EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2021, 22(6), 79–84
https://doi.org/10.12912/27197050/141536
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Received: 2021.08.08
Accepted: 2021.09.03
Published: 2021.09.17

Metal Mobilisation from Obsolete PCB of Mobile Phones Using Chemolithotrophs

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ABSTRACT

Tech is ubiquitous and a major mushrooming stream of hazardous material into the environment produced from the obsolescence of electronic equipment. The successful commercial operations of bioleaching processes from ores are now finding urban mines to be its potential source of base metals and precious metals. Among the six categories of e-waste, mobile phones pose a significant challenge due to technological upgradation and short life span of these gadgets. Thus, this study was precisely projected towards the e-waste generated by mobile phones. The ICP-OES analysis of 0.5 mm particle size of e-waste revealed the presence of base metals Co < Mg < Pb < Zn < Ni < Al < Cu and precious metals Pt < Au. The analysis showed that among base metals Cu is present in the highest concentration i.e., 244.303 g/kg and gold is present in 1106.6 mg/kg. In the current study, the plausibility of bioleaching processes using chemolithotrophs (*Acidithiobacillus thiooxidans* and *Acidithiobacillus ferrooxidans*) for mobilisation of the metals from e-waste was investigated at variable pulp densities (0.5%, 1%, 1.5% and 2%). The results from the study indicated that the pure cultures of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* were able to abundantly leach out base and precious metals at 0.5% and 1% pulp densities of powdered e-waste. At 1% pulp density, *Acidithiobacillus ferrooxidans* leached 79% of Cu and at 0.5% Ni and Al were leached in 80% and 70% respectively. *Acidithiobacillus thiooxidans* at 0.5% pulp density leached out Co, Zn and Pb in 61.7%, 60.9%, and 49.8% respectively. Among precious metals at 1% pulp density *Acidithiobacillus ferrooxidans* leached out Au in 55% and *Acidithiobacillus thiooxidans* in 67%. These findings highlight the potential application of biomining for mobilization and extraction of metals from electronic waste.

Keywords: bioleaching, mobile phones, chemolithotrophs, pulp density, biomining

INTRODUCTION

Globally, electronic waste is a major growing concern (Kumar, 2017). Electronic waste, also known as e-waste, is the unwanted, non-functional, obsolete electrical and electronic equipment or gadgets that turn out to be scraps mongering worldwide. The exponential and unprecedented growth of e-waste is attributed towards enhancement in IT and communication sector. Further, the advent of technology is surging across the globe leading to heaps of obsolete electrical and electronic equipment worldwide. This is resulting in dramatic increase in the most hazardous waste stream. Moreover, most of these redundant electronic wastes have a significant economic worth (Ahamad, 2019). Electronic waste stream according to Statista, increases annually and in 2019 approximately 50 million metric tons were produced globally (Tiseo, 2020). It is expected that the electronic industry will reach $400 billion in 2022 from $69.6 billion in 2012 (Debnath, 2018). In the recent years, researchers, scientists and industries together with government authorities have blanned effective recycling strategies for metal recovery from e-waste (Akcil, 2015). According to TIME magazine, this waste stream is expected to turn into a torrent as the world upgrades to 5G, the next large step in wireless technology (Semuel 2019). According to Statistica, 50 million metric tons of e-waste was produced globally and further estimated it to reach 120 million metric tons till 2050 (Wang, 2019). The global appetite for latest electronic gadgets is increasing at an extraordinary rate with devasting impact on developing countries. China, Peru, Ghana, Nigeria, India and Pakistan are the leading largest end recipients gaining the electronic trash from developed countries. The financial benefits from e-waste have attracted the formal and informal sector for recycling of obsolete electronic and electrical equipment (EEE). According to Basel Action Network (BAN), these obsolete electronic wastes exported to developing countries are either smashed, burned or treated with harmful chemicals. The conventional pyrometallurgical and hydrometallurgical processes for metal extraction have a deleterious effect on the ecosystem. Desperate and reckless migrant workers are exposed to hazardous and noxious toxic metals like Pb, Cr and Hb (Seattle, 2019).

Among the categories of e-waste, mobile phone litterbugs are a major concern that is piling up exponentially. The global prevalence of supply and demand of the latest upgraded versions of mobile phones, short life span and obsession for the latest tempting models in the market are increasing the consumers' demand for mobile phones. Thus, this is further deterring the planet's health where increased obsolescence in mobile phone is increasing the illegal market handlers. Printed circuit boards (PCB) have attracted most attention for their richness in valuable metals as well as for hazardous metal content (Xiu, 2015). The printed circuit boards of mobile phones have a combination of metals, non-metals and hazardous substances. The percent composition of PCB of mobile phones is reported to be 40% metals, 30% ceramics and 30% plastic (Tenorio, 1997 and Solange, 2017). The metal content in PCBs includes Cu 10–20%, Pb 1–5%, Ni 1–3%, Fe 1–4% and precious metals like Ag, Au, Pt in the range of 0.3–0.4% (Huang, 2009, Lu, 2007 and Priya, 2017). The potential value of each scrap PCB varies mainly according to its size and the number of Au-plated connectors, Au pins, small capacitors, integrated circuit chips, and the surface of Au plates (Vermes, 2019). Hence, compared to gold mines, the Au content in e-waste is presumably considered to be higher (Natrajan, 2015). The conventional methods used for metal solubilisation leads to the emission of secondary toxic pollutants. Since bioleaching is an eco-friendly approach, much attention is thus diverted towards its application in e-waste metal mobilization. In addition, in last two decades, research studies revealed the potential use of microorganisms for solubilisation of metals from e-waste (Priya, 2017). Among all microorganisms, the most eligible and active bacterial genus for bioleaching processes is *Acidithiobacillus.* These are gram negative, non-spore forming rods which flourish well under aerobic conditions (Bosekar, 1997). Among them *Acidithiobacillus ferrooxidans* is a well-known and puissant mesophilic bacterium, which thrives at an optimal temperature of 28°C and an optimal pH of 1.5–2.5 (Baniasadi, 2019). Along with it, *Acidithiobacillus thiooxidans* is another sulphur-oxidising bacterium capable of metal mobilisation. Both of these are autotrophic chemolithotrophs which fix carbon dioxide and use inorganic energy sources (ferrous iron and reduced sulphur). Sulphuric acid is the main inorganic acid formed by these sulphur-oxidising microorganisms. These extreme acidophiles are able to survive under extreme acidic conditions (pH < 3.0) by maintaining their intracellular pH near neutral through pH adjustment strategies such as high cell membrane permeability to H^+ ions, proton pumping and cytoplasmic buffering (Zhoa, 2019). The present research aimed to evaluate the efficiency of pure cultures of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* to solubilise the selected metals at varying pulp densities.

MATERIALS AND METHODS

Metal characterization of PCB

The scrap mobile phones Printed Circuit Boards (PCB) were procured from authorised electronic waste recycler i.e., E-Parissara Private Limited, Bangalore. The obtained electronic scrap was shredded PCB which was further ground in Insmart Systems jaw crusher and sieved in series, with standard ASTM sieves of size 1.8, 1.6, 1.4 mm and 0.5 mm. Using FESEM/EDAX AMETAK the structural and elemental characterization was done.

For elemental analysis, the powdered PCB was acid digested in aqua regia. Metal analysis was performed using ICP-OES (Agilent Technologies-700 Series) at varying wavelengths (nm): Cu (324.754), Fe (259.940), Ni (229.592), Co (228.616), Pb (221.349), Zn (213.856), Cr (205.560), Al (167.079), Au (241.791), Pt (214.511). The elemental composition of PCB of mobile phones is reported in Table 01.

Microorganism and culture conditions

The chemolithotrophs used in bioleaching studies were *Acidithiobacillus ferrooxidans* (strain MCM B-90) and *Acidithiobacillus thiooxidans* (strain MCM B-160). The cultures were procured from Agharkar Research Institute, Pune, Maharashtra, India. *Acidithiobacillus ferrooxidans* was grown in Hi-media ATCC 2039 broth with pH 2.5 and *Acidithiobacillus thiooxidans* was grown in Hi-media Thiobacillus broth with pH 3.5. The pH was adjusted with sulfuric acid. The bioleaching experiments were conducted in triplicates. For leaching experiment, 10% pure inoculum of pure cultures with different pulp densities of powdered PCB were selected i.e., 0.5%, 1.0%, 1.5%, and 2.0%. Organisms were cultivated in 500 ml Erlenmeyer flasks with 100 ml of respective culture media and incubated at 28°C on a rotary shaker at 120 rpm condition. The pH was measured periodically and leached metals were analysed after 10 days of incubation period.

Table 1. Elemental composition of scrap PCB using ICP-OES method

Element	mg/Kg
Cu	244303
Fe	4452
Ni	18133
Co	69.8
Pb	1128
Zn	1747
Cr	40.5
Al	23353
Au	1106.6
Pt	0.28

RESULTS AND DISCUSSION

pH profile

The pH profile which also reflects the bacterial growth of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* on different pulp densities is shown in Figure 1 and Figure 2. The initial increase in pH at 1.5% and 2% pulp density can be related to the alkaline nature of the e-waste. Further, the decrease in pH can be comprehended with research findings of previous researchers (Brandl, 2001 and Ilyas, 2007). The reason for a decrease in pH can be related to the ferric ion hydrolysis in the aqueous solution (Mahdokht, 2020). Both organisms were able to grow at all pulp densities, although the higher metal concentration has affected the final pH values obtained. Thus, it can be implicated that as the concentration of electronic scrap material (esm) increases, certain toxicity due to high metal content is exhibited.

Metal mobilization

The bioleaching studies revealed that 0.5% and 1% pulp density showed maximum metal mobilisation. At scrap concentration of 0.5% pulp density *A. ferrooxidans* was able to leach out Ni and Al in 80% and 70%, respectively and Cu in 79% at 1% pulp density. At scrap concentration of 0.5% *A. thiooxidans* leached out Co, Zn, and Pb in 61.7%, 60.9% and 49.8% respectively. At 1% scrap concentration *A. thiooxidans* could leach out Fe and Cr in 74.8% and 49.8% respectively. Among precious metals, at 0.5% pulp density *A. ferrooxidans* leached Au & Pt by 44% in 19%

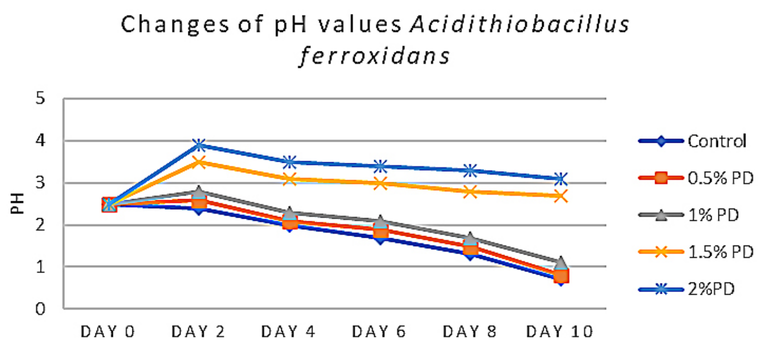

Figure 1. pH profile of *Acidithiobacillus ferrooxidans* at different pulp densities

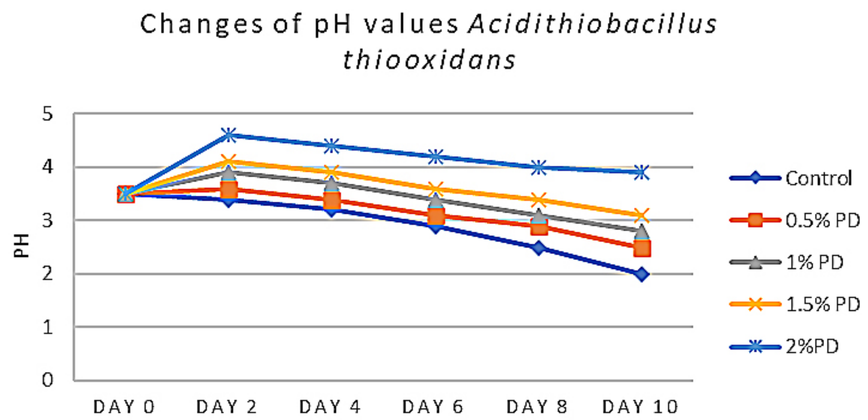

Figure 2. pH profile of *Acidithiobacillus thiooxidans* at different pulp densities

Figure 3. Mobilisation of Cu, Al, Ni, Zn, Fe, Co, Cr, Pb, Pt and Au at different pulp densities of powdered PCB by *A. ferrooxidans (Af)* and *A. thiooxidans (At)*. The incubation period was 10 days at 30° C. Bars represent mean values of triplicate experiments. A. Metal mobilization at 0.5% i.e., 5g L^{-1} pulp density of powdered PCB; B. Metal mobilisation at 1% i.e., 10g L^{-1} pulp density of powdered PCB; C. Metal mobilisation at 1.5% i.e., 15g L^{-1} pulp density of powdered PCB and D. Metal mobilisation at 2% i.e., 20g L^{-1} pulp density of powdered PCB

respectively. In turn, at 1% pulp density *Acidithiobacillus ferrooxidans* leached out Au in 55% and *Acidithiobacillus thiooxidans* in 67%. The results indicated that as the pulp density increased above 1%, there was a noticeable decline in metal leaching. This may be due to the toxicity and alkaline nature of powdered PCB which increases the pH as the amount of e-waste increases. Therefore, adaptation of chemolithotrophs to a higher concentration of e-waste can bring about significant leaching of base and precious metals. Thus, systematic investigation of biotic and abiotic factors affecting leaching capability of chemolithotrophs can be further studied.

CONCLUSIONS

Using chemolithotrophs, bioleaching can be a sustainable method for metal recovery from electronic waste. Biologically produced sulphuric acid mobilises the metal through proton attack and redoxolysis. From the results obtained, it can be indicated that the bioleaching rate is dependent on concentration of electronic waste. In order to leach out metals more efficiently, an optimised culture conditions like pulp density and inoculum level could give better yield. Moreover, adaptation studies, enhancing organism's tolerance to higher concentration of electronic feeds need to be focused. Consequently, these findings also reveal that the mixed culture of respective organisms could leach out metals more efficiently.

Acknowledgments

We appreciate Trans Thane Creek Hazardous Waste Management Association (TTCWMA) for providing laboratory facility to carry out ICP-OES analysis. Also, we extend our thanks to E-Parissara Private Limited, Bangalore for providing PCB of obsolete mobile phones.

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