

Experimental Investigation of a New Electrostatic Separation Process of Metal/Plastic Particles using a Horizontal Rotating Disk

Imane ZENNANI^{1,2}, Samir ZELMAT^{1,2} and Amar TILMATINE²

¹Belhadj Bouchaib University of Ain Temouchent, Algeria

²APELEC Laboratory, Djilali Liabes University of Sidi Bel Abbes, Algeria

Email: atilmatine@gmail.com, Algérie

Abstract - A new rotating disk electrostatic separator is developed in this work based on the travelling waves technique. The rotating disk is realized using a circular electronic printed circuit board (PCB) with two helical electrodes concentrically deposited on its surface. Copper and plastic particles were used to evaluate the separation efficiency of the disk. Different parameters were studied in order to achieve the best separation results such as the level and the shape of the voltage applied to the electrodes, the rotation speed of the disk and the suction force of the vacuum blower used to collect the plastic particles. The obtained results have shown that high values of recovery and purity rates were achieved.

I. INTRODUCTION

The global evolution of technology makes people's lives easier, brings distances closer and minimizes time and energy, but unfortunately it has negative impacts to the environment and living beings. Among these impacts there is electrical and electronic waste which is growing at an alarming rate. The solution found to minimize the risk of this waste is separate it and recycle it [1].

In industry, the electrostatic corona discharge separators [2–8] and the vibrating densitometric tables [9–13] are the most separation devices used. The first ones are based on the difference between their electrical conductivity and the second ones are based on the difference between the density values of the both granules metal and plastic.

Other techniques such as the electric curtain board (ECB) were developed and used for many applications such as the displacement of the insulating micronized particles [14–21]. This movement is caused by a force applied on polarized particles called dielectrophoretic force [22–25]. Another electro-adhesive force exerted on the metal particles was recently observed in several works [26–30]. The ECB was then considered as a new technology used to separate mixtures of metal/plastic particles using both dielectric force and adhesion force. The ECB is an electrical system comprising parallel electrodes (2, 3 or 4) powered by alternating shifted voltages [31].

The purpose of this paper is the development of a new electrostatic separator with a rotating disk that was experimentally investigated to analyze the electro-adhesion force applied on metal particles. The new device is a disk shape-ECB constituted by two helical shape electrodes powered by a high voltage power supply. This device was used to study both of the adhesion force applied to copper particles and the separation of mm-size granular mixture comprising copper and plastic particles.

II. MATERIALS AND METHODS

An experimental setup was developed to study the electro-adhesion force applied to metal particles by using a new rotating disk electrostatic separator. As shown in Figure 1, the device has a circular shape and is constituted of a simple layer PCB of thickness equal to 2 mm and a diameter of 20 cm. Two interdigitated electrodes were deposited on the top side of the circular PCB forming thus two phases ECB. Each electrode has a helical shape and is made of 35 μm thickness of copper with a 1 mm width. The distance between two adjacent electrodes is 2 mm.

The upper side of the disk is covered by an insulating acrylic varnish layer to prevent electrical breakdown between electrodes and metal particles.

As described in Figure 2, each phase of the disk is supplied through a HV connector with a voltage amplifier (Trek, Model 2220, ± 2 kV, ± 20 mA). These amplifiers were controlled by a function generator (SDG Siglent 1025) in order to modify the frequency,

the wave form and the voltage level applied to each electrode. The phase difference between the two signals is fixed at 180° . The signals were visualized using a digital oscilloscope (Gwinstek GDS-3154) via a high voltage probe (Tektronix P6015A). The rotation of the disk is provided through a variable speed DC motor. The plastic/metal particles were spread on the disk using a vibrating feeder with a controlled flow rate and a vacuum blower is used to suck the plastic particles during the separation process (Figure 3).

The size of the copper/plastic particles used in the separation experiments is about 2-3 mm (Figure 4).

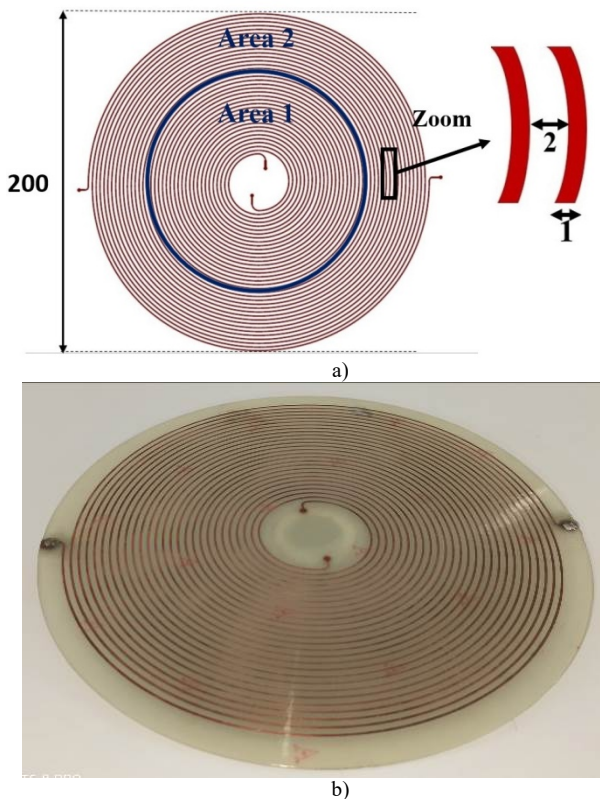


Fig. 1. The rotating ECB device : (a) Dimensions of the ECB in millimeter ; (b) Photography of the ECB.

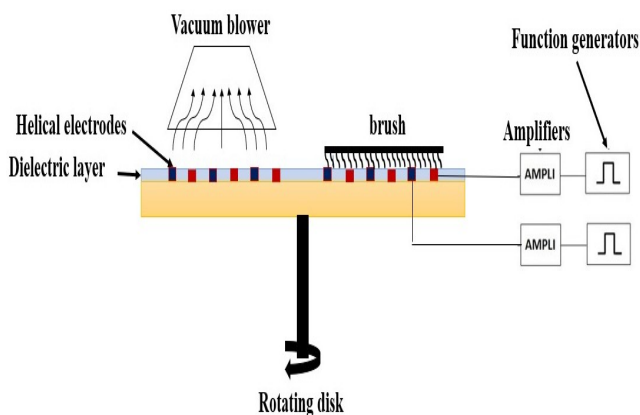


Fig. 2. Descriptive schematic of the electric connections.

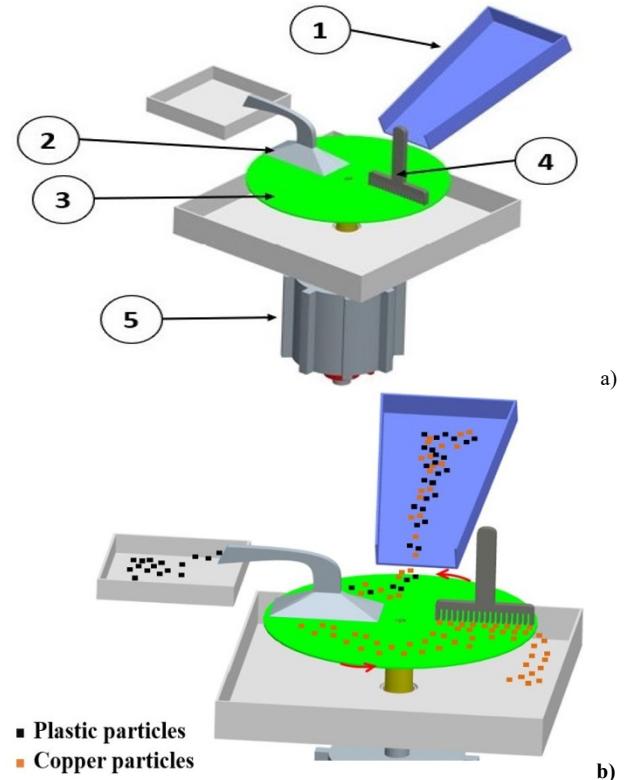


Fig. 3. The experimental setup :
a) General description of the experimental setup.
1-Vibrating feeder; 2-Vacuum blower; 3-The disk; 4- Brush; 5- DC motor
b) Schematic illustration of the separation process.

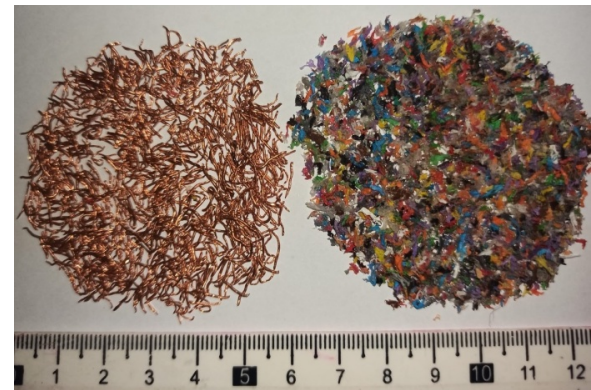


Fig. 4. Photography of copper and plastic particles.

Two sets of experiments were performed in the framework of this study. The aim of the first one is to focus on the adhesion force applied on copper particles, and the second one is to investigate the rotating disk efficiency during the separation process of a copper/plastic mixture.

A) Attraction experiments

As described previously, the purpose of the vacuum blower in the experimental setup is only to suck up the plastic particles. Thus, and because in this part we study only the electro-adhesion force applied

on copper particles, there is no need to use the vacuum blower which remains off in these attraction experiments.

A quantity of copper particles equal to 5g is deposited on the disk surface. The disk is then powered and rotated during 2 min. At the end of the experiment, the mass of the copper remaining on the disk is weighed and compared with the initial 5g deposited at the beginning of the experiment. Thus, we define the parameter “ R_{cu} ” as the metal recovery percentage using the following formula:

$$R_{cu} (\%) = (M_{cu} / M_{cu \text{ tot}}) * 100 \quad (1)$$

Where :

M_{cu} : mass of the metal particles remaining attached on the disk surface after 2 min of rotation.

$M_{cu \text{ tot}}$: total mass of the metal particles deposited initially on the disk surface equal to 5g.

B) Separation experiments

In these experiments, a mixture of copper/plastic particles composed of 50% of copper (5g) and 50% of plastic particles (5g) is deposited on the surface of the disk using a vibrating feeder. The disk is then powered and rotated and the vacuum blower is activated. Plastic particles were lifted by the vacuum blower and the metal particles remain attached to the disk surface till a brush collected them down in a collecting box under the disk.

As some copper particles may be sucked by the vacuum blower with the plastic particles, the mass of the copper collected in the box is compared with the initial 5g deposited on the disk using the “ R_m ” parameter defined here as:

$$R_m (\%) = (M_m / M_{m \text{ tot}}) * 100 \quad (2)$$

Besides, some plastic particles may also fall down in the collection box with the copper particles. Thus, we define the parameter “ P_m ” as the “purity” of copper which calculates the percentage of copper in the total mass collected in the box using the following formula :

$$P_m (\%) = (M_m / M_{box}) * 100 \quad (3)$$

Where:

R_m : The recovery rate of copper particles.

P_m : The purity rate of copper particles.

M_m : mass of the copper particles detached by the brush.

$M_{m \text{ tot}}$: total mass of copper particles deposited on the disk surface.

M_{box} : total mass of the both copper and plastic particles on the collection box

To calculate the recovery and purity of plastic particles we use the following formulas:

$$R_p (\%) = (M_p / M_{p \text{ tot}}) * 100 \quad (4)$$

$$P_p (\%) = (M_p / M_{box}) * 100 \quad (5)$$

Where:

R_p : The recovery rate of plastic particles.

P_p : The purity rate of plastic particles.

M_p : mass of the plastic sucked by the suction blower.

$M_{p \text{ tot}}$: total mass of plastic particles deposited on the disk surface.

III. RESULTS AND DISCUSSION

A) Attraction experiments

In this part, three types of voltage waveform were analyzed and compared for two rotation speed values and two areas (described in Figure 1/a) of the rotating disk.

The variation of the recovery rate (%) of the copper particles remaining attached on disk surface was analyzed according to the applied voltage. The obtained results are plotted in Figure 5 for the different voltage waveforms, two rotation speeds (80 and 120 rpm) and two different areas of the disk.

When the metal particle is on the surface of the disk, the electric field produced by potential difference between the electrodes causes the opposite charges on its surface at the helical electrodes causing an adhesion force on particles (Figure 6).

Figure 5 shown the variation of the recovery rate (%) of copper particles remaining on the disk as function of the applied voltage for three waves forms, two rotation speeds and two areas of disk. For the wave forms; the square wave is the best then the two others waves because the maximum high voltage takes a long time before changing its polarity, so there is a long time of contact between metal particle and electrode. For the rotation speed, when the rotation speed is higher the recovery mass is lower, because the centrifuge force produced by the rotation, which was detached the metal particles from the surface. Also, for the disk area, when the metal particle was deposited far from the center of the disk, the centrifuge force became higher, so the detachment of particle was easier.

The study of the effect of the rotation speed on the recovery rate was carried out for second area only; this area will be used for the experimental analysis of the separation process.

According to the plotted results in Figure 7, for high voltage equal to 2 kV the recovery rate was higher up to 100% until a rotation speed of 120 rpm

where it was beginning to decrease. However, it was decreasing at a rotation speed equal to 70 rpm for a high voltage of 600V due to the centrifuge force.

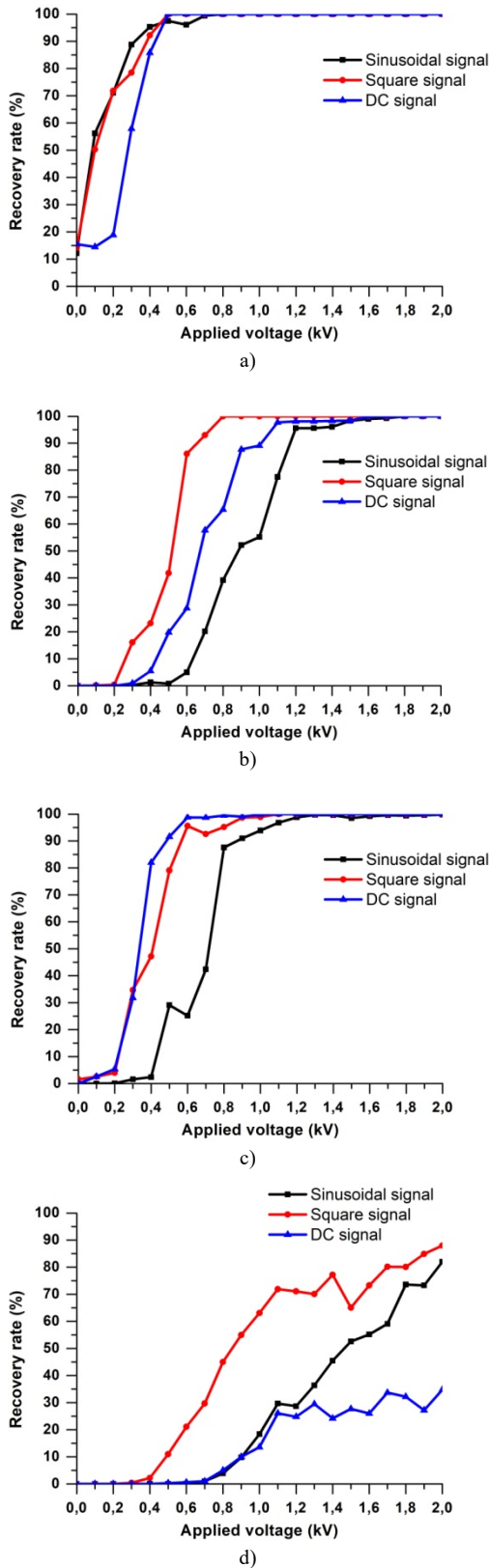


Fig. 5. Variation of the recovery rate (%) of copper particles remaining on the disk as function of the applied voltage for three voltages waves forms, two rotation speeds and two areas

of the disk
 (a) Area 1 & n=80 rpm; (b) Area 1 & n=120 rpm;
 (c) Area 2 & n=80 rpm; (d) Area 2 & n=120 rpm

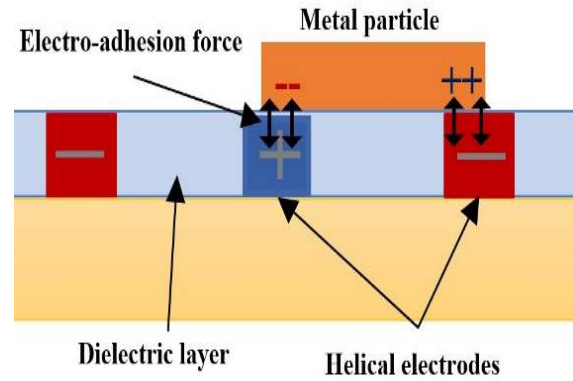


Fig. 6. Schematic illustration of the electro-adhesion force principle applied on conductive particles.

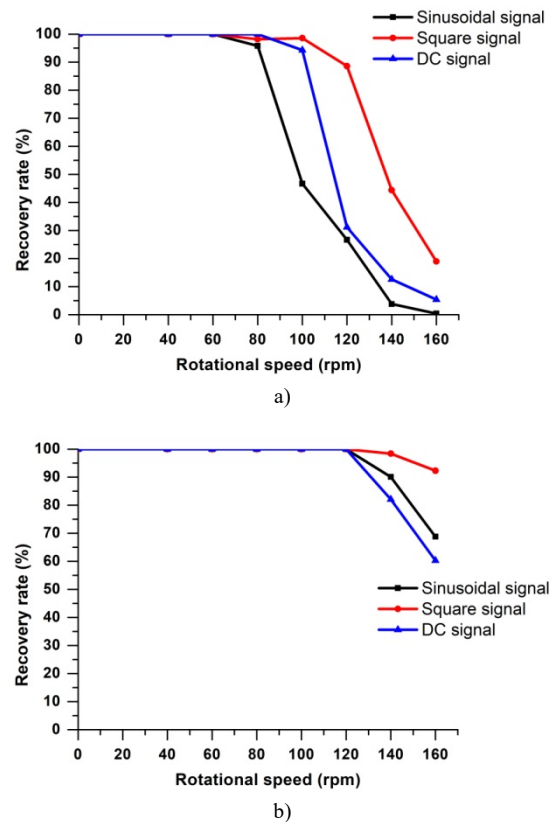


Fig. 7. Variation of the recovery rate (%) of copper particles remaining on the disk as function of the rotational speed for three waves forms and two values of the applied voltage (Area 2) : (a) V=600 V; (b) V= 2 kV.

B) Separation experiments

Following experiments were carried out with granular mixture samples of total mass 10 g comprising 50% of copper and 50% of plastic particles for analyzing the separation efficiency using experimental setup described in Figure 3.

The variation of the recovery and the purity rates (%) of the copper and plastic particles was analyzed

according to the applied voltage using the square signal (Figure8).

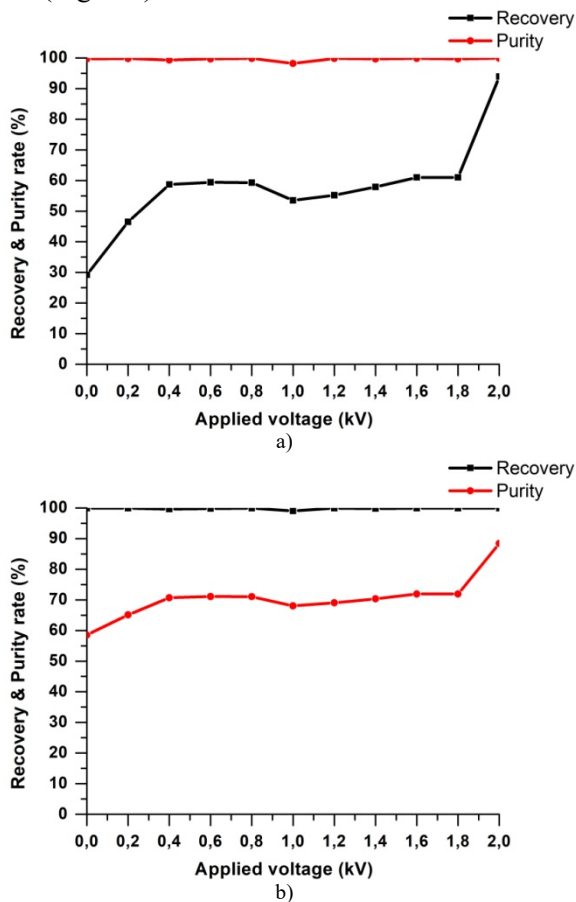


Fig. 8. Variation in the recovery and purity rate of copper and plastic particles as a function of the applied voltage
Conditions: vibrator rate $D = 0,08$ g/s; vacuum blower rate $Q = 1,43$ m³/min; humidity $H = 35-40\%$ and rotation speed $n = 60$ rpm
a) Copper particles ; b) Plastic particles

The obtained results plotted in Figure 8 represent the variation in the recovery and purity rate, of both copper and plastic particles as a function of the applied voltage. For maximal voltage equal to 2 kV, the separation efficiency is better, 94% of metal recovery with its purity at maximal 100%. All the plastic particles are sucked by vacuum blower so in this case, the vacuum blower rate was important.

In the same conditions of vibrator rate, vacuum blower rate, rotation speed, the recovery and purity rates were analyzed for two different values of the ambient humidity (Fig. 9).

The particles were covered by the humidity; therefore, its conductivity was higher which caused the increase of adhesion force. This phenomenon is confirmed by the obtained results shown in Figure 9. For higher humidity and in zero applied voltage, we saw that the recovery of copper was 95%, that caused by charging disk and centrifugal force which will be a positive factor for separation.

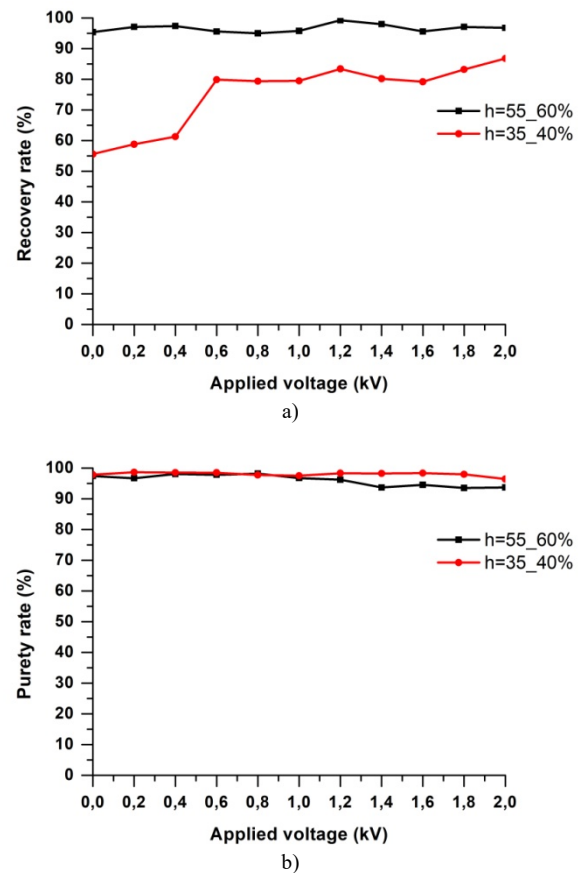


Fig. 9. Variation in the recovery and purity of copper and plastic particles as a function of the applied voltage for two values of humidity Conditions: vibrator rate $D = 0,08$ g/s; vacuum blower rate $Q = 1,27$ m³/min and rotation speed $n = 80$ rpm
a) Copper particles ; b) Plastic particles

IV. CONCLUSION

In this study, the effect of the applied voltage and other parameters on a new rotating disk electrostatic separator was analyzed using millimeter size particles. The experimental results obtained in this work pointed out the following conclusions:

- ✓ The square wave form was better than the others two signals.
- ✓ The feasibility of metal/plastic particles separation using a vacuum blower with high value of recovery and purity.
- ✓ This separator device was efficient in wet conditions.

REFERENCES

- [1] B.Lu, J. Yang, W. Ijomah, W. Wu, G. Zlamparet, "Perspectives on reuse of WEEE in China: lessons from the EU, Resour. Conserv. Recycl.," 135 (2018) 83–92.

- [2] Y. Higashiyama, K. Asano, «Recent progress in electrostatic separation technology," Part. Sci. Technol. 16 (1) (1998) 77–90.
- [3] A. Tilmatine, S. Flazi, K. Medles, Y. Ramdani, L. Dascalescu, "Séparation électrostatique : complément des procédés mécaniques de recyclage des déchets industriels," J. Electrostat. 61 (1) (2004) 21–30.
- [4] L. Dascalescu, A. Tilmatine, F. Aman, M. Mihailescu, "Optimization of electrostatic separation processes using response surface modeling," IEEE Trans. Ind. Appl. 40(1) (2004) 53–59.
- [5] H.M. Veit, T.R. Diehl, A.P. Salami, J.D.S. Rodrigues, A.M. Bernardes, J.A.S. Tenório, "Utilization of magnetic and electrostatic separation in the recycling of printed circuit boards scrap," Waste Manag. 25 (1) (2005) 67–74.
- [6] A. Tilmatine, K. Medles, S.E. Bendimerad, F. Boukholda, L. Dascalescu, "Electrostatic separators of particles: application to plastic/metal, metal/metal and plastic/plastic mixtures," Waste Manag. 29 (1) (2009) 228–232.
- [7] J. Ho-Seok, P. Chul-Hyun, C. Bong-Gyoo, P. Jai-koo, "Separation of PVC and rubber from covering plastics in communication cable scrap by tribo-charging," Separ. Sci. Technol. 44 (2009) 190–202.
- [8] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami, L. Dascalescu, "Optimization of belt-type electrostatic separation of granular plastic mixtures tribocharged in a propeller-type device," in: Journal of Physics: Conference Series, vol. 301, 2011, 012067,1.
- [9] R.Q. Honaker, N. Singh, B. Govindarajan, "Application of dense-medium in an enhanced gravity separator for fine coal cleaning," Miner. Eng. 13 (4) (2000) 415–427.
- [10] J. Svoboda, "Densimetric separation of coal using magnetic fluids," Phys. Sep. Sci. Eng. 13 (3–4) (2004) 127–139.
- [11] N. Aslan, "Modeling and optimization of multi-gravity separator to produce celestite concentrate," Powder Technol. 174 (3) (2007) 127–133.
- [12] S. Brunner, P. Fomin, C. Kargel, "Automated sorting of polymer flakes: fluorescence labeling and development of a measurement system prototype," Waste Manag. 38 (2015) 49–60.
- [13] G. Richard, S. Touhami, T. Zeghloul, L. Dascalescu, "Optimization of metals and plastics recovery from electric cable wastes using a plate-type electrostatic separator," Waste Manag. 60 (2017) 112–122.
- [14] S. Masuda, K. Fujibayashi, K. Ishida, H. Inaba, "Confinement and transportation of charged aerosol clouds via electric curtain," Electr. Eng. Jpn. 92 (1) (1972) 43–52.
- [15] S. Masuda, M. Washizu, I. Kawabata, "Movement of blood cells in liquid by nonuniform traveling field," IEEE Trans. Ind. Appl. 24 (2) (Mar/Apr 1988) 217–222.
- [16] M. Aoyama, T. Oda, T.M. Ogihara, Y. Ikegami, S. Masuda, "Electrodynamical control of bubbles in dielectric liquid using a non-uniform traveling field," J. Electrostat. 30 (1993) 247.
- [17] F.W. Schmidlin, "Modes of traveling wave particle transport and their applications," J. Electrostat. 34 (2–3) (March 1995) 225–244.
- [18] H. Kawamoto, N. Hasegawa, "Traveling wave transport of particles and particle size classification," J. Imag. Sci. Technol. 48 (2004) 404.
- [19] H. Kawamoto, S. Hayashi, "Fundamental investigation on electrostatic traveling wave transport of liquid drop," J. Phys. 39 (2006) 418–423.