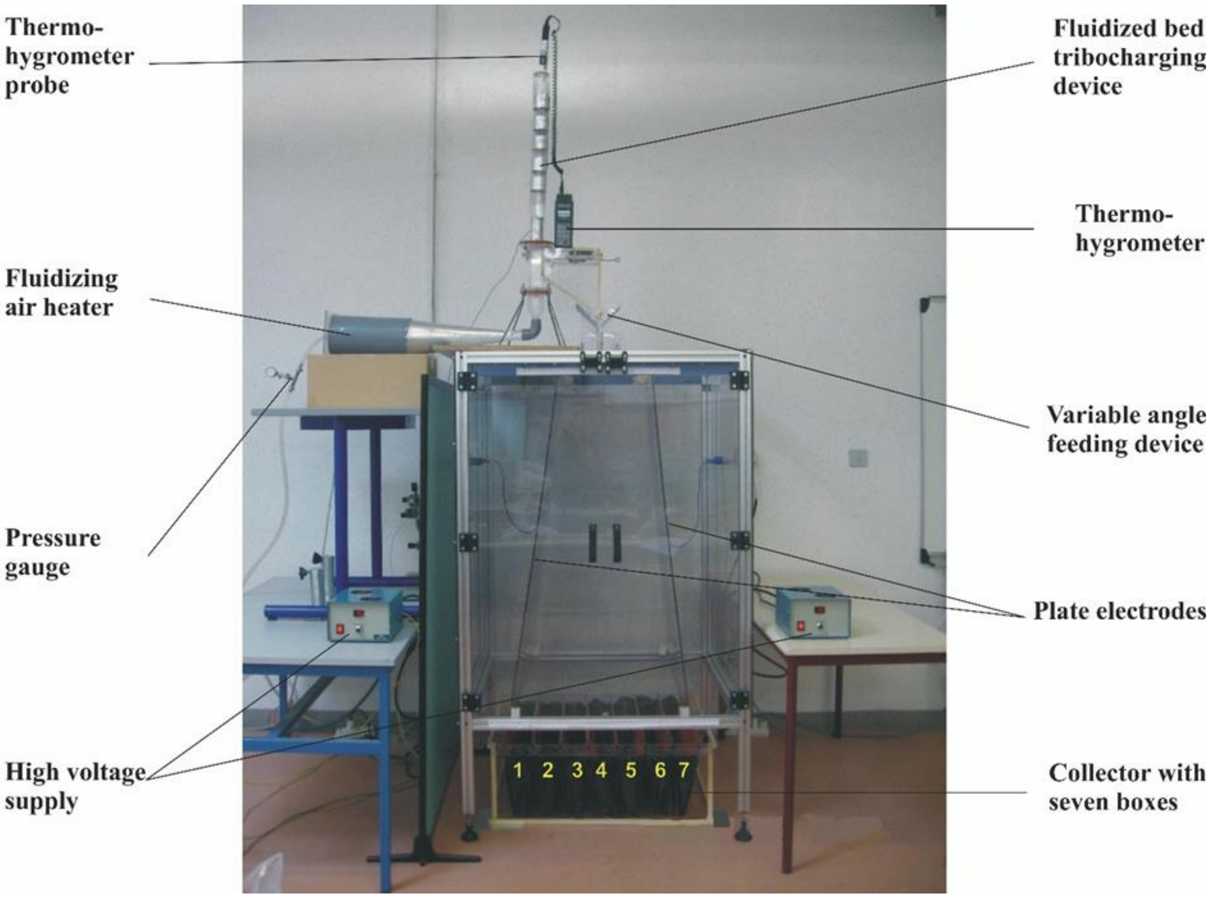

Figure 3. Experimental set-up with fluidized bed tribocharging device and free-fall electrostatic separator

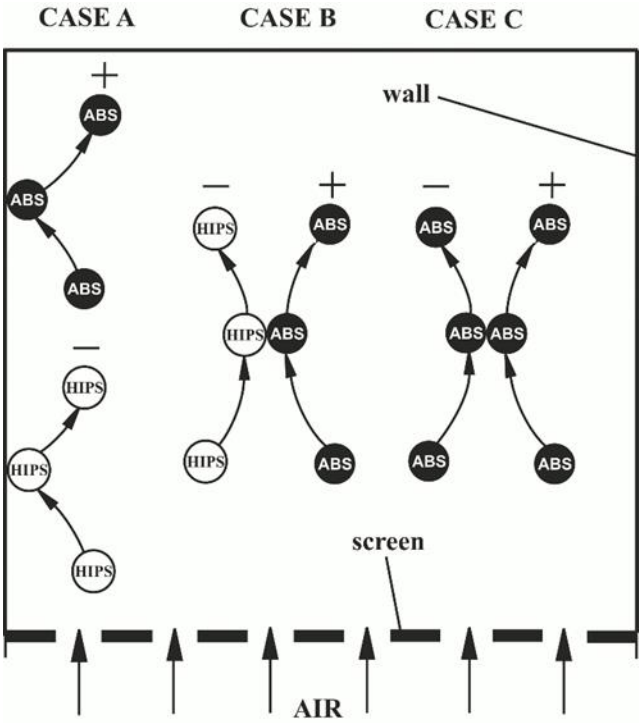

Figure 4. Contact charging mechanisms for granular materials in the tribocharging chamber of the fluidized bed device: granule – wall (case A), granule – granule of different material (case B) and granule – granule of same material (case C)

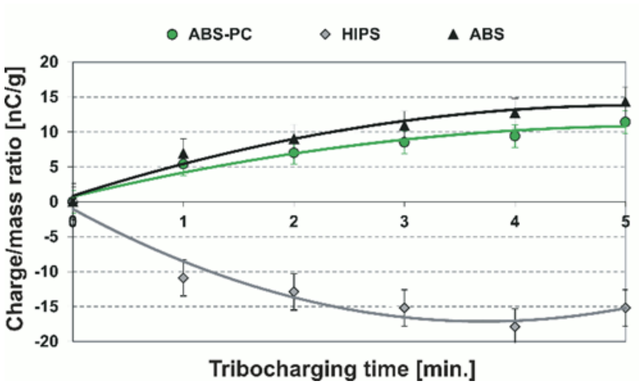

Figure 5. Influence of the tribocharging time on the average charge/mass ratio of ABS, ABS-PC and HIPS granules in a PET tribocharging chamber.

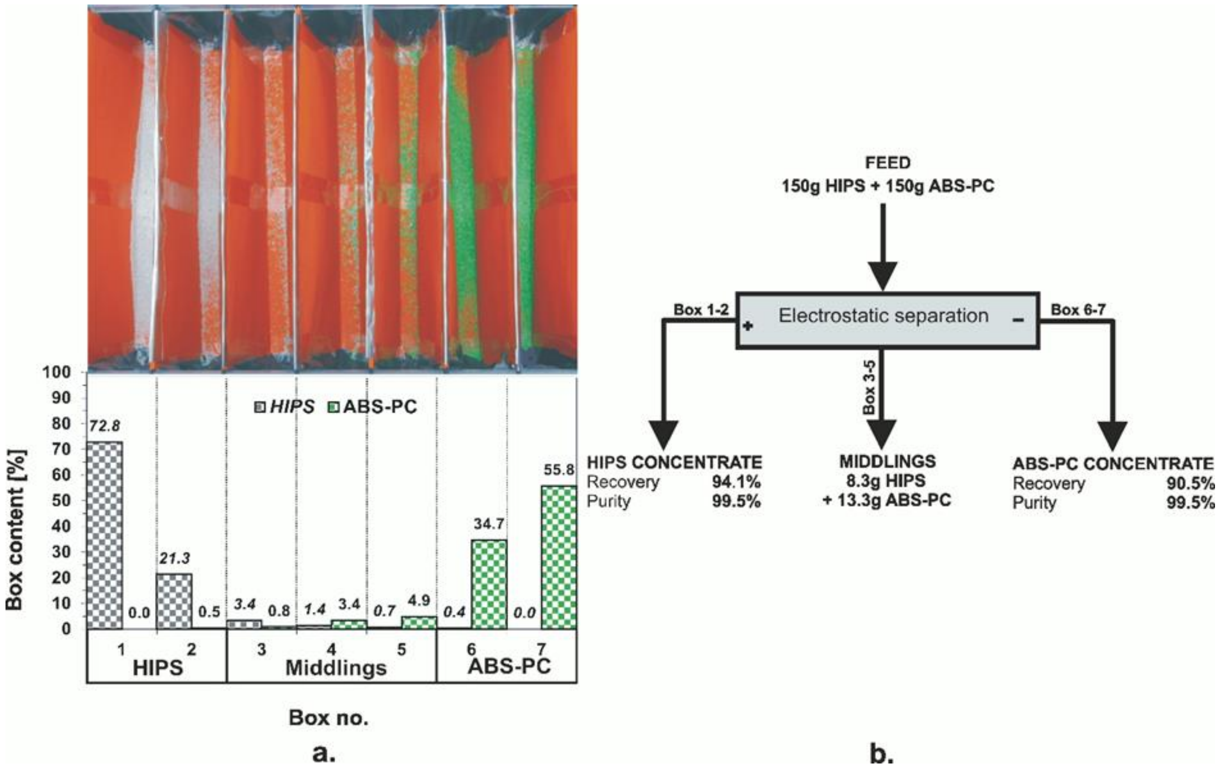

Figure 6. Results of three successive separation runs with balanced (50%-50%) HIPS/ABS-PC samples: material distribution and appearance (a), and recovery rate and purity of separated fractions (b)

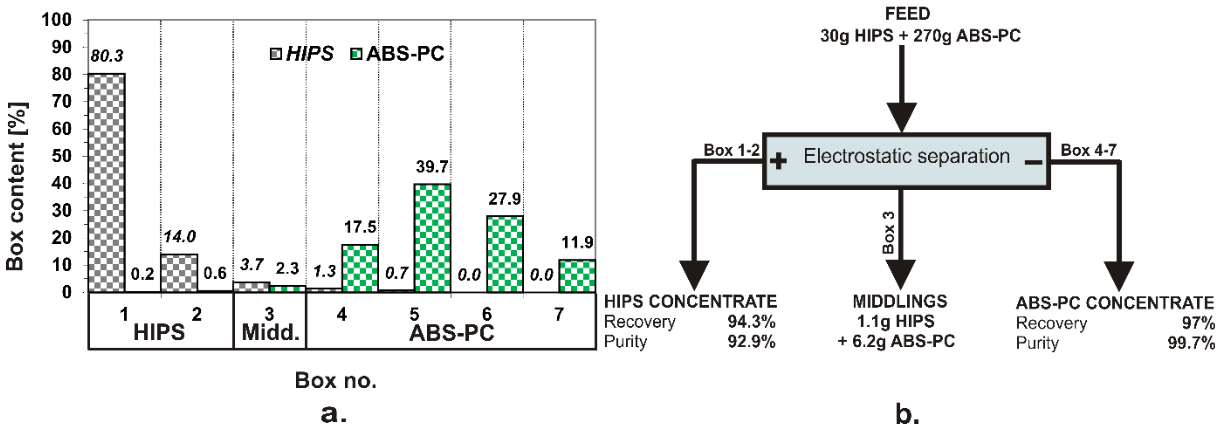

Figure 7. Results of three successive separation runs with heavily unbalanced 10% HIPS - 90% ABS-PC samples: material distribution (a), and recovery rate and purity of separated fractions (b)

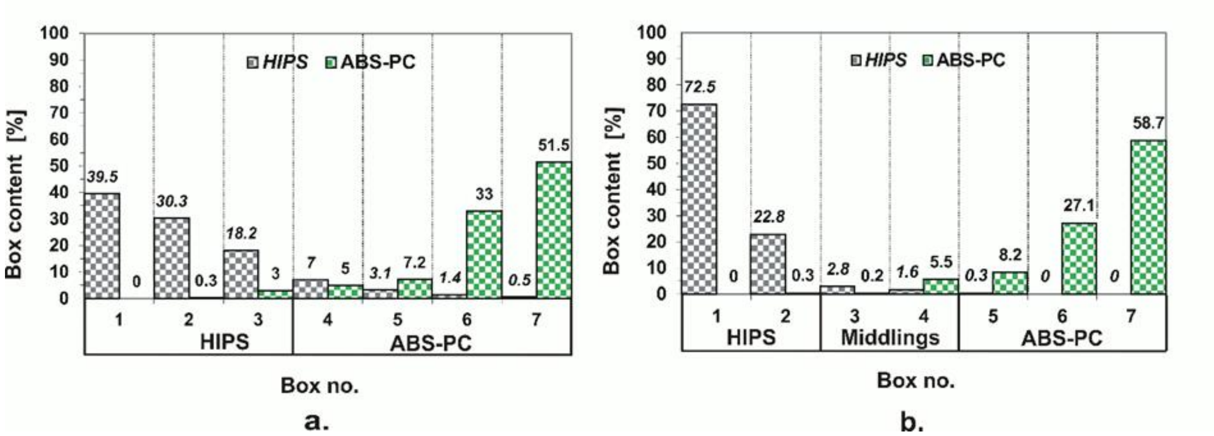

Figure 8. Material distribution after three successive separation runs with heavily unbalanced 90% HIPS - 10% ABS-PC samples (a). Material distribution after the separation of the fraction contained in boxes 4-7 from the first separation (b)

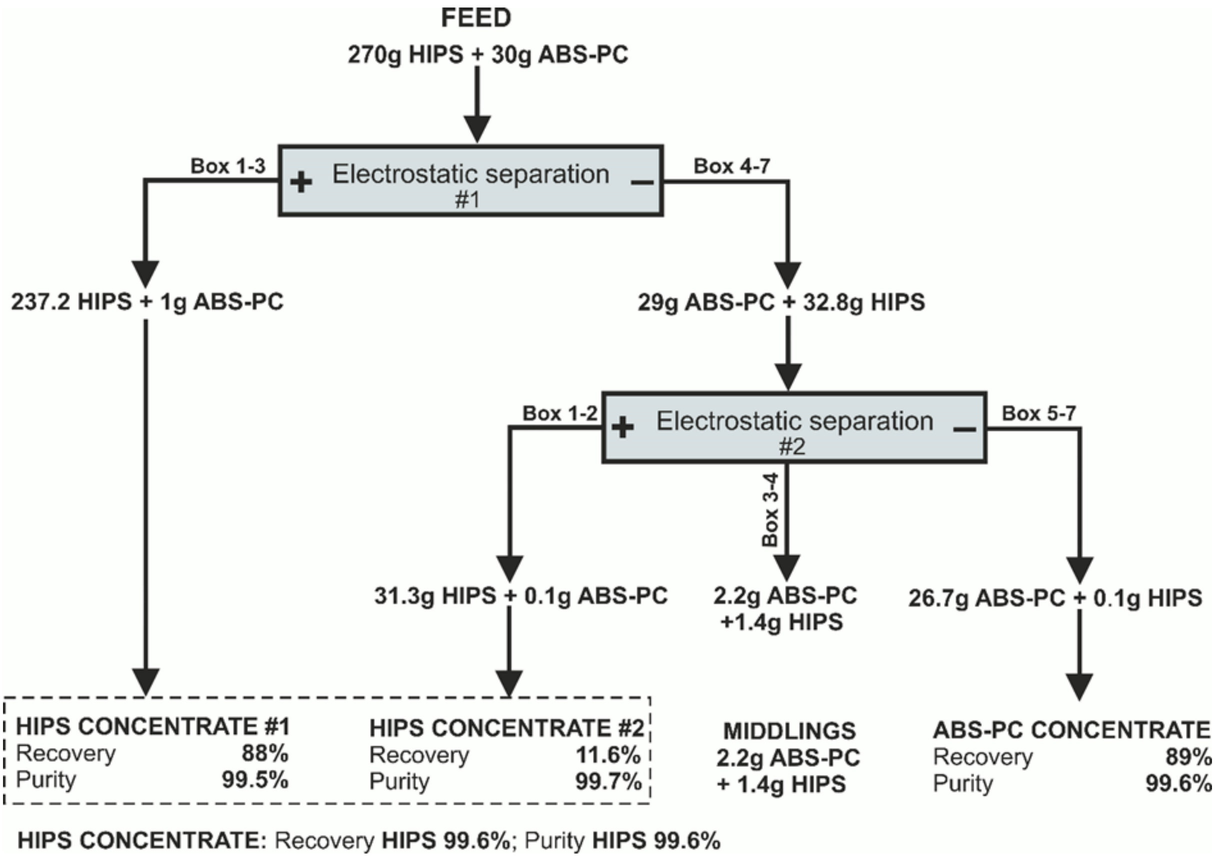

Figure 9. Recovery rate and purity of HIPS and ABS-PC concentrates obtained after a two-step separation of three 90% HIPS / 10% ABS-PC samples

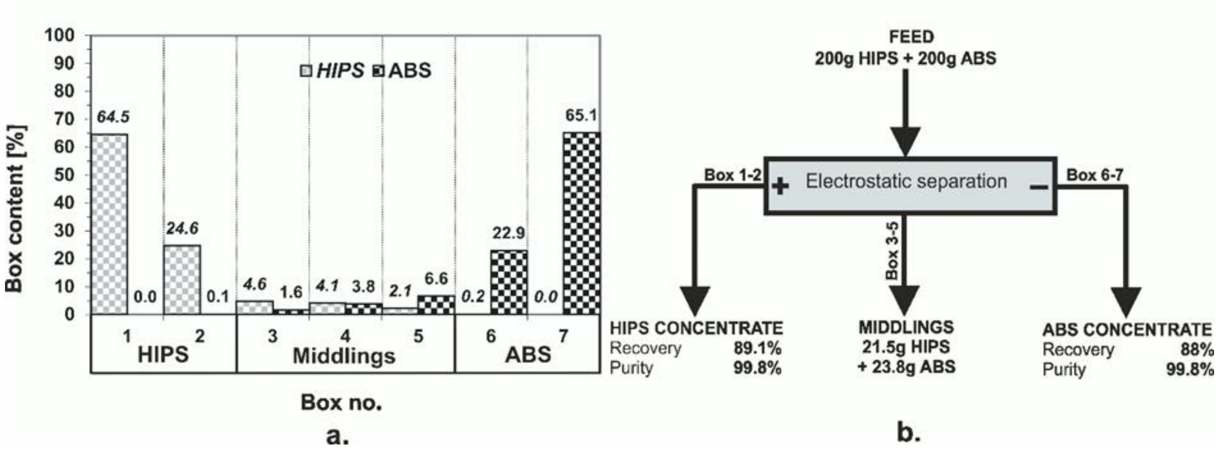

Figure 10. Results of four successive separation runs with balanced ABS / HIPS samples: material distribution (a), and recovery rate and purity of separated fractions (b)

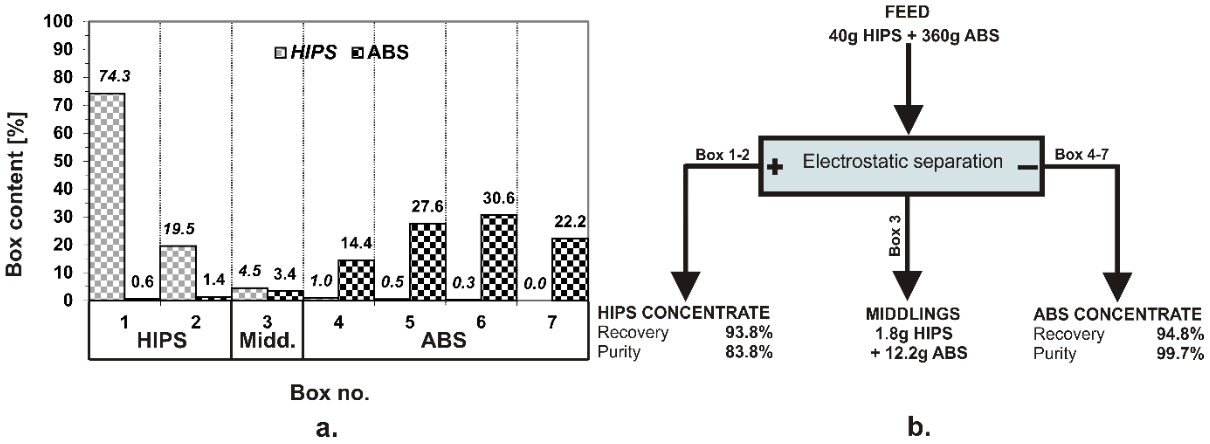

Figure 11. Results of four successive separation runs with heavily unbalanced 10% HIPS - 90% ABS samples: material distribution (a), and recovery rate and purity of separated fractions (b)

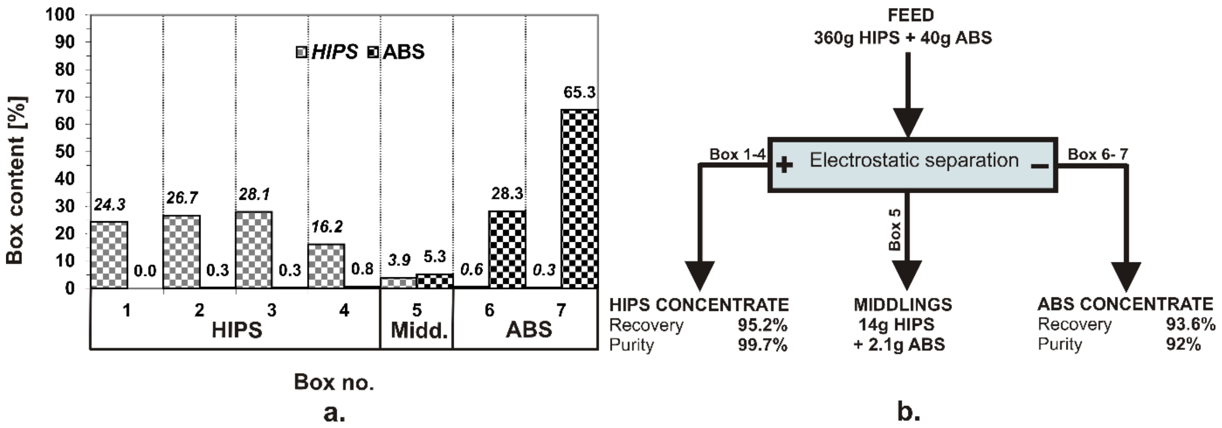

Figure 12. Results of four successive separation runs with heavily unbalanced 90% HIPS - 10% ABS samples: material distribution (a), and recovery rate and purity of separated fractions (b)

Table 1 Quality indicators of the HIPS, ABS-PC, and ABS concentrates obtained after six triboelectrostatic separation tests. In the case of the 90% HIPS and 10% ABS-PC results, the first result (regular text) was obtained after the first separation and the second result (bolded text) was obtained after the second separation.

Mixture	**50%HIPS / 50%ABS-PC**		**10%HIPS / 90%ABS-PC**		**90%HIPS / 10%ABS-PC**	
Material	HIPS	ABS-PC	HIPS	ABS-PC	HIPS	ABS-PC
Recovery rate (%)	94.1	90.5	94.3	97	88/**99.6**	84.5/**89**
Purity (%)	99.5	99.5	92.9	99.7	99.5/**99.6**	82.6/**99.6**
Mixture	**50%HIPS / 50%ABS**		**10%HIPS / 90%ABS**		**90%HIPS / 10%ABS**	
Material	HIPS	ABS	HIPS	ABS	HIPS	ABS
Recovery rate (%)	89.1	88	93.8	94.8	95.2	93.6
Purity (%)	99.8	99.8	83.8	99.7	99.7	92