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Content evaluation of different waste PCBs to enhance basic metals recycling

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ABSTRACT

This research aims to expand the body of information that researchers require before starting electronic waste (E-waste) recovery experiments. With this purpose, the basic metal contents, alkalinity, polymer components, iron magnetic separation, metal recovery priority and economic values of different types of waste printed circuit boards (PCBs) were investigated. The selected wastes were computer PCBs (CPCBs), CPCBs with wires, mobile phone PCBs (MPPCBs), television PCBs (TVPCBs), fax machine PCBs (FPCBs), copy machine PCBs (COPCBs) and central processing units (CPUs). These E-wastes were prepared in the three fraction sizes of $F_1 < 1$ mm, $1 < F_2 < 3$ mm, and $3 < F_3 < 8$ mm to evaluate the metal contents of different PCB fractions. The plastics of some samples were separated through the shaking table method. Magnetic separation of the iron particles attributed the highest amounts of separated iron to the CPCBs (84%) and MPPCBs (76%). Among the investigated E-wastes, the TVPCBs and CPCBs had the highest percentages of plastic (68 and 57%, respectively). Fourier transform infrared (FTIR) spectroscopy declared the presence of polyphenylene oxide (PPO) and polycarbonate (PC) in all evaluated PCBs. The highest quantities of Cu, Ag, Ni and Ti corresponded to the F_1 fraction for all E-waste samples while the economic values of the E-wastes were as follows: CPU > FPCBs > MPPCBs > COPCBs > TVPCBs > CPCBs. Accordingly, FPCBs and COPCBs were determined as the high value E-wastes for metal recovery. In addition, Cu, Ag and Sn respectively were found to be the most economic basic metals that should be recovered from most PCBs. Finally, pH analysis of the samples demonstrated that E-waste alkalinity is due to the presence of alkaline metals not plastics.

1. Introduction

In recent years, increased demand for electrical and electronic instruments and the short lifecycle of electronic devices have resulted in the accumulation of electronic wastes (E-wastes) and serious environmental problems (Börner and Hegger, 2018). E-wastes are usually composed of monitors (10%), televisions (10%), computers, telephones and their peripherals (15%), DVD/VCR/CD players, radios and hi-fi sets (15%), refrigerators (20%), and washing machines, air conditioners and vacuum cleaners (30%) (Arshadi and Mousavi, 2014). The high application rate of these materials has projected E-wastes to form one of the fastest growing municipal waste streams in the world (Ikhlayel, 2016). Currently, the annual growth rate of E-waste is 3–5% and approximately 30–50 million tonnes of E-waste are generated every year (Borthakur and Govind, 2017; Imran et al., 2017). It is while E-wastes contain up to 60% rare and precious metals due to their excellent conductivity. The precious metals that are commonly found in E-wastes include gold, palladium, silver, copper, aluminum, zinc and tin. Therefore, E-waste can be considered as an artificial or secondary ore and used as a potential source of valuable metals (Wang et al., 2017b). In this way, natural ores can be saved and the global demand for production of new metals can be reduced to some extent (Kumar et al., 2017). However, the point is that efficient collection and recovery systems should be considered for each type of E-waste to maximize the efficiency of metal recycling (Oguchi et al., 2011).

The main rare and precious metal containing E-wastes are printed circuit boards (PCBs), which are parts of electronic devices and carry valuable and hazardous metals (Willner and Fornalczyk, 2013). While PCBs make up about 3–6 wt.% of E-wastes, they are the most important E-waste components by including 40% metals, 30% ceramics and 30% plastics (Pinho et al., 2018). Depending on the electronic device, the metal content of PCBs can be consisted of 8–38% iron, 10–27% copper, 2–19% aluminum, 1–3% lead, 0.3–2% nickel, 200–3000 ppm silver, 20–500 ppm gold and 10–200 ppm palladium (Perkins et al., 2014).

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In addition to metals, plastics comprise a noticeable portion of E-wastes. So that, about 20% of E-wastes is made of more than 15 types of plastics (Brunori et al., 2015) that are usually treated using brominated flame retardants and threaten human health by generating toxic substances upon incineration (Holgersson et al., 2018). In the case of PCBs, the main utilized polymers include styrene acrylonitrile (SAN), polystyrene (PS), polyamide (PA), polypropylene (PP), high-impact polystyrene (HIPS), acrylonitrile butadiene-styrene (ABS), polyethylene (PE), acrylonitrile butadiene styrene-polycarbonate (ABS/PC), polyurethane (PU), polyphenylene oxide (PPO) (Colbert, 2012), polyamide 66 (Nylon 66), polybutadiene terephthalate (PBT) and polyphenylene sulfide (PPS) (Brunori et al., 2015). Among these polymers, PS, ABS and PP are more abundant and respectively make up about 31, 16 and 13% of the plastic content of PCBs (Dillon, 1999). With respect to the plastic content of E-wastes, Reena et al. (2011) reported that HIPS and PC/ABS are below 5% in computers (Reena et al., 2011) while Brunori et al. (2015) stated that HIPS and ABS, along with PBT, Nylon 66 and PPS, are the main polymers that can be found in the external cases of personal computers (Brunori et al., 2015).

Since few years ago, material recovery from E-wastes has become a global concern (Wang et al., 2017a) due to the serious global problems that the huge mass of E-wastes have created. The first problem refers to the environmental pollution and threating of human health caused by informal recycling of E-wastes and the second issue corresponds to sustainability of the electronic industries that are subject to the shortage of mineral resources (Zeng et al., 2017). With respect to these issues, recovery of valuable materials from E-wastes has been widely practiced in manufacturing industries all over the world (Scruggs et al., 2016) and some scientists have focused on E-waste recovery. However, the first step towards efficient metal recovery from E-wastes, such as PCBs, is their comprehensive characterization, which provides a better understanding about E-waste recycling processes for sustainable resource conservation and beneficiation purposes (Anshu and Hait, 2018).

According to the important role of characterization studies, some researches have determined the properties of several types of E-waste. The majority of such researches are conducted on MPPCBs and CPCBs (Arshadi and Mousavi, 2015a; Arshadi et al., 2016; Hagelüken and Meskers, 2008; Jing-ying et al., 2012; Mäkinen et al., 2015; Tripathi et al., 2012; Willner, 2012, 2013; Willner and Fornalczyk, 2013; 2014, Xiu et al., 2015; Yamane et al., 2011; Yang et al., 2009) and few studies have defined the composition of TVPCBs (Bas et al., 2013; Deveci et al., 2010; Hagelüken and Meskers, 2008). It should be noted that though many other studies have presented the content of their E-waste samples, they have not mentioned the exact types of their studied E-wastes. In fact, they have used generic names, such as electronic scrap, electronic waste, PC scrap, PCBs and waste PCBs (Ilyas et al., 2007; Karwowska et al., 2014; Xiang et al., 2010). Furthermore, researchers cannot compare the different types of E-waste reported in different studies. The reason is that even the metal contents of special types of E-waste reported in diverse studies are not compatible since each study employs a specific brand, model, manufacturer, obsolescence PCB age and analysis method. Consequently, it is more logical to analyze different types of E-waste by the same method and sample the E-wastes that exist in a definite country to consider the affect of age, type and model. Also, there is no general research indicating the metal content of the important E-wastes other than CPCBs and MPPCBs. For instance, FPCBs and COPCBs are two important E-wastes that have been just considered in very few papers.

Another point about recycling of E-waste materials is that different researchers have followed various size reduction steps in their recovery experiments due to the difference in the flexibility and hardness of various types of E-waste (Ernst et al., 2003; Hall and Williams, 2007; Szalatkiewicz, 2014). Some researchers have applied mechanical processes to prepare different fraction sizes of PCBs and they have reported that the amount of Cu varies up to four times among the different fractions (Huang et al., 2014; Veit et al., 2002). Similarly, the best fraction size suggested for recovery of metals from E-waste through different recovery techniques including pyrometallurgy, hydrometallurgy and biohydrometallurgy varies from centimeter to micron (Arshadi and Mousavi, 2015a; Jing-ying et al., 2012). Due to the significant effect of fraction size on metal recovery, this research analyzes a particle size distribution to evaluate metal recovery from different size fractions of PCBs prepared via a mechanical treatment.

In general, this study is an effort to expand the body of information that researchers require before starting E-waste recovery experiments. The main goal is gathering adequate information about different types of important E-wastes and comparing their properties. In this respect, computer PCBs (CPCBs), mobile phone PCBs (MPPCBs), fax machine PCBs (FMPCBs), copy machine PCBs (CMPCBs), television PCBs (TVPCBs) and CPUs are selected as the most important types of E-waste to perform a comprehensive study about their basic metals, alkalinity, polymer content, magnetic iron separation, metal recovery priority and economic value. It should be noted that the recovery of precious metals will be presented in our future study due to the large volume of findings in this research.

2. Material and methods

2.1. Waste printed circuit boards

Different types of PCBs including MPPCBs, CPCBs, CPCBs with attached wires, TVPCBs, FPCBs and COPCBs were purchased from the Pars Charkheshe Asia Company, Tehran, Iran. The examined CPUs were obtained from an E-waste collection center located in Tehran, Iran. The prices of the MPPCBs, CPCBs, TVPCBs, FPCBs and COPCBs were about 23.00, 3.47, 2.89, 2.89 and 3.60 USD per kg, respectively. The CPUs had different prices due to their various types. However, their average price was 0.81 USD per CPU at September 2015. It is noteworthy that these prices are higher than those of wholesale buying.

2.2. E-waste fragmentation

E-wastes are too flexible and hard. That is why most laboratory techniques including cutting and corroding are not effective for E-waste grinding. Also, in different recovery techniques, the optimal particle size lies in the range of micron to centimeter. Therefore, a particle size distribution was created by powdering the E-waste samples in three steps to investigate the effect of the different fraction sizes obtained upon grinding of the PCBs on recovery of the metals. It should be noted that no pretreatment was done on the PCBs and the applied PCB platforms contained the mounted components and no wire. Among all PCBs, the CPCBs had a significant amount of attached copper wires. As an outcome, just the CPCBs were studied with and without wires. The following steps were considered to fragmentate the E-wastes:

1 The purchased PCBs were grinded to lower than 2 cm using a hammer mill. In this step, the iron particles were separated from the samples by a magnetic separator, as a simple way of iron recovery. The amount of the separated iron for the MPPCBs, CPCBs, FPCBs and COPCBs was 76, 84, 28 and 54%, respectively.
2 In some recycling techniques, such as bioleaching, lower fraction sizes are needed. Moreover, some portions of the grinded E-wastes should be ignored due to their low metal content. Therefore, a second grinding technique was employed to reduce the dimensions of the particles in addition to hammer milling. For this purpose, an industrial hammer mill was used that is commonly utilized in aviculture industries to produce cornmeal (Gharegozlu, Iran). This mill provided three E-waste fractions. Some parts of the E-waste samples were trapped in the device, which were mainly consisted of plastics and grinded by the device to particles with less than 9 mm dimension. The output particles of the device were lower than 3 mm in