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Optimization of wet shaking table process using response surface methodology applied to the separation of copper and aluminum from the fine fraction of shredder ELVs

Helga Jordão *, António Jorge Sousa, M. Teresa Carvalho

CERENA – Centro de Recursos Naturais e Ambiente, Avenida Rovisco Pais, 1049-001 Lisbon, Portugal

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ABSTRACT

With the purpose of reducing the waste generated by end-of-life vehicles (ELVs) by enhancing the recovery and recycling of nonferrous metals, an experimental study was conducted with the finest size fraction of nonferrous stream produced at an ELV shredder plant. The aim of this work was to characterize the nonferrous stream and to evaluate the efficiency of a gravity concentration process in separating light and heavy nonferrous metal particles that could be easily integrated in a ELV shredder plant (in this case study the separation explicitly addressed copper and aluminum separation). The characterization of a sample of the 0–10 mm particle size fraction showed a mixture of nonferrous metals with a certain degree of impurity due to the present of contaminants such as plastics. The majority of the particles exhibited a wire shape, preventing an efficient separation of materials without prior fragmentation. The gravity concentration process selected for this study was the wet shaking table and three operating parameters of the equipment were manipulated. A full factorial design in combination with a central composite design was employed to model metals recovery. Two second order polynomial equations were successfully fitted to describe the process and predict the recovery of copper and aluminum in Cu concentrate under the conditions of the present study. The optimum conditions were determined to be 11.1° of inclination, 2.8 L/min of feed water flow and 4.9 L/min of wash water flow. All three final products of the wet shaking table had a content higher than 90% in relation to one of the metals, wherein a Cu concentrate product was obtained with a Cu content of 96%, and 78% of Cu recovery and 2% of Al recovery.

1. Introduction

Every year, end-of-life vehicles (ELVs) constitute between 7 and 8 million tonnes of waste in the European Union that, if integrated in a correct waste management system, would represent an important source of secondary raw materials, especially metals (Eurostat, 2014). An ELV recycling system management includes collectors, dismantlers and re-manufacturers, shredders and post-shred sorters (Dalmijn and De Jong, 2007; Fiore et al., 2012; Manouchehri, 2006; Smink, 2007). The major role of dismantlers and re-manufacturers is the decontamination of vehicles by removing the hazardous constituents and dismantling valuable spare parts either for reuse or recycling. The remaining vehicle ("hulk") is dispatched to a shredding plant where size reduction is applied, followed by mechanical separation to sort the particles into different streams (ferrous, nonferrous mixture and shredder residue). The main operations employed are: fragmentation; air classification; magnetic and electromagnetic separation; classification; and heavy media separation. However, each shredding plant has slightly different processing diagrams (Reuter et al., 2006).

Fig. 1 shows the simplified flow sheet of the industrial facility where the sample used in the present study was collected. First, the "hulk" is shredded and air classification is used to remove the light fraction (e. g. paper, textile), also called automotive shredded residue (ASR). The heavy fraction is sent to a magnetic separator producing two streams: ferrous metals (iron and steel) and nonferrous materials (metals and non-metals). In the ferrous fraction, because there are still middling particles (made of more than one material) and eventually nonmetals, further hand sorting is applied to remove these particles, which cause a certain degree of impurity. The resulting ferrous scrap is a finished product sent to steel smelters.

The remaining output of magnetic separation is a mixture of nonferrous metals such as aluminum, copper, brass/bronze and

* Corresponding author.
E-mail addresses: helgajordao@ist.utl.pt (H. Jordão), ajsousa@ist.utl.pt (A.J. Sousa), teresa.carvalho@ist.utl.pt (M.T. Carvalho).

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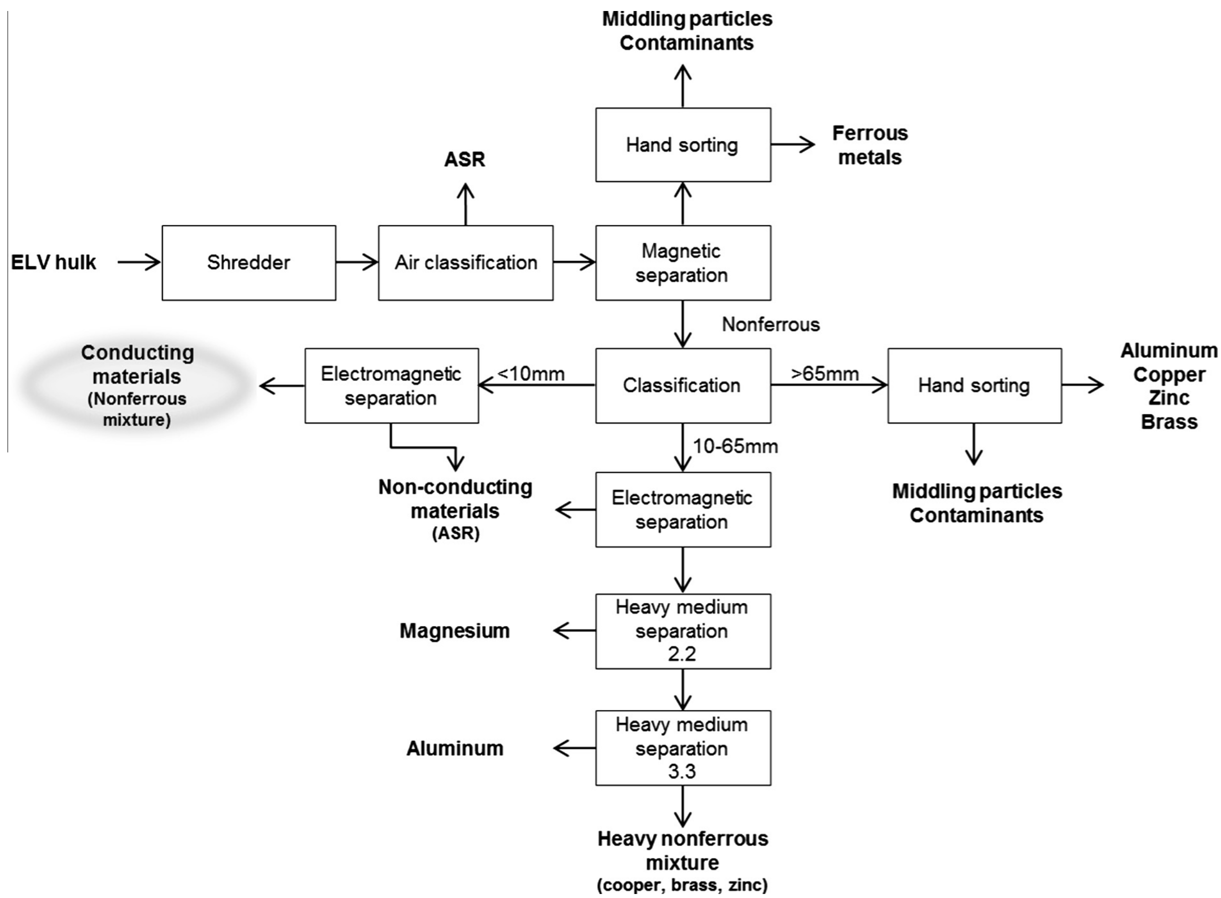

Fig. 1. Typical ELV mechanical processing flow sheet (the studied sample was collected from the highlighted product).

zinc as well as nonmetals (e.g. glass, stone, plastics, rubber). This mixture is heterogeneous in material composition, particle size and shape. It is commonly classified into 3 particle size intervals that are processed independently to improve efficiency. The coarse fraction is hand sorted to separate nonferrous metals by type (e.g. aluminum, copper) and to remove steel, iron and middling particles (that may have dragged along with this fraction). The latter are usually returned to the shredder for further liberation of materials. The intermediate and fine fractions are sent to electromagnetic separation, each size fraction creating two streams: non-conducting and conducting materials.

The non-conducting materials are classified as ASR. The conducting materials of the intermediate size fraction proceed to a heavy media process in two stages, to separate magnesium, aluminum and heavy metals (zinc, brass/bronze and copper). Aluminum and magnesium are typically sold to smelters; whereas the mixture of heavy metals is sold to post-shred sorting companies that further separate this product. The fine size fraction (the focus product of this work) is either exported or sent to landfill (Reuter et al., 2006).

In the last few years, in order to improve waste management of ELVs, numerous studies concerning the optimization of ELVs recycling were reported. The works presented by Koyanaka and Kobayashi (2011), Vermeulen et al. (2011) and Ruffino et al. (2014) are examples of research conducted in post-shredding techniques with focus on improving recycling and recovery of valuable materials present in ELVs. However, to the best knowledge of the authors, there are no studies on the valorization of the nonferrous finest fraction coming from ELVs processing diagrams similar to the one shown in Fig. 1.

The primary purpose of this work was to characterize the nonferrous 0–10 mm size fraction collected from a Portuguese industrial shredding plant in operation. Based on the sample characterization results, a series of experiments were conducted to evaluate the efficiency of a gravity concentration process to separate light and heavy nonferrous metal particles (in this size fraction) that could be easily integrated in an ELV shredder plant.

In the present work, the separation of the light metal (aluminum) from the heavier metals by gravity concentration explicitly addresses the separation of aluminum and copper. The separation of heavy metals (copper, zinc and brass/bronze) was not considered.

The wet shaking table was chosen to separate the materials. This is a process commonly used in mineral processing to concentrate ore with particle size range between 0.6 mm and 8.0 mm (Wills et al., 2005). The wet shaking table is quite a complex process and the equipment has several operating parameters that must be set for maximum efficiency. These depend on the feed characteristics, namely density, particle size and shape (Kelly and Spottiswood, 1982). A full factorial design (FFD) in combination with a central composite design (CCD) was employed. This is not the commonly used experimental procedure to design experimentation and evaluate the results in published works such as the present one, which study the efficiency of the physical separation process. However, this methodology allows the identification of the parameters and the parameter-interactions that significantly affect the outputs of the process, the generation of predictive mathematical models that describe the physical system behavior and the determination of the optimal operating settings.