Characterisation of Rare Earth Elements in Waste Printed Circuit Boards (WPCBs) and their bioleaching potential

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Abstract

Printed circuit boards (PCBs) are part of everyday items such as cellular phones and computers, and they constitute a significant proportion of e-waste. PCBs contain hazardous components but also valuable and critical materials such as copper, gold, silver and rare earth elements. Rare earth elements (REE) are crucial to modern hardware and due to their increasing demand and high supply risk, they are now considered to be amongst the most critical elements in the world. In this research, WPCBs were supplied by local recycling companies after crushing/grinding process and metal analysis of the material was carried out. The concentration of the REE and their distributions in particle sizes is determined, and the potential of WPCBs for REE bioleaching is also discussed.

Keywords: Bioleaching, PCBs, Rare earth elements, WEEE.

1. Introduction

Approximately 4% to 7% of the total WEEE mass corresponds to waste printed circuit boards, however, the number is higher in some equipment like televisions (10%), computers (20%) and cellular phones (30%) (Wang *et. al*, 2017). Hazardous materials found in WPCBs such as brominated flame-retardants and heavy metals, represent a threat to the environment and human health, when sent to conventional landfill and incineration treatments. Nevertheless, the presence of valuable and critical metals in WPCBs such as copper, gold, silver and palladium makes this e-waste economically attractive for recycling. In recent years, the bioleaching of metals from WPCBs has attracted more attention; this is an environmentally-friendly alternative which exploits the ability of microorganisms to mobilize the metals from a solid matrix. The use of acidophilic bacteria and filamentous fungi for metal mobilization of Zn, Ni, Cu and Au has been widely reported (e.g. Arshadi and Mousavi, 2015; Madrigal-Arias *et al.*, 2015). Other critical elements such as the rare earths Neodymium (Nd), Dysprosium (Dy), La (Lanthanum), Scandium (Sc) and Yttrium (Y) can be also found in WPCBs. However, little research has been focused on this group of elements. To our knowledge, bacterial or fungal bioleaching of rare earth elements from WPCBs has not been entirely addressed. One of the limitations in recovering REE from e-waste, particularly from WPCBs, is the high loss of these elements during the mechanical pre-treatment of the waste material (Marra *et al.,* 2018); therefore, more attention needs to be paid to the dust and fine fractions as potential sources of critical metals. In this study, three different samples from e-waste recycling companies are characterised, the distribution of REE in different particle sizes is examined and their potential for bioleaching is discussed.

2. Materials and Methods

2.2. WPCBs characterisation

WPCBs were obtained after crushing/grinding process from three different companies (named as company 1,2 and 3 for the purpose of this study). The origin of the WPCBs has been described by the suppliers as "*miscellaneous electric and electronic equipment (EEE)*". Metal characterisation was carried out by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, iCAP 6000 series, Thermo Scientific). REE were analysed by Mass Spectrometry (ICP-MS, X Series 2, Thermo Scientific), with the use of collision cell technology (CCT). Microwave-assisted digestion of the samples was performed using aqua regia extraction plus H_2O_2. The microwave settings consisted of two steps; first 10 minutes to reach 195 $\pm$ 5 °C, then the temperature was hold for another 20 minutes, 1000W maximum power. All reagents for digestion were purchased from Fisher Scientific, trace metal analysis grade. ICP standards were acquired from Sigma and Fisher Scientific.

3. Results and Discussion

3.1 Metal characterisation Company 1

Approximately two kilograms of crushed WPCBs were obtained from Company 1. The mass distribution of the material after dry sieving was as follows: Fraction A (< 0.5mm): 18%; B (0.5mm – 1mm): 24%; C (1mm – 2mm): 31%; and D (> 2mm): 26%. After analysing the metal content of each fraction, most of rare earth elements were concentrated in the fraction with the smallest particle size, as shown in Figure 1. Fraction A had two times more La than Fraction B, and 1000 times more than Fraction D. La has been found in concentrations around 2000 ppm, followed by Y and Nd with more than 100 ppm. Other REE such us Sc, Dy and Ho were found in concentrations lower than 10 ppm. Arshadi and Mousavi (2015) found almost 1000 ppm of La and more than 100 ppm of Y in WPCBs from cellular phones, but less than 5 ppm of the same elements in WPCBs from computers. In a review by Lu and Xu (2016), they cited REE concentrations from 9 up to only 90 ppm in WPCBs. However, the number of studies actually reporting concentrations of REE in WPCBs is very limited; these values can vary considerably, depending on the origin of the WPCBs and their year of production. Priya and Hait (2018) have also discussed the lack of investigations in REE content from WPCBs and their potential, which is a missed opportunity. Precious metals like Ag and Au, usually studied for bioleaching, were not specifically concentrated in the small particle size fractions. Au was found mainly in particle size between 1 to 2mm, whilst Ag seems to be distributed in all different sizes. However, the loss of these elements during the crushing process is very high. Marra *et al.*, (2018), reported that approximately half of these precious metals end up in the plastic and dust streams, which are not intended for metal recovery. Unlike REE, most of base metals including Al, Cu, Sn and Zn were more abundant in the large particle sizes (> 1mm), see Figure 1. Similar research also showed that these metals were mainly found in the larger particle size range; which can be explained by their higher malleability (Chao et al.,2011).

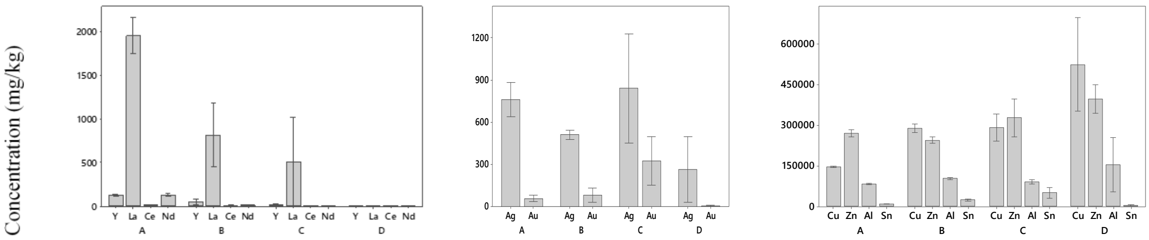

Figure 1. Metal analysis. Fraction A: particle size < 0.5mm; B: 0.5mm - 1mm; C: 1mm - 2mm; D: > 2mm. n = 3, Means ± standard error.

3.2 Metal characterisation Company 2 and 3

The sample from Company 2. showed also concentration of REE mainly in the smaller particle sizes, with values of Nd above 2000 ppm, Dy and Y around 500 ppm (data not shown). Contrary to the previous sample, La concentration was only around 10 ppm. The material supplied by Company 3., was very different as it went through a more rigorous grinding process, leaving particle sizes of only <75 µm and <180 µm. In this case, there was no significant difference between the concentration of REE in both particle sizes. The most abundant REE was Nd, with about 400 ppm, followed by La and Ce with less than 50 ppm. The difference in REE concentrations is related to the heterogeneous EEE from where the PCBs are originated.

3.3 Bioleaching potential

Understanding the distribution of REE in the WPCBs material can help to improve the recovery of this group of elements. In the samples investigated, REE were accumulated mainly in the fraction with the smallest particle size (<0.5mm). Therefore, the REE bioleaching process can be optimised by focusing in this specific fraction. Preliminary results from an *Aspergillus niger* strain, have shown high tolerance of this strain to the WPCBs material, especially in the small particle size range (results not shown). The next step in this research project includes bioleaching experiments and an in-depth study of the microbial mechanisms involved in the process.

4. Conclusions

The distribution of REE in different particle sizes of WPCBs after crushing/grinding treatment has shown that higher concentrations of this group of elements can be found in the smaller particle size range. The most abundant REE were La, Nd, Dy and Y. In the sample from Company 1, for instance, La was found in concentrations of 2000 ppm in the fraction < 0.5 mm, which was 1000 times more than the larger particles > 2 mm. This study has shown that WPCBs could also be considered as a secondary source for recovery of REE, and preliminary results have proved the suitability of this material for a bioleaching approach.

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