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Distinct recovery of copper and aluminum from waste electric wires using a roll-type electrostatic separator

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ABSTRACT

Electrostatic separators are commonly employed for the sorting of insulating and conducting fractions of granular mixtures. However, separation of the various metals that compose the conductive fraction still represents a major challenge for the recycling industry. The aim of this paper is to identify the conditions in which a roll-type electrostatic separator could be used for distinctly recover the copper and aluminum from waste electric wires. A numerical model of particle trajectories was employed to predefine these conditions and guide the experimental study. The electrostatic separation experiments were carried out using a reverse-S-type-plate high-voltage electrode. The visualization of particle trajectories using a high-speed camera paved the way to an original design. Thus, a metallic trap was attached to the high-voltage electrode, to facilitate the collection of the aluminum flake-like particles from a mixture that also contains copper strands. With a plastic trap replacing the metallic one, to avoid electric field modification, 68.6% of the copper was recovered with a purity attaining 99%.

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1. Introduction

The quantities of waste electric and electronic equipment (WEEE) increase at a rapid pace. Metals (copper, brass, aluminum, steel, etc.) represent roughly 50% of these wastes, and need to be separated as high purity distinct products, to facilitate their recycling. Various technologies have been developed for the recycling of metals from WEEE (Gundupalli et al., 2017). Some of them are based on density separation such as gravity table separation or froth flotation (Fujita et al., 2014; Pita and Castilho, 2017). These are based on density difference between the mixture components and better work if the difference is high. Eddy current separation is another way to separate metals and insulators by ejecting metals. This system works for large and light pieces of metals like aluminum cans (Ruan et al., 2017). Electrostatic separation is one of the physical processes commonly used in the recycling industry, to achieve the selective sorting of insulating and conducting fractions of granular wastes (Haga, 1995; Abdel-Salam et al., 2000; Dascalescu et al., 2016).

A wide variety of minerals, wastes or agricultural matter can be processed in roll-type electrostatic separators, in a way that is well

described in the literature (Dascalescu et al., 1998; Kohnlechner and Dascalescu, 2005; Medles et al., 2007). Thus, the insulating and conductive granules are introduced in the intense electric field created between a grounded rotating roll electrode and one or several high-voltage electrodes. Under the action of this field all conductive granules are charged by electrostatic induction and are attracted by the high-voltage electrode, while the insulating granules remain unaffected and fall freely in a different compartment of the collector (Das et al., 2009; Dascalescu et al., 2001; Younes et al., 2013).

Up to now, the use of this class of electrostatic separators to distinctly recover different metals contained in granular wastes has not been fully investigated (Tilmatine et al., 2009). The reason is that in most cases the operation can be performed using other physical methods, strictly based on the differences in the mass density of the constituents. However, associating electrical and mechanical forces may lead to higher separation efficiencies, as suggested by the numerical simulations that were made on the behavior of conducting particles in a different type of electrostatic separators (Vlad et al., 2003; Das et al., 2007; Younes et al., 2010).

The aim of this paper is to identify the conditions in which the sorting of the constituents of a granular metallic mixture might be possible using the roll-type electrostatic separator, which has the advantage of being already widely-employed in the recycling

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industry. The study is specifically focused on the separation of aluminum and copper particles originating from waste flexible electric wires used in electric and electronic equipment.

2. Challenges of purifying the copper product recovered from waste electric wires

When including an electrostatic separation operation in the recycling process of waste electric wires (Bezerra de Araújo et al., 2008; Dascalescu et al., 2016), several metals can be simultaneously recovered as a “conductor product”. Quite often, the aim of the recycler is just to recover copper with the highest possible purity (Oguchi et al., 2011; Richard et al., 2016). The presence of other conductors decreases its purity and hence deteriorates the properties of the copper product obtained from the recycling of a wider range of WEEE (Menad et al., 2013; Dascalescu et al., 2016). Moreover, these other conductors can be recycled too. Therefore, it is very important to separate the constituents of the “conductor product” obtained as outcome of a standard insulation/metal electrostatic separation process.

From an industrial point of view, a mixture of 95% Cu and 5% Al can be sold to recyclers as mixed copper. In September 2017, this mixed copper could be sold between 3920 € and 4320 € per ton (Source: *Recyclage Récupération* n°29, 11.09.2017). However, if copper purity increased up to 99%, its price would range between 4430 € and 4630 € per ton. Moreover, it is also possible to sell the recovered aluminum at prices between 510 € and 560 € per ton. As a consequence, 945 € could be earned for each ton of recycled material. C.I.T.F. Company has built an electrostatic separator which could treat 100 kg/h of electric cables using 9 kWh electricity. In France, electricity costs 0.15 €/kWh (EDF, 2017). Based on these values, the price for processing a ton of waste is 810 €. Thus, the gain per ton of 945 € pays the processing and even more.

To handle the difficulty of separating the two metals from a mm-size granular mixture, a two-steps approach was adopted. At first, the numerical computation of the trajectories of the two types of particles enabled the prediction of the optimal operating conditions (i.e., the configuration of the electrode system and the high-voltage applied to it). Then, an electrostatic separation experiment was carried out in the conditions suggested by the numerical simulations, and a high-speed camera was employed to visualize the particle trajectories. A modification of the standard electrode configuration was proposed and validated by an additional experiment.

3. Materials and method

The objective of the study was a granular metallic mixture composed of 95% of tinned and bare copper and 5% of aluminum. This type of product was obtained from previously-shredded waste flexible electric wires, after removing the insulating fraction by electrostatic separation. During this study, the relative humidity varied from 52.3% to 56.1% and the temperature from 19.5 °C to 21.1 °C.

The particles (Fig. 1) were aluminum flakes (size: 2–6 mm, thickness: 0.2 mm) and tinned and bare copper strands (diameter: 0.08–0.16 mm; length: 2–8 mm). Aluminum particles corresponded to the shielding of these wires whereas copper particles originated from the core of the cable. These types of cables are common in many industry and EEE applications and the resulting grinded particles always have these kinds of shapes and size. Thus, this study is general and can have many applications.

A laboratory roll-type electrostatic separator (CARPCO, Inc.) was used during this study (Fig. 2). In these separators, an electromagnetic feeder (1) (Feed rate: 4 g/s) brings particles at the surface of a

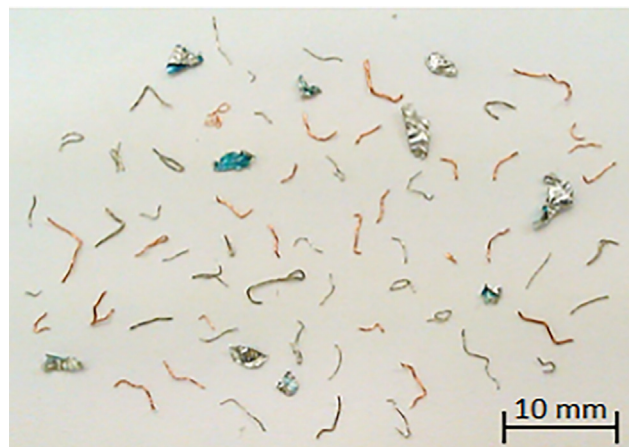


Fig. 1. Copper and aluminum particles, originating from waste electric wires.

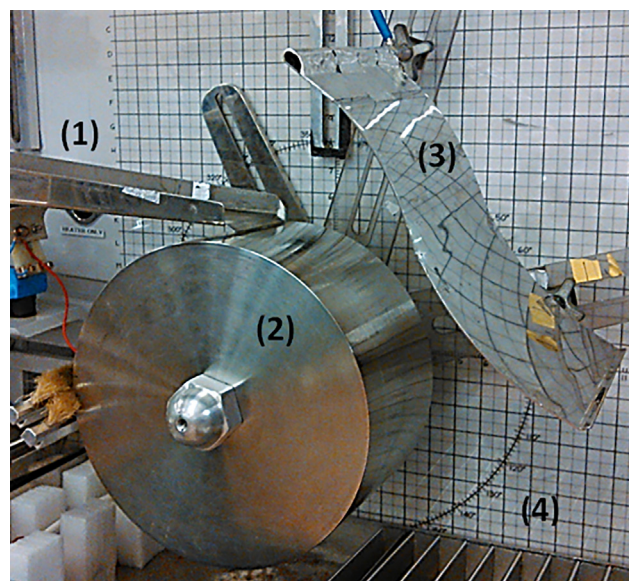


Fig. 2. Laboratory roll-type electrostatic separator (CARPCO, Inc.). (1) Electromagnetic feeder, (2) grounded roll electrode, (3) reversed-S-shaped plate electrode, (4) 15-compartment collector.

grounded rotating cylindrical electrode (2) (Rotation speed: 40 rpm). The values of feed-rate and roll-speed chosen for this study are correlated. At a given feed-rate, imposed by the technological process to which separation is integrated, a too low roll-speed would not allow to have a single layer of product on the surface of the rotating electrode, which is a prerequisite of good separation. Roll-speed should not be too high, either. If the rotation speed is high, the centrifugal force will also be high, and the copper particles will detach sooner from the roll-electrode. They will also have higher initial speeds when detaching from the electrode. Thus, the copper particles will attain the collecting plane at longer distances from the axis of the rotating electrode. This means that more of them will be collected in the same sector with the aluminum particles, the trajectories of which are less affected by the speed at the moment of detachment from the roll electrode, as they have a different aerodynamic behavior, due to their flake-like shape. In a present design, a reversed-S-shaped plate electrode, connected to a high-voltage supply, create an intense electric field. This electrode configuration was defined as the best configuration for bare and tinned copper separation (Richard et al., 2017). Under

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