



Bioleaching of copper from low grade scrap TV circuit boards using mesophilic bacteria



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ABSTRACT

In this study, the extraction of copper from manufacturing scrap TV circuit boards (STVB) by bacteria-assisted leaching was studied using a mixed culture of mesophilic bacteria. Initial availability of soluble iron appeared to be of prime importance for the extraction of copper from STVB, which contains 43 g/ton Fe. In this respect, the addition of 1–8 g/L Fe(II) significantly improved (by up to 54%) the extraction of copper from STVB at the expense of the increased acid consumption. A new approach for the bioleaching process was adopted, which is based on the addition of pyrite (5–50 g/L pyrite concentrate (PyC)) as a source of iron and sulphur. Copper extraction was observed to enhance from 24% to 84% in the presence of 50 g/L PyC with a significant decrease (62%) in the consumption of acid. An increase in the size of inoculum from 10% to 50% v/v was also observed to improve the bioleaching rate of copper. The findings in the current study highlight the practical importance of the availability of iron (and hence, iron content of wastes) for the successful development of a bioleaching process for e-waste and the potential for utilisation of pyrite as a suitable source of iron and sulphur in bioleaching of e-waste.

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1. Introduction

In recent years, the rapid development of technology has led to a drastic increase in diversity and consumption of electrical and electronic equipments with their reduced life span and concomitantly, generation of ever increasing amounts of end-of-life equipments, known as waste of electrical and electronic equipments (WEEE) or e-waste (EPA, 2008; Yazici et al., 2011a). WEEE is the fastest growing waste stream in the world. In the EU, about 8.3–9.1 million tonnes of WEEE (in 2005) were estimated to be generated and this figure are forecast to reach 12.3 million tonnes by 2020 with an annual growth rate of 2.5–2.7% (Huisman et al., 2007). It is also estimated that approximately 20–50 million tonnes of WEEE are globally generated (Huisman et al., 2007; UNEP, 2009). WEEE contains a variety of hazardous organic (chlorinated/brominated flame retardants) and inorganic (Hg, Pb, etc.) substances, which may cause some environmental problems when it is not properly managed (Robinson, 2009; Widmer et al., 2005; Yazici et al., 2010). On the other hand, WEEE can contain base (Cu, in particular) and precious metals (Au, Ag and Pd) in quantities even higher than the ores, which renders them as potentially an important secondary resource for these metals (Hagelüken, 2006; Huisman et al., 2007; Yazici et al., 2011a). Therefore, recycling of WEEE is of prime importance from both environmental and economic points of view as regulations have already been issued in many countries (EU, 2012; Terazono et al., 2006).

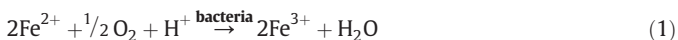
Traditional physical separation, hydrometallurgical and pyrometallurgical processes can be exploited for the recovery of contained metal values from WEEE (Cui and Forssberg, 2003; Cui and Zhang, 2008; Tuncuk et al., 2012; Yazici and Deveci, 2009). Pyrometallurgical processes are extensively used for the treatment of WEEE; albeit, they suffer from the requirement for high precious metals grade (Au, in particular) in feed, environmental concerns associated with off-gas/dust emissions and high cost of off-gas/dust treatment. Hydrometallurgical processes with their potential for the treatment of low grade WEEE and small scale applications have received particular interest in recent years (Tuncuk et al., 2012; UNEP, 2009). However, an innovative, cost-effective, environmentally friendly and effective process as alternative to pyrometallurgical processes has yet to be developed.

Biohydrometallurgical processes are often promoted as low cost and eco-friendly processes for the treatment of low-grade ores and wastes. They are essentially hydrometallurgical processes using microorganisms (i.e. bacteria, archaea and fungi) to enhance the dissolution of metals from ores, concentrates and wastes. In these processes, the exploitation of microorganisms is based on their inherent characteristics to oxidise/utilise inorganic and organic substrates so as to generate lixiviant for dissolution of metals (Deveci and Ball, 2010; Jain and Sharma, 2006). A variety of bacterial and fungal cultures have been used for bioleaching of metals from WEEE (Bas et al., 2012; Brandl et al., 2001; Chi et al., 2011; Choi et al., 2004; Ilyas et al., 2007). Notwithstanding this, iron oxidising acidophiles such as mesophilic *At. ferrooxidans* and *L. ferrooxidans*, and thermophilic *S. thermosulphidooxidans* have received the most interest (Lee and Pandey, 2012). These bacteria oxidise Fe(II)

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(Eq. (1)) under suitable conditions leading to the generation of Fe(III), which is a powerful oxidant with a reduction potential of 0.77 V for most sulphide minerals and metals (Nemati et al., 1998).

Since metals are present in native form and/or as alloys in e-waste e.g. printed circuit boards (PCBs), oxidative leaching conditions should be maintained for efficient extraction of base and precious metals. Ferric iron, which can be generated in-situ from the oxidation of ferrous iron by bacteria (Eq. (1)), is a suitable oxidising agent to leach copper from e-waste (Eq. (2)). The rate of bioleaching of copper from e-waste is apparently controlled intimately by the availability (i.e. initial concentration) and the rate of biooxidation of ferrous iron (i.e. the rate of generation of ferric iron) in the bioleaching environment. Many studies have already demonstrated the beneficial effect of external addition of Fe(II)/Fe(III) on the rate and extent of copper extraction (Choi et al., 2004; Lewis et al., 2011; Xiang et al., 2010; Yang et al., 2009; Zhu et al., 2011). Others have reported remarkably slow rate of metal extraction apparently due to the limited availability of soluble iron at the onset of bioleaching and/or low iron content of the e-waste sample used (Brandl et al., 2001; Ilyas et al., 2007, 2010; Willscher et al., 2007). Biooxidation of Fe(II) to Fe(III) is an acid consuming reaction (Eq. (1)) and the addition of acid is required to control pH (i.e. at < pH 1.8) and hence, the undesired precipitation of iron (Deveci et al., 2003). It can be inferred from these earlier studies that the external supply of iron and acid is required for efficient bioleaching of e-waste with low iron content, in particular. Recently, Ilyas et al. (2013) reported the use of FeS₂ and S⁰ (1% w/v) as additional energy source during bioleaching of electronic scrap using moderately thermophilic bacteria. They attributed the improved bioleaching efficiency to the partial compensation of acid consumption by S⁰ oxidation providing more suitable conditions for bacteria.



To date, studies have focused mainly on bioleaching of high grade e-waste such as personal computers and mobile phones. In this study, bioleaching of copper from low grade scrap TV circuit boards (STVB) with low iron content was investigated using a mixed mesophilic culture of acidophilic bacteria. Effects of initial concentration of iron (up to 8 g/L Fe(II)) and size of inoculum (10–50% v/v) on the rate and extent of copper extraction were studied. Furthermore, a novel approach was adopted for the bioleaching of STVBs in that the addition of pyrite to provide iron source and to reduce acid consumption in the bioleaching process was tested.

2. Experimental

2.1. E-waste and pyrite samples

An 80-kg sample of manufacturing scrap TV circuit boards (STVB) was obtained from an electronics company (Vestel Electronics in Manisa/Turkey). STVB was received after having been subjected to heat treatment for the removal of solder and recovery of many components for re-use at the manufacturing plant site. The sample as received was initially crushed to –3.35 mm in a rotary cutting shredder and then, ground to –250 μm in a two-stage grinding process using an Ultra Centrifugal Mill (Retsch ZM 200) (Fig. 1). The ground sample was riffled and packed into 250-g portions prior to use in the bioleaching experiments (Bas, 2012).

Chemical composition of STVB sample was determined by wet chemical analysis as shown in Table 1. Low content of precious metals of STVB renders it not a particularly suitable feedstock for pyrometallurgical processes. Earlier studies also demonstrated that physical

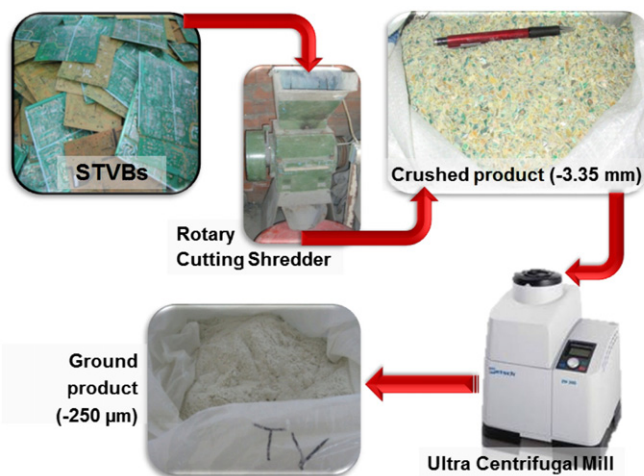


Fig. 1. An illustration of preparation of STVBs for bioleaching tests, the feed and products at each stage of size reduction.

separation of metals from the crushed product (–8 mm) was not effective with the unacceptably low metal recovery (Yazici et al., 2011b). The STVB sample contains 11.2% Cu with only 43 g/ton Fe, which is of practical importance for the development of a bioleaching process.

In view of the low iron content of STVBs (Table 1), the supplementary addition of pyrite (up to 50 g/L) as a source of iron and sulphur into the bioleaching media was tested. A pyrite concentrate (PyC) assaying 42.2% Fe, 0.6% Cu and 44.6% S (Table 1), which was obtained from Kure Copper Mine, Turkey was used. Consistent with its chemical composition, pyrite was identified to be the predominant phase in the concentrate.

2.2. Bacteria and growth media

A mixed culture of mesophilic bacteria, MES1 (*At. ferrooxidans*, *L. ferrooxidans*, *At. thiooxidans*), were used in this study (Bas, 2012; Deveci and Ball, 2010). The culture is routinely grown and maintained on pyritic materials (mill tailings or concentrate) (1–2% w/vol) using the growth media with a composition of (NH₄)₂SO₄–1.5 g/L, MgSO₄·7H₂O–0.5 g/L, KH₂PO₄–0.5 g/L, KCl–0.1 g/L. Prior to the bioleaching tests, the culture was transferred onto ferrous iron (200 mM Fe(II)) and successively subcultured (at pH 1.7, 35 °C and 170 rpm) to obtain an adapted and active bacterial population with a high capacity for iron oxidation. Bacteria grown on 200 mM Fe(II) were used in the bioleaching tests. The mixed culture was not further characterised prior to use in the bioleaching tests.

Table 1
Chemical composition of STVB and pyrite concentrate used in this study.

Metal	STVB	Pyrite concentrate (PyC)
Cu (%)	11.2	0.6
Fe (%)	0.0043	42.2
Zn (%)	0.15	0.20
Al (%)	0.30	0.40
Ca (%)	0.40	0.50
Co (%)	0.04	0.16
Ni (%)	0.02	0.004
S (%)	ND*	44.6
As (g/ton)	2.2	50
Cd (g/ton)	157	10
Cr (g/ton)	91	50
Au (g/ton)	0.14	ND*
Ag (g/ton)	48	6

* ND: not determined.

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