WEEE MECHANICAL TREATMENTS: RECOVERY EFFECTIVENESS OF CRITICAL MATERIALS

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ABSTRACT

Over the last two decades the generation of Waste Electrical and Electronic Equipment (WEEE) has increased due to the rapid innovation in technology that led to a reduction in the lifespan of many electronic devices.

E-waste is a complex waste stream: it can contain harmful substances as well as valuable and strategic materials, such as precious metals and rare earth elements, whose recovery represents a relevant economic driver for WEEE recycling. Moreover, the European Commission identified rare earth elements as critical raw materials at risk of supply, so that electronic waste is being regarded as an important secondary source of these materials.

In European Union waste recycling is a legal obligation, and thus well-established technologies are currently used to separate the main constituents of WEEE, which are plastics and metals.
WEEE recycling follows three main steps: collection, pre-processing and end-processing. Pre-processing is the most relevant step to ensure an effective material recovery from electronic waste. It is typically performed via physical and mechanical treatments, aiming at selecting different components, which are then processed to obtained more homogeneous material streams that can be effectively sent to further refining processes. The selection step includes manual sorting and dismantling of the parts that can be re-used; the residual fractions from the selection stage are mechanically treated, using conventional technologies to separate plastics from metals.

It has been recognized that such pre-processing can effectively recover mass-relevant materials like iron and copper, but lower selection yields can be pursued for both precious metals and rare earth elements, which are usually present in WEEE at trace level concentrations.

The aim of this study was in quantifying the content of valuable trace metals in the electronic waste processed at a mechanical treatment plant as well as in the process output fractions, in order to assess the distribution of both precious metals and rare earth elements in the final material streams. The recovery effectiveness of the mechanical treatment was thus assessed with reference to target metals and wider considerations on the management options of the material flows originating from the process itself were discussed.

Keywords: mass balance, precious metals, rare earth elements, resource recovery, selection processes

1. Introduction

In the last decades the rapid innovation in technology, the changes in lifestyle and the downward trend in prices of most electronic devices have led to a growing generation of Waste Electrical and Electronic Equipment, also known as WEEE (Tanskanen, 2013).

Electronic waste (e-waste) is a complex and heterogeneous stream, both in terms of materials and devices. Its composition can be even variable within the same category of product, depending on its age, origin and manufacturer (Cui and Zhang, 2008)

WEEE generally consists of a mixture of metals, plastics and ceramics: it can contain up to 21% plastics, but more than half of the material is composed by metals (Widmer *et al*., 2005).

E-waste is generally considered as hazardous due to the presence of heavy metals, such as mercury, cadmium and lead, flame retardants and other potentially harmful substances that, if improperly managed, may represent a risk for human health and environment (Tsydenova and Bengtsson, 2011). On the other hand, it has been recognized as an important secondary source of valuable materials (Jadhav and Hocheng, 2012; Lee and Pandey, 2012; Tunkuc *et al*., 2012), such as copper and precious metals, which are mainly concentrated in specific WEEE components (Hagelüken, 2006, Chancerel and Rotter, 2009; Oguchi *et al*., 2011).

Approximately 60% of the value of PC boards, mobile phones as well as Printed Circuit Board scraps is related to their content in gold. It is therefore evident that the recovery of precious metals represents the major economic driver for e-waste recycling (Cui and Zhang, 2008).

Furthermore, WEEE contains rare earth elements (REEs), which includes 15 lanthanides, scandium and yttrium. The European Commission identified REEs as the most critical raw material group, with the highest supply risk (European Commission, 2010); neodymium, in particular, was acknowledged as one of the five most critical REEs, along with europium, terbium, dysprosium and yttrium (U.S. Department of Energy, 2011).

REEs are mainly used in permanent magnets (Schüler *et al*., 2011) of different kind of electric and electronic devices (Guyonnet *et al*., 2015). In 2011 less than 1% of the REEs was recycled, indicating that a drastic improvement in the recovery of these critical elements from WEEE is mandatory (Binnemans *et al*., 2013).

In order to develop a suitable recycling strategy, it is essential to identify and quantify valuable and hazardous materials that are contained in electric and electronic waste (Cui and Forssberg, 2003).

Currently recycling of e-waste consists of three major steps: collection, pre-processing (physical and mechanical pre-treatment) and metallurgical end processing (Meskers *et al*., 2009).

The pre-processing represents a crucial step, as its effectiveness has a relevant impact on the recovery of a specific substance over the whole recycling chain (Chancerel *et al*., 2009). During pre-processing e-waste is manually sorted and dismantled in order to separate its re-usable parts. Then the waste is mechanically processed, with the primary aim of separating metals and non-metals using techniques such as screening, magnetic separation, eddy current and density separation (Khaliq, 2014).

Although conventional mechanical treatments are optimized to recover mass-relevant materials such as iron and copper (Veit *et al*., 2002), they do not allow an efficient recovery of precious metals (Cui and Zhang, 2008), which are often lost during the pre-processing step (Chancerel *et al*., 2009; Oguchi *et al*., 2012).

The present study aims at quantifying both precious metals ad REEs in the electronic waste processed at a conventional mechanical treatment plant. The distribution of these materials in the output fractions is also discussed, thus pointing out the recovery effectiveness of the mechanical process.

2. Methodology

The samples analysed in this study were collected at an industrial facility, located in the South of Italy. The plant treats e-waste coming from small electronic equipment, IT and consumer appliances.

The treatment line (Figure 1) mainly consists of: i) pre-treatment by shredding and magnetic separation; ii) patented disintegration process to detach plastics from metals; ii) final treatment via sieving, fluid bed and electrostatic separation, to separate a plastic stream from metals. Throughout the treatment line, process air filtration is also provided.

Among the output fractions, plastics and metals were collected along with the dust originated from process air filtration. Large iron scraps were not included among the analyzed samples as they were entirely classified as ferrous materials.

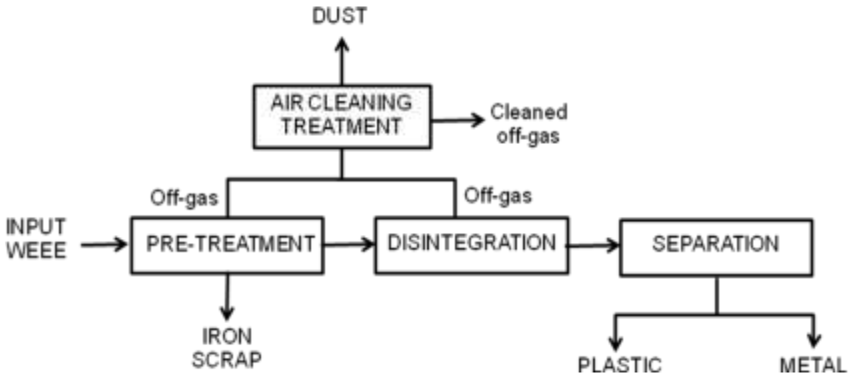

Figure 1. General flow sheet of the investigated mechanical process

Each sampled fraction was digested with aqua regia according to ISO 11466:1995 and the resulting solution was analysed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) to determine the concentration of base metals, precious metals and rare earth elements. Analysis were repeated three times.

In order to evaluate the recovery effectiveness of the investigated mechanical process, a mass flow analysis was conducted with regard to copper as base metal, gold as precious metal and neodymium as rare earth element.

3. Results and discussion

Analytical results showed that iron, copper and aluminium were the prevalent metals in the input WEEE. Both precious metals and rare earth elements were found to be present at trace concentrations: the input WEEE held about 5 mg/kg of gold and 10 mg/kg of neodymium. These results are consistent with the ones reported by Oguchi *et al*. (2012), who estimated an average content of 5-11 mg/kg for precious metals and a range of 10^{-1} - 10^{2} mg/kg for rare earth elements in the input WEEE at a Japanese municipal treatment plant. The highest concentration of REEs can be reasonably ascribed to the presence of lamps, which are not processed at the plant under investigation.

Results of mass balances are plotted in Figure 2.

Over 80% of the incoming copper ended up in the metallic output fraction, which is sent to further recovery processes. The high efficiency of copper selection can be related to the metal higher specific weight, which produced a more efficient density separation of metallic grains from plastics. This evidence confirmed the outcomes of previous studies reporting an average metals recovery of 80%, especially for copper, from the mechanical treatment of WEEE printed circuit boards (Veit el al., 2002).

On the other hand, the recovery rate of both gold and neodymium was estimated to be lower than the one of copper: only two-fifths of precious metals were detected in the metallic output fraction destined to recovery, while the remaining portion was found in the plastic output as well as in the dust, which are not addressed to metal recovery processes. Relevant process losses were estimated for rare earth elements: almost all the neodymium (approximately 90%) ended up in the process air dust.

Similar investigations showed that after mechanical treatments, despite the high recovery rates of mass relevant metals like iron and copper, only a quarter of gold ends up in outputs from which precious metals may be recovered (Chancerel *et al*., 2009) and most of the total mass of the less common metals is distributed to the fraction which is landfilled (Oguchi *et al*., 2012). The results of the present study confirmed that conventional mechanical treatments enable an efficient recovery of base metals, such as copper, while they fail in the recovery of precious metals and REEs, which are mainly removed in the dust stream.

Analytical results further pointed out that significant concentrations of valuable elements can be found in dust originating from process air filtration, which is considered a waste stream, typically destined to landfilling. Conversely, if properly concentrated in dust flow, both precious metals and rare earth elements could be effectively recovered via refining processes.

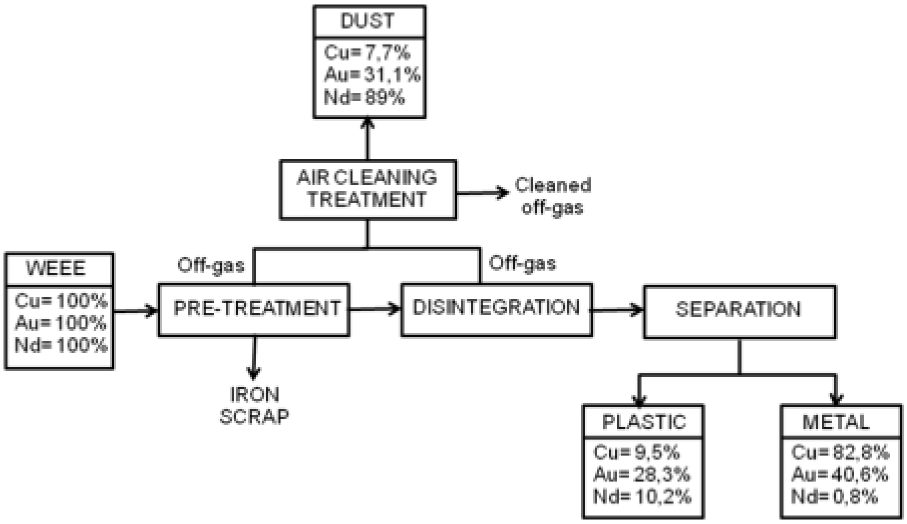

Figure 2. Mass balance of critical metals during the investigated mechanical process

4. Conclusion

Electronic waste, which results from obsolete electronic equipment put on the market, is rapidly increasing on the global scale. E-waste contains both materials which can be recovered as well as hazardous materials and substances. Thus, for a sustainable environment, e-waste needs to be directed to a proper recycling chain. Since conventional mechanical treatments allow the recovery of base metals, such as iron and copper, research is currently directed towards the optimization of these processes to ensure the recovery of precious metals and rare earth elements.

In order to evaluate the efficiency of WEEE mechanical treatment, the fate of critical metals contained in WEEE during pre-processing was investigated. WEEE samples were collected at a full-scale treatment plant and analysed in term of critical metals content. Analytical results confirmed the presence of both precious metals and rare earth elements in WEEE. These elements are present at trace level concentrations (mg/kg), while iron, copper and aluminium were detected at higher concentrations.

A mass flow analysis revealed that significant amounts of precious metals and rare earth elements end up in the dust fraction originating from process air cleaning. In order to avoid process losses, dust could be further processed via refining treatment, such as hydrometallurgical processes.

Due to the detected concentration of valuable metals as well as the composition, more homogeneous than the one of WEEE, the dust fraction originating from process air cleaning could be efficiently destined to further treatment, emerging as a target matrix for the recovery of critical metals from WEEE.

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