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The influence of waste printed circuit boards characteristics and nonmetal surface energy regulation on flotation

Jun Han, Chenlong Duan *, Guofeng Li, Long Huang, Xuesen Chai, Dan Wang

Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China

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This paper studied the influence of waste printed circuit boards (PCBs) characteristics and nonmetal surface energy (SE) regulation on flotation. First, SEM-EDS was applied to study the appearance and surface element distribution of the glass fiber and copper. The results showed that the glass fiber was present in a bundle and the surface carbon content was 49.42%, which facilitated glass fiber floating. The copper appearance contained many nodules, with a carbon content of 32.54%, which hindered copper sorting. XPS analysis further discovered that copper was mainly present in the forms of CuO, Cu(Met), and Al_2Cu. A FT-IR analysis revealed that the organic matter in the PCBs was essentially the same as the epoxy resin. It was easy to achieve floating and some polar functional groups promoted the adsorption of the flotation reagents. Based on this, by calculating the nonmetal SE, it was found that the proportion of the non-polar component of the nonmetal SE was 94.60%. The EDLVO theory was applied to research interactions between nonmetal particles. Hydrophobic attraction was found to be the main factor causing nonmetal particles to agglomerate. Further, the tannin was used to improve the dispersion of nonmetal by adjusting the nonmetal SE. Furthermore, the hydroxyl and carbonyl groups in the tannin may form hydrogen bonds with the bromine, epoxy and hydroxyl groups in the nonmetal. Finally, flotation test results indicated that tannin added significantly enhanced PCBs flotation efficiency. When the amount of tannin added increased from 0 to 60 mg/L, the recovery of copper increased from 61.92% to 90.53%. Thus, this study provides an alternative approach to improve the flotation efficiency of waste PCBs.

1. Introduction

As China's economy has rapidly developed, there has been an acceleration in the rate of electronic product upgrades. One study found that the number of mobile phones increased from 988 million to 2.018 billion from 2010 to 2016 in China (Li et al., 2017). This will inevitably led to an increase of e-waste. China currently generates 70 million waste mobile phones (WMPs) every year; of these, only 1% undergo regular recovery and 40.02% are idle (Yin et al., 2014; Liu et al., 2014). It is estimated that every ton of waste mobile phones contain about 130 kg of copper, 3.5 kg of silver, 340 g of gold, and 140 g of palladium. The levels of metals in waste PCBs are the highest among WMPs (Cao et al., 2016); the grades of these metals are dozens or even hundreds of times the original grade of the mined ore. Therefore, recovering metals from these waste PCBs is an important goal. In particular, 0.17% of the increased energy consumption in China is attributable to mobile phone manufacturing (Yu et al., 2010). Waste PCBs also contain many heavy metals, including arsenic, lead, cadmium, and nickel. If these metals are burned in a smelter or buried in a waste dump, they will pollute the air and harmful substances will be leached into the soil, causing groundwater contamination (Nnorom and Osibanjo, 2009). As such, the recycling of WMPs is currently a significant environmental protection issue in China. On January 1, 2015, WMPs were included in e-waste types for the first time by new WEEE regulation (Li et al., 2017). Therefore, applying proper methods to address these e-wastes both protects the environment and supports resource recycling.

There is an increasing number of technologies for addressing waste PCBs, including pyrometallurgy, hydrometallurgy, and biometallurgy. However, these technologies have some disadvantages during application. For pyrometallurgy, the combustion of nonmetal parts produces brominated organics and other toxic emissions (Bidini et al., 2015). It also produces approximately 20–25% ash, which contains a large amount of heavy metals that require further handling (Long et al., 2010). Hydrometallurgy produces significant levels of high-risk wastewater, which can pollute

* Corresponding author.
E-mail address: clduan@cumt.edu.cn (C. Duan).

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groundwater and soil, causing secondary pollution (Ma et al., 2018). Biometallurgy has a relatively high recovery rate and less environmental impact (Liang et al., 2013; Ilyas et al., 2010); however, it requires long treatment cycle and a very fine particle size. This will result in very high energy consumption (Yang et al., 2009). Some mechanical processing technologies have advantages in the disposal of waste PCBs (Zhao et al., 2004; Zhao et al., 2012; Duan et al., 2009); however, they have deficiencies for fine particles treatment. For example, jigging sorting is suitable for sorting coarse particles. However, the presence of significant glass fiber hinders delamination, affecting the sorting effect (Sarvar et al., 2015). For electrostatic separation technology, it can be discovered that the optimum size for electrostatic separation was 0.6–1.2 mm (Li et al., 2008). When magnetic separation is used to dispose of waste PCBs, there are many nontarget materials in the magnetic portion (Yoo et al., 2009; Veit et al., 2005). The vibrating fluidized bed separation technology has also poor accuracy when sorting fine particles (Wang et al., 2017, Zhang et al., 2017); this method also generates a large amount of waste dust, causing environmental pollution.

Flotation technology has been also used to treat waste PCBs (Ogunniyi and Vermaak, 2009); the technology has the advantages of low pollution, low energy consumption, and a high recovery rate. The principle underlying the flotation approach is based on the differences in the chemical properties of different particles that float to the surface (Farrokhpay, 2011; He and Duan, 2017). Hydrophobic particles float because of the selective adsorption of bubbles, and hydrophilic particles sink (Shean and Cilliers, 2011). The greater the differences in the chemical properties of the different particle surfaces, the easier the separation can be achieved (Wills and Finch, 2016). For waste PCBs, the difference in the properties of metal and nonmetal surfaces is favorable for the flotation process. As such, this technology has attracted the attention of researchers. For example, Flores-Campos et al. found that the nonmetal contact angles in PCBs can be increased by enhancing the temperature and the concentration of the foaming reagent (Flores-Campos et al., 2017). Estrada-Ruiz et al. discovered that the flotation feed size and aeration levels are the main factors affecting the flotation effect (Estrada-Ruiz et al., 2016). However, the study also revealed some problems. Sarvar et al. showed that when the PCBs size range changed from 0.30 to 0.59 mm to less than 0.1 mm, the metal recovery rate decreased from 80.83% to 44.10%. They postulated that this may be because as the PCBs particle size decreases, the mechanical entrainment becomes increasingly significant (Sarvar et al., 2015). Vidyadhar and Das also found that fine particles PCBs tend to agglomerate in the pulp and entrap small metal particles, which degrades the sorting effect (Vidyadhar and Das, 2013). Other studies have also shown that as the particle size decreases, the metal recovery rate from PCBs sharply drops (He and Duan, 2017).

These previous studies confirm that as the particle size decreases, the PCBs flotation efficiency worsens. The reasons for the low flotation efficiency of fine particles have already been extensively studied (Miettinen et al., 2010), with material properties appearing to be one of the main factor affecting flotation efficiency. However, few studies have examined the influence of waste PCBs characteristics on flotation.

This study examined the characteristics of glass fiber, copper, and resin in waste PCBs, and analyzed the effect of these characteristics on flotation. Based on this, the nonmetal SE was calculated to investigate the polarity and non-polarity of the nonmetal particle surfaces. The EDLVO theory was applied to analyze and calculate the free energy of interaction between nonmetal particles, and to determine why nonmetals are easily agglomerated in the pulp. Organic dispersant was used to adjust the nonmetal SE, thereby promoting its nonmetal dispersion in the pulp. In addition, the study examined the dispersion mechanism of reagent and the adsorption mechanism on nonmetal surfaces. Finally, experiments evaluated the effect of dispersant on flotation efficiency. In summary, the influence of PCBs characteristics on flotation was analyzed using instrumentation, and theoretical calculations were used to investigate the reason for the easy agglomeration of nonmetals in the pulp. Based on this, the study proposes a method for solving nonmetal agglomeration to improve waste PCBs flotation efficiency.

2. Materials and methods

2.1. Materials

The waste mobile phone PCBs were purchased from the waste electronic market in Xuzhou City, Jiangsu Province, China. The electronic components on the PCBs were manually dismantled and recycled, and the disassembled PCBs were further cleaned to remove dirt from the surface. The materials were then dried naturally.

The prepared PCBs were crushed using a shear crusher, containing a sieve with a 0.5 mm diameter hole in the discharge section. This allowed material smaller than 0.5 mm to pass through the sieve hole into the collection drum during the crushing process. The crushed material was divided into five fractions from largest to smallest (>0.5 mm, −0.5+0.25 mm, −0.25+0.125 mm, −0.125 +0.074 mm, and <0.074 mm) using a standard sieve. The yield of each fraction was calculated as shown in Fig. 1. PCBs particles of a size less than 0.25 mm were used as flotation feed.

Fig. 1 shows that as the particle sizes decreased, the grade of copper also sharply decreased. This is mainly due to the good ductility of copper; it is difficult to reduce its particle size using external force during the crushing process. The particles of size less than 0.074 mm yield was 27.51%. This result indicated that a large amount of fine materials were produced after crushing, and these materials contained a large amount of nonmetal materials. This is mainly because glass fibers and resins are brittle materials and can easily become smaller through the crushing process. Therefore, it is important to study the impact of these nonmetal properties on flotation. In addition, the grade of copper in these fine materials is far greater than the grade of copper ores. Thus, it is very important to effectively handle this part of the material.

2.2. Nonmetal surface energy detection and calculation

To study nonmetal surface energy, three different liquids were used to test the contact angle with the nonmetal: deionized water, ethanol, and glycerin. Test samples were prepared by pressurizing

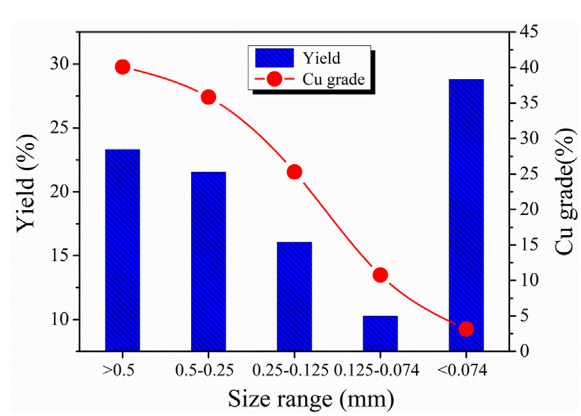

Fig. 1. Yield distribution and grade of copper in different size range.