ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Optimization of metals and plastics recovery from electric cable wastes using a plate-type electrostatic separator

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ARTICLE INFO

Article history:
Received 28 March 2016
Revised 11 June 2016
Accepted 28 June 2016
Available online xxxx

Keywords:
WEEE
Electric wire wastes
Design of experiments
Electrostatic separation
Electric field
Particulate matter

ABSTRACT

Plate-type electrostatic separators are commonly employed for the selective sorting of conductive and non-conductive granular materials. The aim of this work is to identify the optimal operating conditions of such equipment, when employed for separating copper and plastics from either flexible or rigid electric wire wastes. The experiments are performed according to the response surface methodology, on samples composed of either "calibrated" particles, obtained by manually cutting of electric wires at a predefined length (4 mm), or actual machine-grinded scraps, characterized by a relatively-wide size distribution (1–4 mm). The results point out the effect of particle size and shape on the effectiveness of the electrostatic separation. Different optimal operating conditions are found for flexible and rigid wires. A separate processing of the two classes of wire wastes is recommended.

1. Introduction

Society evolution leads to the generation of increased quantities of electric and electronic equipment wastes (WEEE) (Li et al., 2013). Decrease of fossil resources makes their recycling necessary. That is why a lot of studies have been conducted on the recovery of valuable materials from end of life computers, printers, fridges, TV-sets, cell-phones, and other such devices (Veit et al., 2005; Oguchi et al., 2011; Menad et al., 2013). Electric wires represent a significant part of these wastes, so it is important to find efficient and reliable solutions to recycle them (Bezerra de Araújo et al., 2008). The two major steps of the technologies that allow the recovery of metals and plastics from this kind of waste are: (1) finely-grinding of the scrap wires, to dissociate the constitutive materials; (2) separation of the constituents, based on the differences in their mass density and/or electric conductivity.

Roll-type corona-assisted electrostatic separators are widely used for sorting out of conductive and non-conductive particles from a variety of mixed granular materials, such as minerals, industrial wastes or agricultural products (Ralston, 1961; Félici, 1966; Lawver and Dyrenforth, 1973; Haga, 1995; Dascalescu et al., 1998; Brands et al., 2000; Kohnlechner and Dascalescu, 2005; Tilmatine et al., 2009). In these installations, the electrical field, allowing electrostatic separation, is created between a rotating cylindrical electrode, connected to the ground, and one or more high-voltage electrodes. At least one of them generates a DC corona discharge (Dascalescu et al., 1995; Iuga et al., 2001, 2011).

S-shaped plate-type electrostatic separator (Fig. 1) is another solution (Inculet et al., 1998; Dascalescu et al., 2001; Das et al., 2007). In this case, the electrical field is created between an elliptical-cross-section cylindrical electrode (1) that is connected to the high-voltage, and a grounded S-shaped metal plate (2). The only electric charging mechanism is the electrostatic induction (Vlad et al., 2000a,b; Park et al., 2015). Granules (more or less good conductors) are transported by the electromagnetic vibratory feeder (3) and deposited at the upper edge of the plate electrode (2). Then, they slide down along the surface of the plate and behave differently depending on their electrical conductivity. Conductive granules, by coming in the electric field area generated by high-voltage electrode (1), acquire by electrostatic induction an electric charge, the polarity of which is opposed to that of the high-voltage electrode. They are affected by three main forces: the electric attraction (Coulomb) force oriented to the elliptical electrode, the gravity force and the centrifugal force perpendicular to the surface of the S-shaped electrode (2).

When the sum of the electric and centrifugal force surpasses the normal component of gravity force, the conductive granules detach from plate electrode and accumulate in the right-hand-side compartment of the collector (4). The non-conductive granules

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http://dx.doi.org/10.1016/j.wasman.2016.06.036
0956-053X/

Please cite this article in press as: Richard, G., et al. Optimization of metals and plastics recovery from electric cable wastes using a plate-type electrostatic separator. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.06.036

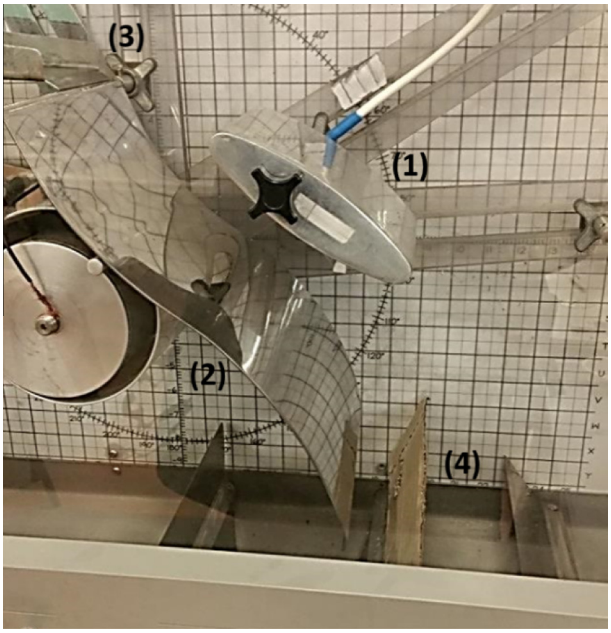

Fig. 1. Laboratory plate-type electrostatic separator (CARPCO, Inc.); (1) elliptical-cross-section cylindrical electrode connected to the high-voltage supply (negative polarity); (2) grounded plate electrode; (3) electromagnetic vibratory feeder; (4) collector.

acquire no electric charge by electrostatic induction. They are not attracted by the high-voltage electrode (1) and the sum of the gravitational and centrifugal forces drives them in a different compartment. It is possible to add a corona electrode to better control non-conductive granules trajectories by charging them in an ionized electric field (Zeghloul et al., 2015).

The reported applications of this separator have mainly been in the field of minerals separation (Iuga et al., 2004, 2011). The researchers have also performed numerical simulations of the electric field and of particles trajectories in these types of separators, for various electrode configurations (Vlad et al., 2000a,b, 2003; Abouelsaad et al., 2013).

This is the simplest electrostatic separator that can be used for the selective sorting of conductive and non-conductive constituents of a granular mixture. It is characterized by less energy consumption and less maintenance that the roll-type electrostatic separators.

The present work is aimed at validating a methodology that would optimize the outcome of an industrial plate-type electrostatic separation process employed for the selective sorting of granular metals and plastics, originating from either flexible or rigid electric wire wastes. Therefore, the two control factors that have been chosen are the ones that can commonly be adjusted in an industrial separator: the inclination angle of the high-voltage electrode and the high-voltage value applied on the elliptical electrode. These two factors act directly on the electric field and hence on the efficiency of the separation. The study is performed according to the response surface methodology (Frigon and Mathews, 1996; Goupy, 1999), on samples composed of either manually-cut "calibrated" cylindrical copper and PVC particles (length: 4 mm), or actual industrial grinded electric wire scraps, characterized by a relatively-wide size distribution (1–4 mm).

The paper describes an experimental procedure that has paved the way from the laboratory study to industrial application. The electrostatic separator designed, engineered and manufactured in accordance with authors' recommendations is capable of typically treating 100 kg of grinded WEEE per hour. The purity of the recycled copper is higher than 90%, for a recovery rate of 80% or more.

2. Materials

Flexible electric wires are composed of a multitude of copper filaments wrapped with a layer of PVC as electrical insulation. They are composed of roughly 55% of copper and 45% of PVC, in terms of mass. Conversely, rigid wires are made of a single strand of copper, surrounded with a layer of PVC. The percentage of copper is higher (about 65%) and the one of PVC is lower (35%) than in flexible wires.

For a first set of experiments, primarily aimed at validating the feasibility of the electrostatic separation, "calibrated" cylindrical particles of 4 mm long are manually-cut from flexible and rigid electrical wire wastes having a cross-section of 0.5 mm^2 (Figs. 2a and 3a). The other experiments are performed with machine-grinded electrical wire wastes of various sections. The plastic particles of this second mixture are characterized by a wide dispersion of size (1–4 mm) and various shapes (Figs. 2b and 3b). The presence of hybrid particles (i.e. unfree copper wire in plastic insulation – Fig. 3c) is expected to deteriorate the quality of electrostatic separation.

The insulation hampers the contact between the copper wire and the plate electrode and hence its charging by electrostatic induction. These uncharged granules will not be recovered in the same compartment as the induction-charged copper ones. At the same time, they are too heavy to fall in the same compartment with the majority of the plastics. As a consequence, they are separately recovered with the middling product, which contains some copper granules deviated after an impact with the high-voltage electrode (Fig. 4).

3. Experimental procedure

The experiments described hereafter are performed on a laboratory electrostatic separator (model EHTP(2 5,36)111·15, Carpco Inc., Jacksonville, Fl), the collector of which is composed of 16 compartments, each 25-mm wide (Fig. 5). These compartments are numbered, from right to left, from 1 to 16, and are grouped in 4 sections. The first one, B1, corresponds to compartments #1 to #7 and it principally collects the copper particles. Sections B2.1 and B2.2 correspond to compartments #8 and #9, in which are collected both copper and plastic (the former usually contains mainly copper, while the latter collects a majority of plastic particles). These two boxes are distinguished because, in some case, one (or both) of them could be pure enough to be considered as pure product. The product recovered in section B3 is composed of the previously-described "hybrid" granules, as well as a middling of copper and plastic particles which bounced off the other compartments. Compartments #14 to #16 are useless because no granules are recovered in them.

To obtain optimum functioning point of the separator for the four sample types of granular electric wire wastes, the experiments are performed using the response surface method (Frigon and Mathews, 1996; Goupy, 1999; Hicks and Turner, 1999; Eriksson et al., 2000). This method has already been used to define optimum functioning point of other electrostatic separation processes (Dascalescu et al., 2004; Medles et al., 2007).

The experimental design is focused on the variation of two factors (Fig. 5):

- Inclination angle of the elliptical electrode (α, °).
- High-voltage applied to the elliptical-cross-section cylindrical electrode (*U*, kV).

Inclination angle of the plate electrode (β, °) is fixed at 55°, which has been defined as the optimum value by a series of

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