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Analysis of a novel insulating conveyor-belt tribo-electrostatic separator for highly humid granular products

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The objective of this work is to describe a new configuration of tribo-electrostatic separator equipped with an insulating rubber belt conveyor, to facilitate the processing particles saturated with moisture. The insulating belt is continually charged by corona discharge produced by a fine-wire electrode, placed at a distance of 5 mm above it. The experiments were carried out under conditions of high humidity using samples of HDPE and PP particles. Separation experiments have shown that when the belt is charged by corona, more than 50% of the particles were separated with purity higher than 95%.

1. Introduction

Plastic waste is a major environmental hazard [1–7]. Before recycling, plastics must be strictly separated into different types of polymers [8–10]. Today, the selective sorting of granular plastics based on electrostatic forces is increasingly employed in the recycling industry [11–16].

The tribo-electrostatic separation of granular plastic mixtures is frequently used as a major operation of technologies that have been developed for the recycling of waste of electrical and electronic equipment (WEEE) [17–20]. The efficiency of such process depends mainly on the charge level that the granules acquire by triboelectric effect, using vibratory chargers or fluidized bed devices, before being exposed to the action of intense electric field forces [21–23].

Triboelectric charging is a complex phenomenon characterized by great variability and depends on many factors, such as: nature and properties of the material, state of the surface, type of contact, environmental conditions [24–27]. Significant efforts have been made to understand the physics of triboelectric mechanisms and to control these factors. The relative humidity of the ambient air seems to have a great influence on the efficiency of the triboelectric charging process [28–30]. It has been shown that the presence of water on the surface or inside the polymer increases the surface conductivity and contributes to the dissipation of the electric charge [24–26,30]. This phenomenon is detrimental to electrostatic separation, when the particles in contact with a metal electrode loose part of their charge and are less affected by

the electric field forces.

On the other hand, the water layer on the surface of the plastic forms water bridges that increase surface contact and facilitates charge transfer, decreasing the efficiency of the tribocharging process [27,30–32].

The objective of this work is the description of a new tribo-electrostatic separation configuration dedicated for highly humid granular plastic products, using a corona-charged insulating conveyor-belt instead of a metal belt as carrier electrode. The main feature of the process is that the tribocharged granular mixture preserve its charge while in contact with the plastic conveyor belt that carries it through the active zone of the separator. In addition to this, the plastic belt is continuously charged using a fine wire corona-electrode connected to a DC high voltage source, to produce a high intensity electric field with respect to a standard metal-roll electrode of opposite polarity [33–35]. Experimental analysis was performed using humid plastic granular mixtures and a comparison was carried out between charged and non-charged conveyor belt. Moreover, the new separator configuration was compared with the conventional free-fall tribo-electrostatic separator.

2. Materiel and methods

The experimental setup shown in Fig. 1, is constituted of a plastic-belt conveyor of dimensions $1980 \times 195 \times 2 \text{ mm}^3$, moving at a constant linear speed of 30 cm/s. The electric field is generated by a cylindrical static electrode of 10 cm length and 5 cm diameter connected

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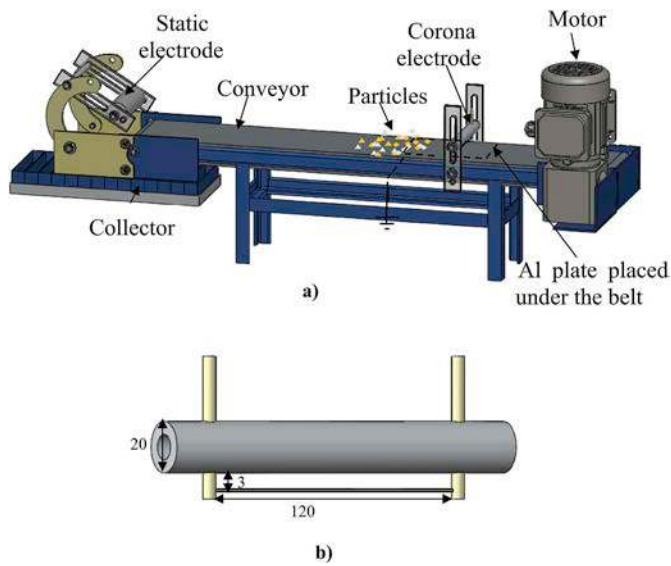


Fig. 1. The experimental setup. a) the conveyor belt separator; b) dimensions of the corona electrode (in mm).

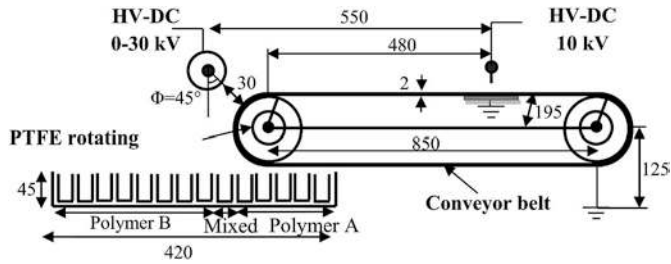


Fig. 2. Descriptive schematic of the tribo-electrostatic separator (All dimensions in mm).

to a variable DC high-voltage supply (Spellman, 40 kV, 9 mA). A corona electrode consisting of a 1 mm diameter copper wire is connected to a DC high voltage source (20 kV, 10 mA), placed at a distance of 5 mm above the belt. A metal plate placed under the belt right below the corona electrode represents the ground electrode; the belt is thus charged by corona generated between both electrodes (Fig. 2). For all the experiments, the corona voltage was kept constant and equal to $V_c = 10$ kV.

Two types of experiments were carried out:

- Separation experiments without charging the belt.
- Separation experiments with charging the belt: the belt is charged first for at least 20 min before starting the experiments, leaving the belt in charging mode until the end of the experiments.

The experiments were performed using samples of HDPE and PP particles, originating from granular plastic wastes, with an average particle size of 5 mm (Fig. 3). Notice that the particles were saturated with moisture after placing them in ordinary tap water for 20 min and left for 12 h spread on a grounded metal plate. Preliminary tests were carried out to evaluate the water content by measuring the mass of the particles before and after to put them in water. The estimated average water content of three identical tests was equal to 2.9% and 5.6% for PEHD and PP particles, respectively.

Before separation, the granules were tribo-charged in a fluidized bed for a period of 30 s and then deposited on the conveyor belt downstream the corona electrode (Fig. 1) [13,36]; they were slowly deposited using a plastic spoon to avoid any further tribocharging. The fluidized bed is frequently used for the acquisition of triboelectric

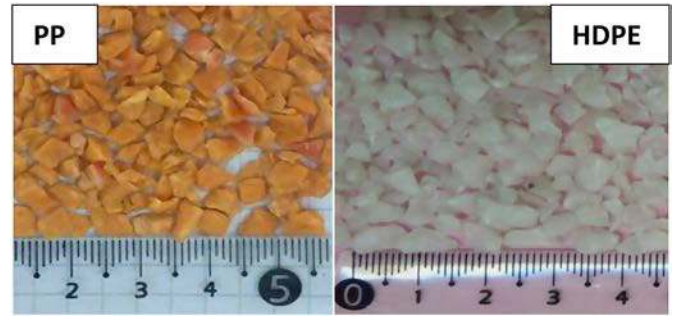


Fig. 3. Particle samples.

charge; the mixture of particles is deposited on a sieve support and then brought into agitation by the upward-oriented air flux generated by a blower. The particles acquire electric charges of opposite signs due to collisions between them. In this case, there is little charge acquired by collisions with the walls, which are made of poly-methyl-methacrylate (PMMA). Measurement of the electrical charge acquired by the particles was carried out using a Faraday cage connected to a sensitive electrometer (Monroe, Model 284). Moreover, the electric field at the surface of the conveyor belt was measured by using a digital field-meter (Monroe, Model 257D).

The same total mass of granular mixture equal to 20 g was used for all the experiments, comprising 50% of HDPE and 50% of PP. After tribocharging in the fluidized bed, the charged product was recovered in a plastic container and then deposited manually on the belt moving with a flow rate of 3.3 g/s.

The factors that were analyzed in this work are the following:

- Level of the voltage applied to the cylindrical static electrode V_s (kV);
- Charging time duration of the corona electrode t (min).

The performance of the separator was analyzed by measuring both the recovery and the purity rates of the separated products using a 0.01 g precision digital balance. All plotted points represent the average value of three runs. For all the experiments, a negative polarity was applied to the static electrode and a positive polarity for the corona electrode.

The purity and recovery rates of the separated products were calculated as follows:

$$Pur(\%) = (m_{ic}/m_{it}) \times 100 \quad (1)$$

$$Rec(\%) = (m_{ic}/m_{it}) \times 100 \quad (2)$$

where.

m_{ic} is the quantity of product i that is collected in the compartment reserved for it

m_{it} is the total mass (both products) collected in the same compartment.

m_{it} the total mass of product i introduced in the feed

Moreover, the new configuration has been compared with the conventional free-fall tribo-electrostatic separator (FFTES) which is considered as the most used tribo-electrostatic separation process in industry. A descriptive schematic of the FFTES is represented in Fig. 4. First, the particles are tribo-charged in the fluidized bed device and then are introduced in the separator falling vertically through an intense horizontal electric field produced by two rectangular metal electrodes of dimensions 40×80 cm², connected to two DC high-voltage supplies of opposite polarities. The particles charged negatively are attracted towards the positive electrode and the ones charged positively are attracted towards the negative electrode. The products are

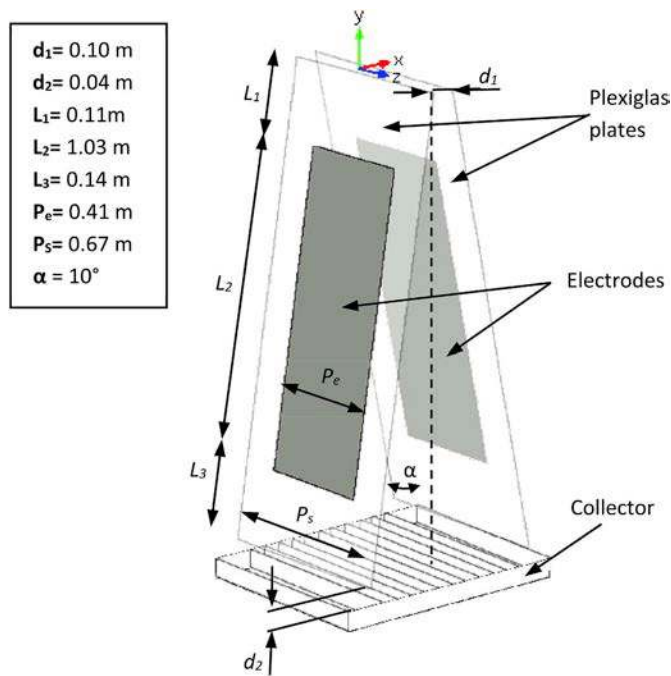


Fig. 4. Descriptive schematic of free-fall tribo-electrostatic separator (FFTES).

recovered in a collector constituted of three compartments (material 1, mixed product and material 2).

3. Results and discussion

Obtained results of the measured mass of HDPE, PP and mixed products as a function of voltage V_s applied to the static electrode, for a constant corona voltage $V_c = 10$ kV, are summarized in Table 1 and illustrated in Fig. 5.

In addition to the higher mass values of HDPE and PP particles recovered with belt charging, the purity values of the products are also significantly increased. For example, at $V_s = 26$ kV the purity values of HDPE particles without and with charging are equal to 52.27% and 92.47%, respectively. Furthermore, almost half of the mass introduced in the separator was recovered when charging the conveyor. For example for $V_s = 26$ kV, out of a total mass of 20 g, more than 4 g of HDPE and more than 5 g of PP was separated with a purity level higher than 96% (Table 1). On the other hand, in non-charging mode, all the particles have been recovered in the compartment of the mixed product (Fig. 5).

Table 1

Mass values of HDPE, PP and mixed products, without ($V_c = 0$ kV) and with corona charging ($V_c = 10$ kV), as a function of voltage V_s applied to the static electrode.

HDPE Compartment					Mixed	PP Compartment		
V_s (kV)	V_c (kV)	Mass (g) HDPE	Mass (g) PP	Purity (%)	Mass (g)	Mass (g) PP	Mass (g) HDPE	Purity (%)
16	0	0.30	0.35	46.15	16.75	1.30	1.35	49.05
	10	1.70	0.20	89.47	16.00	2.05	0.00	100.00
18	0	0.50	0.55	47.61	15.60	1.95	1.75	52.70
	10	1.40	0.35	80.00	16.60	0.35	0.15	90.00
20	0	0.35	0.30	53.84	16.75	1.80	1.05	63.15
	10	2.90	0.20	93.54	13.05	3.75	0.20	94.93
22	0	1.15	0.80	58.97	16.10	1.40	0.75	65.11
	10	3.35	0.25	93.05	11.65	4.25	0.40	91.39
24	0	1.90	1.15	62.29	14.80	1.40	0.75	65.11
	10	4.05	0.25	94.18	10.40	4.90	0.50	90.74
26	0	1.15	1.05	52.27	14.05	2.20	1.75	55.69
	10	4.30	0.35	92.47	9.90	5.35	0.20	96.39

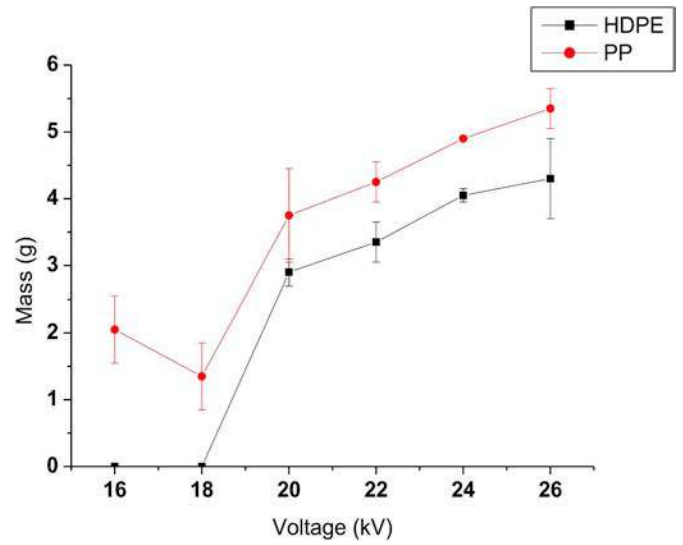


Fig. 5. Variation of the recovered mass of HDPE and PP according to voltage V_s with corona charging of the belt (*no separation without corona charging, the whole product fell into the mixed compartment).

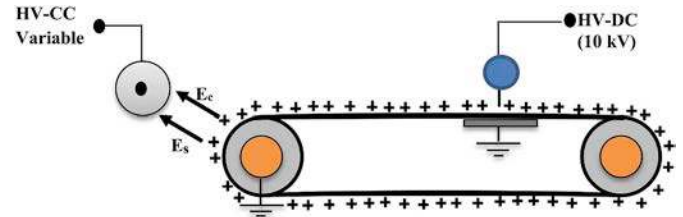


Fig. 6. Electric fields produced (Negative Static Electrode; Positive Corona Electrode).

When the plastic belt is positively charged, the accumulated corona charge on it produces an electric field E_c in the same direction as the one generated by the static electrode E_s , enhancing thus the total electric field $\vec{E} = \vec{E}_c + \vec{E}_s$ (Fig. 6). We noticed during the experiments that when the belt is charged, and due to the increase of the total electric field, the trajectories of the granules are clearly modified. The PP particles that have a positive charge are ejected further while the negatively charged HDPE granules become strongly pinned to the conveyor belt.

The evolution of the electric field E_c produced by corona charging is

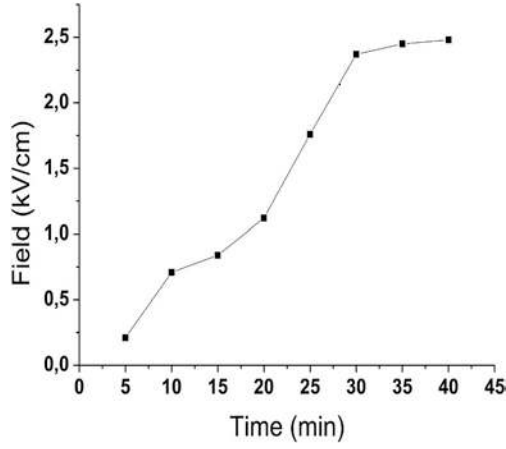


Fig. 7. Electric field measured at the surface of the belt according to the charging time duration.

plotted in Fig. 7. The obtained results show an almost linear increase of the field with time to a saturation value of about 2.5 kV/cm. The superficial charge density σ_s produced at the surface of the belt is calculated as follows:

Since

$$E_c = \frac{\sigma_s}{2\epsilon_0} \quad (3)$$

Thus,

$$\sigma_s = 2\epsilon_0 E_c = 2 \times 8.85 \cdot 10^{-12} \times 2.5 \cdot 10^5 = 4.4 \cdot 10^{-10} \text{ C/cm}^2 \quad (4)$$

with.

$$\epsilon_0 = 8.85 \cdot 10^{-12} \text{ F/m: dielectric permittivity of the air}$$

The potential V_b of the belt with respect to the ground, located at $l = 10 \text{ mm}$ from its surface:

$$V_b = \sigma_s / \epsilon_0 = 2 \times 8.85 \cdot 10^{-12} \times 2.5 \cdot 10^5 \times 1.10^{-2} / 8.85 \cdot 10^{-12} = 5 \text{ kV/cm}$$

For $V_s = 26 \text{ kV}$, the electric field E_s – assumed uniform – produced by the static electrode with respect to the belt, is given by:

$$E_s = \frac{V_s + V_b}{d} = \frac{31}{3} = 10.3 \text{ kV/cm}$$

On the other hand, the values of the electrical charge acquired by the particles, measured after separation, made it possible to determine the magnitude order of the electric, the gravitational and the centrifuge forces applied to HDPE and PP particles. Based on the average values of mass m_0 and charge q_0 of a single particle of HDPE and PP, we determined the values of the (Table 2):

- gravitational force: $F_g = m_0 g$
- electric force: $F_e = q_0 E_s$
- centrifuge force: $F_c = m \omega^2 R$

with.

Table 2

Estimated values of the gravitational, electric and centrifuge forces applied on the particles.

	Average mass m_0 of a single particle (g)	Average charge q_0 of a single particle (nC)	Force F_g (N)	Force F_e (N)	Force F_c (N)
HDPE	0.027	0.163	$0.27 \cdot 10^{-3}$	$0.17 \cdot 10^{-3}$	$3.6 \cdot 10^{-3}$
PP	0.022	0.0572	$0.21 \cdot 10^{-3}$	$0.06 \cdot 10^{-3}$	$2.98 \cdot 10^{-3}$

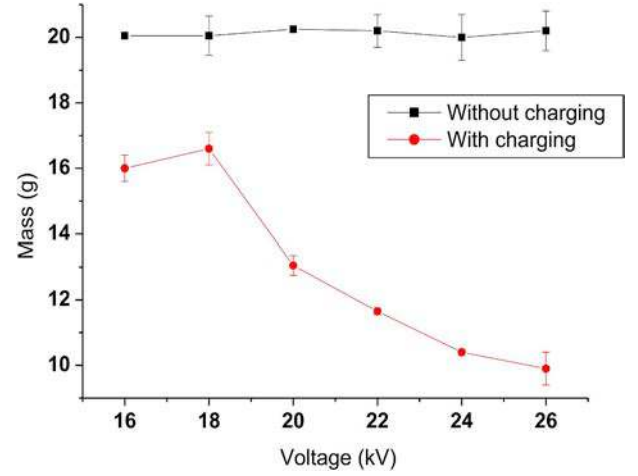


Fig. 8. Variation of the mixed product mass as a function of voltage V_s with and without corona-charging.

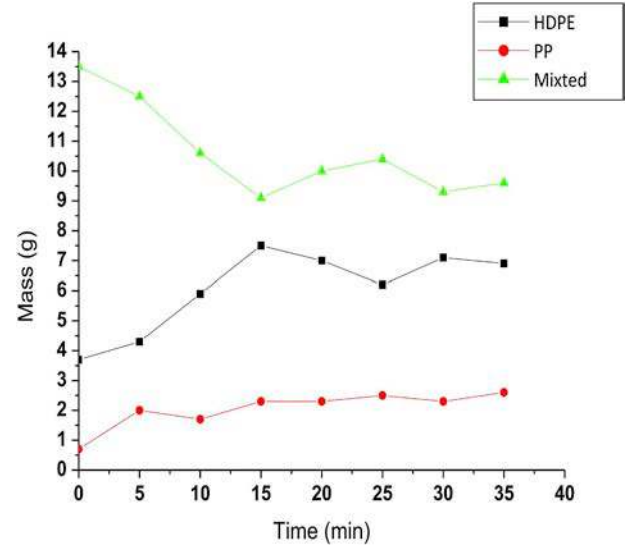


Fig. 9. Evolution of the mass of HDPE, PP and mixed product according to the charging time duration.

m_0 : mass of a single particle

q_0 : electric charge of a single particle

$\omega = 1.79 \text{ rad/s}$: Rotation speed of the belt

$R = 42 \text{ mm}$: radius

Consequently, following the increase of the recovered mass in the case of corona charging, a decrease of the mixed product mass was observed as shown in Fig. 8, representing the variation of the mixed product according to voltage V_s for both cases. While the entire product was recovered in the mixed compartment without charging, almost half of the total mass was separated when the belt was corona-charged.

The results shown in Fig. 9 describe the evolution of the separation efficiency as a function of the charging time duration of the belt. The curve in Fig. 9 was plotted without error bars, because no significant

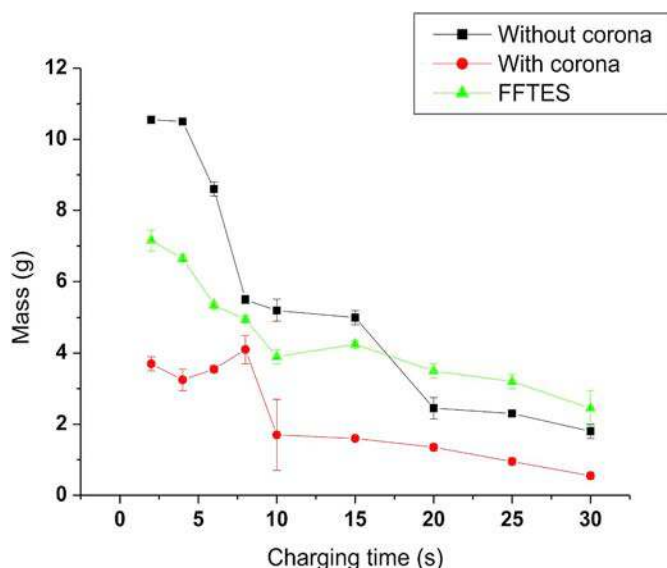


Fig. 10. Variation of the mixed product mass as function of the charging time.

variability between the results of the repetitive experiments was observed; the experimental error was estimated smaller than 10%.

As expected, the performance of the separator increases with the charging time, a saturation state is achieved after 30 min of operation. Therefore, before using the separator with corona charging, it should be charged sufficiently for a minimum duration until saturation enough to produce a significant electric field E_c .

Notice that for $t = 0$, i.e. without charging the belt, no separation was observed since the recovered products have a much smaller purity value not exceeding 70%. This charging duration depends on the nature of the conveyor belt; these results are valid only for our experimental device.

In Fig. 10, is represented the variation of the mixed product mass obtained with same samples using the free-fall tribo-electrostatic separator (FFTES) and the rotating belt separator, according to the tribo-charging time duration of the particles with the fluidized bed tribo-charger. The voltage difference between the electrodes for the FFTES was equal to 60 kV, while for the conveyor belt separator the voltage of the static electrode was fixed at 26 kV.

According to the obtained results, the mixed mass becomes significantly smaller using the conveyor belt with corona charging. The difference between the two separators is even greater when the particles are weakly charged, up to charging times of 6s. Therefore, the new configuration is a recommended solution for granular materials that do not acquire high triboelectric charges. Indeed, one of the major constraints of tribo-electrostatic separation is the low triboelectric charge acquired by many materials even if they are charged for long periods of time.

4. Conclusion

A new configuration of an insulating conveyor tribo-electrostatic separator for humid granular materials has been described and analyzed in this paper. The corona charging of the conveyor belt using a fine wire electrode has significantly improved the recovery rates of the separated products with a purity higher than 90%. The improvement is due to the increase of the electric field caused by the charge accumulated on the insulating belt. A comparison with the conventional free-fall separator has shown that the performance of the new separator is much better.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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