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Supergravity separation for recovering metals from waste printed circuit boards

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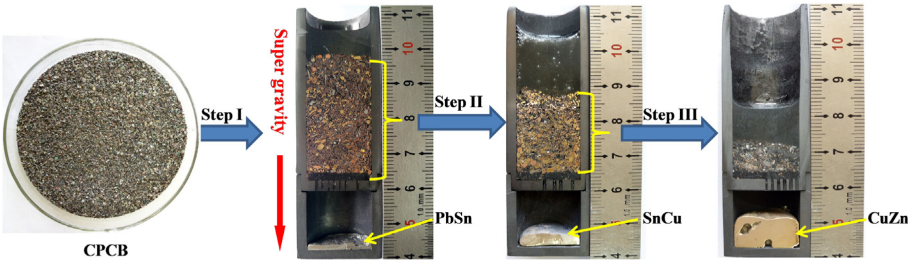
HIGHLIGHTS

- E-waste contains complex combinations of alloys, metals, and toxic substances.
- Cost-effective and environmental recovery are difficult via traditional methods.
- Supergravity separation provides highly efficient recovery of metals from PCBs.
- Higher gravity coefficient improved recovery rates.
- The process achieves closed-loop, clean recycling of e-waste with high efficiency.

GRAPHICAL ABSTRACT

Based on the different melting points of metals or alloys, three alloys (Pb-Sn, Sn-Cu and Cu-Zn) were selectively and gradually recovered from granulated computer printed circuit boards (CPCBs) by supergravity separation.



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ABSTRACT

The recovery of metals from electronic waste has become increasingly important due to environmental concerns and potential risks to the supply of strategic raw materials. Electronic waste, especially waste printed circuit boards from a variety of sources, is of inherently high complexity in composition, phase, and physiochemical properties. Waste PCBs contain valuable metals and multiple toxic substances, motivating a search for processes or technologies to allow their cost-effective and environmental recycling. A novel process was developed, using supergravity separation to recover valuable metals (Pb, Sn, Zn, and Cu) from granulated computer printed circuit boards. A three-step separation process was adopted to selectively recover metals or alloys and to concentrate precious metals. Total recovery values for Pb, Sn, Zn, and Cu were 96.37%, 92.32%, 93.71%, and 97.90%, respectively. The mass fraction of (Pb + Sn) in Pb-Sn alloy, (Sn + Cu) in Sn-Cu alloy, and (Cu + Zn) in Cu-Zn alloy reached 94.84%, 85.18%, and 84.73%, respectively, during the individual separation steps. Compared with the contents of Au (44 ppm), Ag (124 ppm), and Pd (6.5 ppm) in the computer printed circuit boards, the contents of Au, Ag, and Pd in the residues after three-step separation were concentrated to 150 ppm, 550 ppm, and 12 ppm, respectively. By a combination of appropriate hydrometallurgical process and supergravity separation of metals or alloys, this process can achieve closed-loop, clean recycling of electronic waste with significant efficiency.

1. Introduction

Due to technological advances and obsolescence of electrical and electronic equipment (EEE), the production of electronic waste

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(e-waste) is increasing [1]. In 2016, global production of e-waste was about 45 million tons, with annual growth of 2 million tons per year. As an important part of EEE, waste printed circuit boards (WPCBs) accounted for about 3% of total e-wastes generated. PCBs contain many valuable metals such as Cu, Pb, Sn, Cd, Au, and Ag. However, the toxic substances (i.e., brominated flame retardants (BFR), polyvinyl chloride plastic (PVC), and heavy metals) in WPCBs can pose serious environmental threats if not properly treated [2]. Therefore, recycling of WPCBs is an important subject not only for the recovery of valuable materials, but also for protection of the environment.

To date, many technologies have been developed to recover valuable metals, including hydrometallurgy [3–5], bioleaching [6–8], pyrometallurgy [9–11], and physical methods [12–14]. These methods can successfully recover and recycle different metals, but have some notable shortcomings in some cases. The hydrometallurgical recycling of various metals in WPCBs is a very long and complicated process, leading to higher costs; furthermore, large amounts of waste acid liquid and sludge are produced, which require careful treatment [15]. Bioleaching processes are hindered by the difficulty of selecting suitable bacteria, and by the long period. Traditional pyrometallurgical procedures are highly dependent on investment, and generate atmospheric pollution due to evolution of toxic dioxins, furan gases, and carcinogenic compounds [16]. Physical methods have some disadvantages but were the earliest and most widely used approach for separating and recovering metals from WPCBs. Compared with other methods, physical recovery offers advantages such as high efficiency, low cost and pollution, simple principles, and ease of upscaling production. However, due to the complex compositions of raw materials, traditional physical methods can not completely separate the constituent metals. Supergravity, as a physical method of strengthening mass transfer, can effectively separate components from complex materials. Supergravity is the force of matter greater than that under normal gravity acceleration ($9.80\ \mathrm{m/s^2}$). In the supergravity field, molecular diffusion and mass transfer process are faster and liquid phase can flow in and out of porous media or channels and contact with other phases at hundreds of times than in normal gravity field. Great shearing force by supergravity tears liquid into micron to nanometer liquid membranes, filaments and droplets, then forms huge and new phase interface, making the micro mixing and mass transfer process greatly improved. The technology has been successfully applied to the enrichment of valuable elements from different slags [17–19], the fabrication of functionally graded materials [20–22], and removal of impurities from alloys or metals [23–25].

The use of supergravity offers a highly attractive and promising technology with many advantages such as improved environmental performance, high efficiency, low investment cost, and wide range of practical applications. The difference in melting point between the solid-particle and liquid melt results in the gradual distribution and separation of particles along the centrifugal direction in a supergravity field [26,27]. The supergravity field is provided by a centrifugal force produced by a centrifugal apparatus. The differing melting points of metals and alloys within waste computer PCBs (CPCBs) enable their selective separation by supergravity. In this study, supergravity technology was used for separation and recovery of Sn, Pb, Zn, and Cu from CPCBs at different temperatures. A flow chart of the various steps for separating metals from granulated CPCBs is given in Fig. 1. The main objective of the present study was to recover valuable or strategic metals from complex waste electrical and electronic equipment by integrating fundamental physical principles with the aim of minimized environmental effects, lower energy consumption, and improved recovery efficiency.

2. Experimental

2.1. Materials

Waste CPCBs were purchased from an enterprise in Hunan Province, China, and crushed and milled into powder samples of particle size approximately 1.0 mm (Fig. 2).

2.2. Equipment and methods

The CPCBs were placed into a furnace that put into a centrifugal apparatus. The supergravity field was generated by a centrifugal apparatus from the vertical angle with the heating furnace and the counterweight fixed symmetrically onto the horizontal rotor

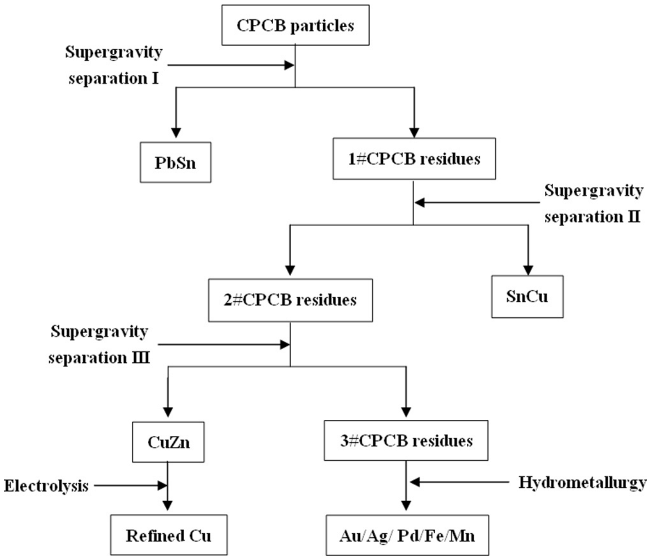

Fig. 1. Flow chart of the separation and concentration of metals from CPCB particles.

Fig. 2. CPCBs used in the experiments.