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Increasing the Recovery Rate of Metals from WEEE by Corona-electrostatic Separation

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Abstract **The aim of the paper is to show the possibility of using electrostatic technologies for the recovery of non-ferrous metals from the non-conductive fraction obtained in the recycling process of waste electrical and electronic equipment (WEEE). Prior to electrostatic separation, the material undergoes in-situ operations such as size reduction and dust and light component removal. Two granular mixtures of the same material are obtained, a coarse fraction (3.15-6) mm that contains metals, plastics and doesn't contain any glass and a fine fraction (0-3.15) mm containing metals, plastics and a significant amount of glass. The granular mixtures are then separated using a laboratory version of a conventional roll-type corona-electrostatic separator with an extended charging zone. The virtually pure conductive fraction recovered from the mixtures makes up 4.34% of the initial material and is composed of mainly copper and brass (>70%), along with nickel, zinc, tin, and lead in lower quantities.**

Keywords**: corona-electrostatic separation, WEEE, material recovery**

I. INTRODUCTION

Waste electrical and electronic equipment (WEEE) represents one of the fastest growing waste streams in the EU where more than an estimated 12 million tons were generated in 2020 [1].

WEEE is a complex mixture of components, some containing hazardous materials, that can lead to major environmental and health problems if they are not properly managed. Moreover, high value materials, especially metals, can be recovered from WEEE. The proper treatment and recycling of WEEE is considered of crucial importance to improve the environmental protection, and to contribute to the circular economy, all the while enhancing the resource efficiency.

Within a circular economy the WEEE represents an important source of secondary raw materials that could be made readily available to re-enter the manufacturing process, while reducing the extraction of virgin raw materials. Up to 69 elements from the periodic table can be found in WEEE mixtures, including precious metals (gold, silver, platinum, copper, etc.) and critical raw materials (cobalt, palladium, indium, germanium, etc.), as well as non-critical raw materials (iron, aluminum) [2].

Typical materials in WEEE are iron and steel (48%), copper (7%), aluminum (5%), plastic (21%), and glass (5%) [3] and the recycling process typically aim to recover primarily ferrous and non-ferrous metals, but also plastic materials and glass (Fig. 1).

The purity and recovery rate of the recycling process outputs are influenced by both the quality of the feeding WEEE composition and the recycling technology. In order to obtain high purity of the metallic fractions, a number of metals – especially non-ferrous metals of small size, are frequently lost in the non-conductive fraction of the eddy current separation stage. Recovering the non-ferrous metals from this mixture will increase the recovery rate of non-ferrous fraction as well as the purity of the non-metallic fraction.

In particular, the WEEE originating from electric lamps contain a large quantity of glass which is recovered in the non-conductive fraction of the eddy current separation stage mixed in with a range of different plastic materials. This glass component must be removed in order to allow and facilitate the plastic separation stage.

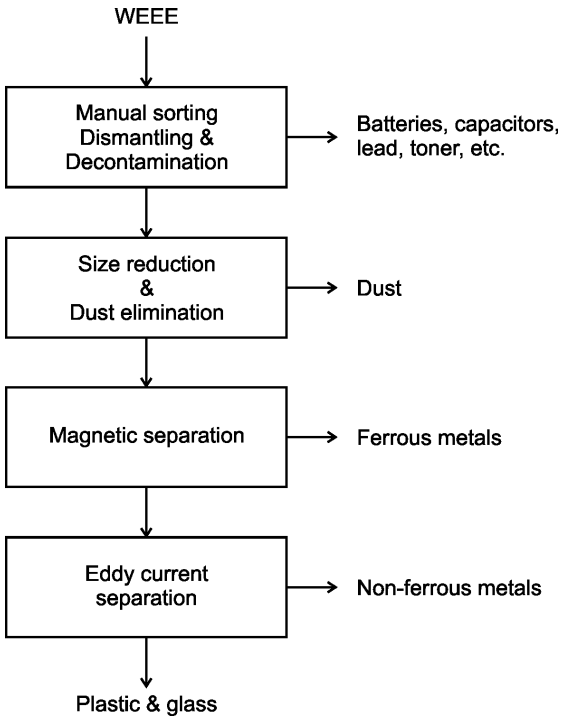

Fig. 1 The main stages of a typical WEEE recycling process.

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The aim of this paper is to show how the corona - electrostatic separation technology can be used for the recovery of non-ferrous metallic granules (copper, brass, aluminum, zinc) from the non-conductive fraction obtained in the recycling process of WEEE.

II. MATERIALS

The samples of granular material used in laboratory experiments were sourced from a WEEE recycler and consist in a mixture of granules, irregularly shaped and, generally, larger than 40 mm, obtained as "waste" in the recycling process of electric lamps, after the separation of both ferrous and non-ferrous metals.

An initial visual evaluation of this material shows the presence of metallic granules – both stranded copper and other metals (brass, aluminum, and zinc), along with different plastic materials, paper, and glass (Fig. 2).

The metals content of the granular mixture justifies the use of a corona-electrostatic separation process for the recovery of the conductive fraction [4-8].

In order to do so, the granular mixture has to have completely dissociated conductive and non-conductive components.

Therefore, in the preparation of the granular material samples for electrostatic separation, the first operation was a two-step shredding operation (Fig. 3) using a laboratory cutting mill (model Retsch SM300).

Fig. 2 Components of the granular waste obtained from the recycling process of WEEE after the first shredding operation with a 20 mm sieve.

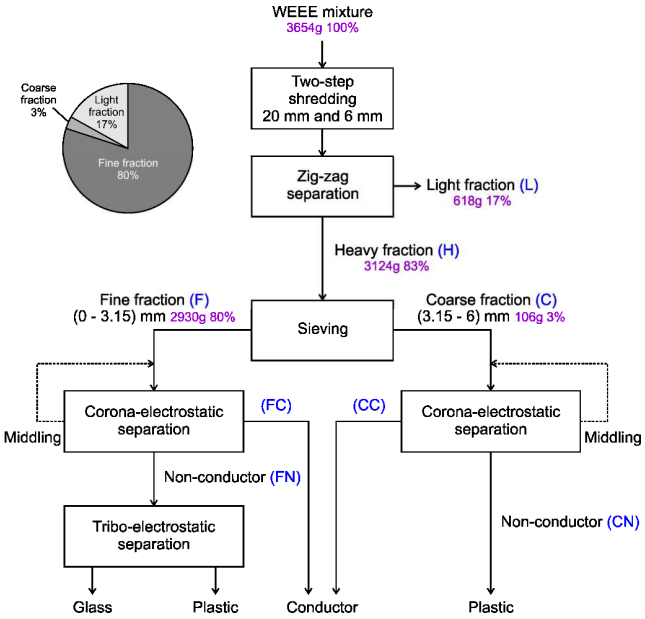

Fig. 3 Laboratory treatment of the waste originating from the WEEE recycling process.

A 20 mm sieve was firstly used which dissociated some of the granules, like paper, plastic foils/insulators, or metallic components, but it did not completely dissociate other granules such as electronic components or insulated copper conductors. A second pass through the mill was necessary, this time using a 6 mm sieve, to obtain completely dissociated mono-material granules.

Following the successive shredding operations, the very fine fraction resulted in the mixture has to be removed because it impedes the corona-electrostatic separation process [9-11]. As consequence, the material has been subjected to a zig-zag separation where the very fine fraction, along with dust and other light components such as paper and plastic foil, were removed (Fig. 4).

The removed material, to be referred collectively as the light fraction *L*, makes up approximately 17% of the total mass of the input WEEE mixture.

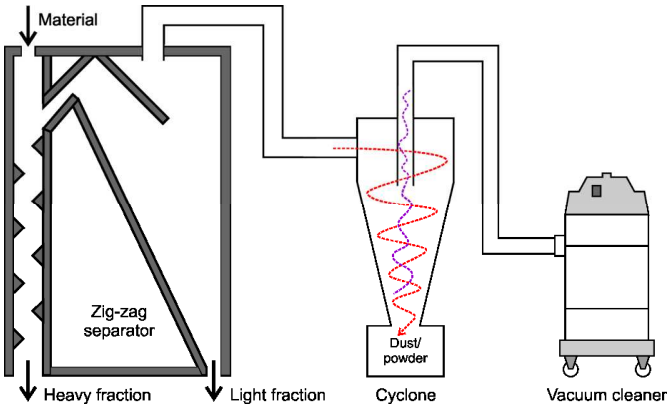

Fig. 4 Zig-zag air separator equipped with a dust collecting cyclone used for the removal of the light fraction (L) from the granular mixture.

The remaining heavy fraction (*H*), representing 83% of the input material, presents a wide granular dispersion making it unsuitable for the corona-electrostatic separation, where the centrifugal force plays an important role [12-13].

For this reason, the heavy fraction was divided into two fractions using a 3.15 mm sieve: a fine fraction *F* (0-3.15) mm consisting the bulk of the heavy fraction (80% of the input material), and a coarse fraction *C* (3.15-6) mm representing 3% of the input material.

Although similar in their composition, containing both conductive and non-conductive granules, the fine and the coarse fraction notably differ by the fact that the coarse fraction does not contain any glass. Since glass is a highly breakable material, all initial large granules were easily crushed into smaller granules during the two-step grinding operation.

Both fine and coarse fractions were independently subjected to the corona-electrostatic separation because the optimal operating parameters of the separator are different for each fraction.

III. EXPERIMENTAL SET-UP AND METHOD

Corona-electrostatic separator experimental set-up

The corona-electrostatic separation technology (Fig. 5) is the classical solution for the selective sorting of granular mixtures containing plastic and metal granules.

In the roll-type corona-electrostatic separator a mono-polar space charge zone [14-15] is generated between the corona electrodes [16] connected to a DC high voltage power supply and the grounded rotating roll electrode. In our application, because the feeding material contains glass and not just plastic as non-conductive components, an extended corona discharge zone with two corona electrodes was necessary.

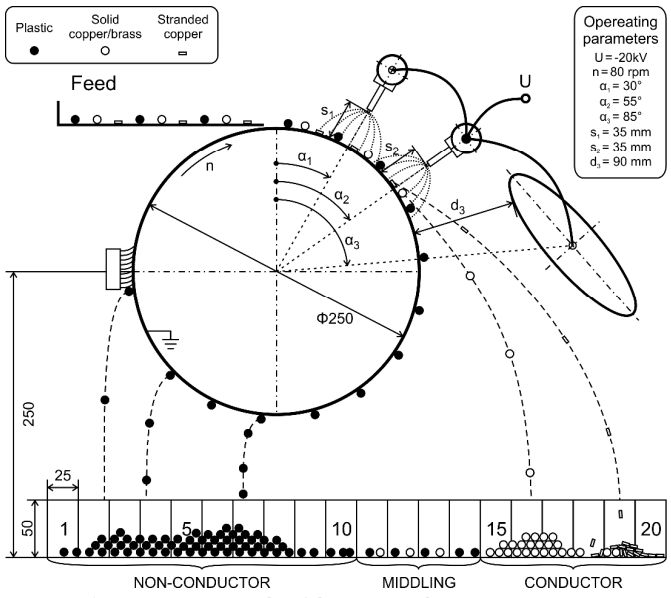

Fig. 5. Operating principle of the corona-electrostatic separator.

The vibratory feeder lays the granular mixture as a single layer on the rotating roll surface. This way all the components of the granular mixture pass through the space charge zone, are subjected to an intense ion bombardment, and get an electric charge of the same polarity as the HV supply. In contact with the grounded metallic roll electrode, the conductive granules pass their electric charge to the ground. As the roll electrode rotates, the granules enter a quasi-uniform electric field zone generated between the electrostatic electrode and the grounded roll electrode and they acquire, by electrostatic induction, an electric charge of opposite polarity with respect to the HV supply.

Subjected to the action of the centrifugal force F_c and the electric field force F_e, the conductive granules are attracted by the electrostatic electrode, being deflected towards the right side of the collector [17].

The non-conductive granules keep their electric charge acquired by ion bombardment and, under the action of the electric field force F_e and the electric image force F_i, remain pinned to the roll's surface and rotate with it. In the end they detach from the roll surface either by the combined action of the and centrifugal force F_c and the gravitational force F_g, or mechanically by the brush. As consequence, the non-conductive granules fall and are collected in the left side of the collector (Fig. 5).

A small middling fraction composed of both conductive and non-conductive materials is collected spatially between their respective fractions. Having a middling fraction ensures the control of the conductive and non-conductive fractions purity, and as this fraction is usually reintroduced into the feed (Fig. 3) it is eventually separated. In the end, a process that renders two high purity fractions and no middling fraction is obtained.

Corona-electrostatic separation methodology

The same methodology for the corona-electrostatic separation of the conductive and non-conductive granular mixture was followed for both classified fractions obtained after sieving (Fig. 3): fraction *F* (0-3.15) mm and fraction *C* (3.15-6) mm.

For each separation run, an arbitrary quantity was fed progressively by the vibratory feeder at constant feed rate. As the grounded roll electrode rotates, the granular material is charged and then separated and collected as three separation products in boxes placed under the electrodes.

The contents of the twenty collecting boxes is then analyzed in order to establish the three separation fractions and to determine the separation quality. For each separated fraction, the recovery rate was calculated as the ratio of recovered material weight to material weight in the feeding sample. The purity of each fraction was calculated as the ratio of recovered material weight to separated fraction weight and was aimed towards 100% by choosing a restricted sequence of boxes that contains pure (or almost pure) material. As consequence, the box range for each fraction of each separated granular mixture is different.

The operating parameters of the separator, as highlighted in Fig. 5, were the voltage U applied to all three electrodes (two wire corona electrodes and one elliptical electrostatic electrode), the speed n of the rotating electrode, and the position of each of the three active electrodes relative to the grounded electrode. This is established by the angle α between the vertical axis that passes through the center of the rotating electrode and the center of the electrode, and the minimum distance between the active electrode and the grounded electrode. Therefore, the position of the electrodes is characterized by: α_1 and s_1 for the first corona electrode, α_2 and s_2 for the second corona electrode, and α_3 and d for the elliptical electrode. The feed rate of the granular material was corelated with the roll electrode speed, so that a monolayer of granules was laid on the roll surface.

IV. Results and Discussion

The operating parameters of the separator were set for each granular sample after a number of preliminary runs conducted with the aim to optimize the separation results. Therefore, starting with an initial run that yields mediocre results, the parameters and the range of boxes for each separated fraction were adjusted empirically until the quality of the results cannot be increased anymore [18].

The final operating parameters were set at U = -20 kV, n = 80 rpm, $\alpha_1 = \alpha_2 = 30°$, $\alpha_3 = 55°$, $s_1 = s_2 = 35$ mm, and $d_3 = 90$ mm.

For the fine fraction F (Fig. 3) a two-step separation was considered because the first separation yields a relatively large middling fraction with a high conductive material content. This fraction was reintroduced into the feed and separated again (second step) in order to increase the recovery rate of the conductive fraction (Fig. 6).

The non-conductive fraction (Fig. 7a) contains plastic granules as well as glass granules (the majority of reduced size compared to the plastic granules), while the conductive fraction contains mainly stranded copper (Fig. 7b).

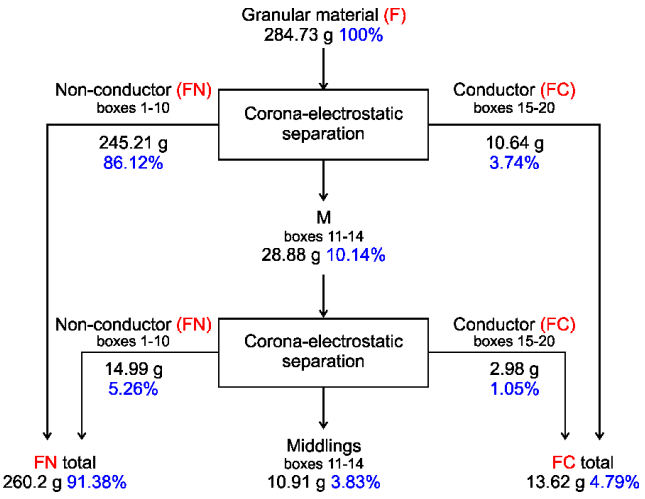

Fig. 6 Two-step corona-electrostatic separation of the fine fraction (F).

Since the coarse fraction C only amounts to 106.34 g, the entirety of the fraction was separated using the same operating parameters, but in this case only a single-step separation was needed, as the middling fraction contained a negligeable amount of conductive material.

The results of the coarse fraction separation show the absence of glass in the non-conductive fraction (Fig. 8a) and a higher conductive material content of almost 18.7% represented by mainly massive copper and brass granules (Fig. 8b).

These results, along with the extrapolated results of the fine fraction to the entire quantity of the fraction show a combined total mass of conductive material of 160.06 g representing 4.34% of the initial waste quantity (Table 1).

A further analysis of the conductive fraction, using X-ray fluorescence (INNOV-X Alpha) shows that copper, originating from wires, heat-sinks, and brass components, is the main component of the mixture (Fig. 9). Other materials such as lead, nickel, tin, zinc, manganese, and iron are present in lower quantities (up to a combined 30% of the mixture).

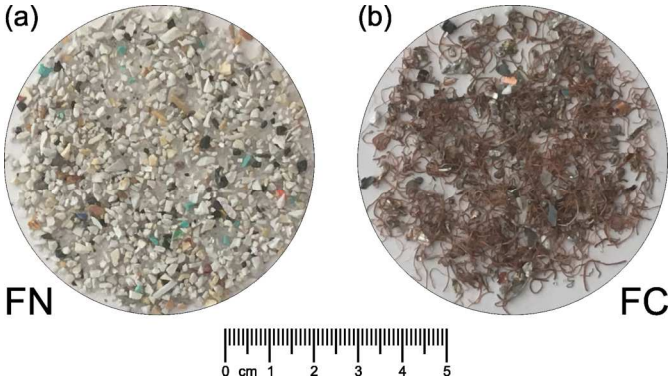

Fig. 7 Size and shape of the non-conductive (a) and conductive (b) fractions obtained after the separation of the fine fraction F.

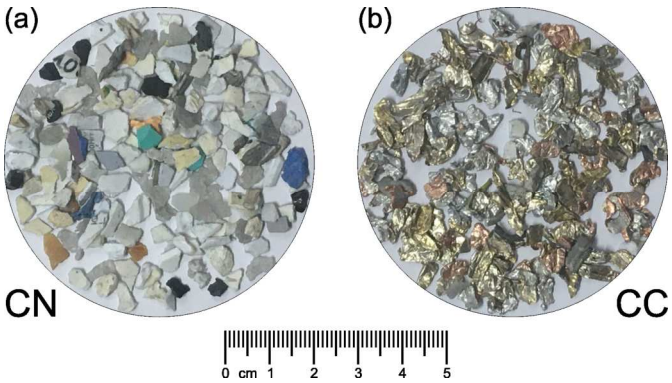

Fig. 8 Size and shape of the non-conductive (a) and conductive (b) fractions obtained after the separation of the coarse fraction *C*.

Table 1. Corona-electrostatic separation results of fine (*F*) and coarse (*C*) granular fractions.

Fraction		Material	
		fine *F*	coarse *C*
Feed	m (g)	2930.3	106.34
	%	100	100
NC	m (g)	2677.8	79.10
	%	91.38	74.38
M	m (g)	112.31	7.37
	%	3.83	6.93
C	m (g)	140.19	19.87
	%	4.79	18.69

Triboelectrostatic separation (Fig. 3) can be a solution to remove the glass granules from the remaining non-conductive NC mixture of glass and plastics, and to further separate the mixed plastics in the plastic fraction obtained after the glass removal.

However, this proves to be a challenging endeavor as we've tried with no success to separate the glass and plastic mixture, failing to coherently charge the components of the mixture.

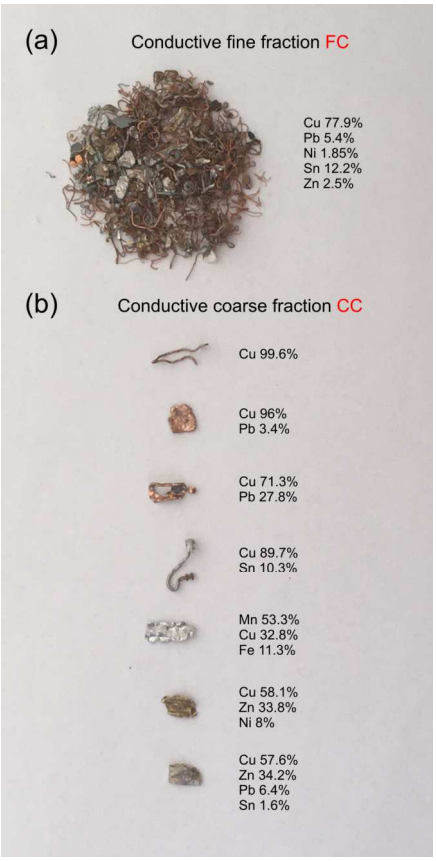

Fig. 9 X-ray fluorescence analysis of the conductive fraction.

V. CONCLUSIONS

The results obtained after corona-electrostatic separation experiments with prior size reduction and dust/fines removal confirm the improved recovery of non-ferrous metals from a waste fraction obtained after the separation of both ferrous and non-ferrous metals from WEEE recycler.

Experimental results yield an almost pure conductive fraction obtained after the separation of coarse (3.15-6) mm and fine (0-.15) mm granular mixtures. Further analysis highlights the presence of mainly copper (>70%) with other materials such as lead, zinc, nickel, tin, and iron making the remaining ~30% of the fraction.

Even if the products of the separation are of high quality, only the conductive fraction was successfully separated, and the recovery rate is little above 4%. The overall efficiency of the process can be maximized if the tribocharging process is employed to separate mixed glass and plastics. However, this proves to be a challenging endeavor since the granular components of the mixture are difficult to charge coherently in order to be separated.

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REFERENCES

1. European Comission, 2012, Waste from electrical and electronic equipment (WEEE), Accessed on 19 February 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704
2. ITU Committed to connecting the world, "Global E-waste Monitor 2020", Accessed on 13 February 2021, https://www.itu.int/en/ITU-D/Environment/Pages/Spotlight/Global-Ewaste-Monitor-2020.aspx
3. Meinander M, (ed.), Mroueh U-M, (ed.), Bacher J, Laine-Ylijoki J, Wahlström M, Jermakka J et al., "Directions of future developments in waste recycling," *VTT Technical Research Centre of Finland*, 2013. pp. 142.
4. L. Dascalescu, R. Morar, A. Iuga, A. Samuila, and V. Neamtu, "Electrostatic separation of insulating and conductive particles from granular mixes," *Particul Sci Technol*, vol. 16, pp. 25–42, January 1998.
5. L. Dascalescu, T. Zeghloul, and A. Iuga, "Electrostatic separation of metals and plastics from waste electrical and electronic equipment," In *WEEE Recycling. Research, Development, and Policies*, A. Chagnes, G. Cote, C. Ekberg, M. Nilsson, and T. Retegan, Elsevier, 2017, pp. 75-106.
6. L. Dascalescu, A. Iuga, and R. Morar, "Corona-electrostatic separation-an efficient technique for the recovery of metals and plastics from industrial wastes," *Magnetic and Electrical Separation*, vol. 4, pp. 241-255, March 1993.
7. A. Iuga, L. Dascalescu, R. Morar, I. Csorvassy, and V. Neamtu, "Corona-electrostatic separators for recovery of waste non-ferrous metals," *J. Electrostat*, vol. 23, pp. 235 – 243, April 1989.
8. R. Morar, A. Samuila, and L. Dascalescu, "Electrostatic separation of metals and plastics from granular industrial wastes," *IEE Proc Sci Meas Tech*, vol. 148, pp. 47–54, March 2001.
9. F. Hamerski, D.P. Bernardes, and H.M. Veit, "Operational conditions of an electrostatic separator for concentrate copper from electronic waste," *REM Int Eng J*, vol. 71, July 2018.
10. J. Wu, J. Li, Zh. Xu, "Electrostatic separation for recovering metals and nonmetals from waste printed circuit board. Problems and

improvements," *Environ Sci Technol*, vol. 42, pp. 5272 – 5276, June 2008.
11. J. Li, Zh. Xu, and Y. Zhou, "Application of corona discharge and electrostatic force to separate metals and nonmetals from crushed particles of waste printed circuit boards," *J Electrostat*, vol. 65, pp. 233-238, April 2007.
12. R. Morar, A. Iuga, L. Dascalescu, and A. Samuila, "Factors which influence the insulation-metal electroseparation," *J Electrostat*, vol. 30, pp. 403 – 412, May 1993.
13. M. Younes, A. Tilmatine, K. Medles, M. Rahli, and L. Dascalescu, "Numerical modeling of conductive particle trajectories in roll-type corona-electrostatic separators," *IEEE T Ind Appl*, pp. 1130-1136, vol. 43, September 2007.
14. L.M. Dumitran, O. Blejan, P. Notingher, A. Samuila, and L. Dascalescu. "Particle charging in combined corona-electrostatic fields," *IEEE T Ind Appl*, vol. 44, pp. 1385 – 1390, September 2008.
15. M. Younes, A. Younes, H. Sayah, A. Tilmatine, A. Samuila, and L. Dascalescu, "Numerical and experimental study of insulating particles behavior in roll-type corona-lectrostatic separators," *Particul Sci Technol*, vol. 31, pp. 71-80, January 2012.
16. L. Dascalescu, A. Iuga, R. Morar, V. Neamtu, I. Suarasan, A. Samuila, and D. Rafiroiu, "Corona and electrostatic electrodes for high-tension separators," *J Electrostat*, vol. 29, pp. 211-225, June 1993.
17. A. Catinean, L. Dascalescu, M. Lungu, L.M. Dumitran, and A. Samuila, "Improving the recovery of copper from electric cable waste derived from automotive industry by corona-electrostatic separation," *Particul Sci Technol*, April 2020
18. K. Medles, L. Dascalescu, A. Tilmatine, and A. Bendaoud, "Experimental modeling of the electrostatic separation of granular materials," *Particul Sci Technol*, vol 25. pp. 163 – 171, March 2007.