BIORECOVERY OF METALS FROM WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) AND ITS TECHNO-ECONOMIC AND SUSTAINABILITY ASSESSMENT

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Abstract

Global waste electrical and electronic equipment WEEE generation reached 41.8 million tons in 2014, and forecasted to rise to 50 million tons in 2018 (Baldé *et al.*, 2015). In addition to the prevalence of toxic compounds, WEEE also contains valuable metals such as copper (Cu), gold (Au), aluminum (Al) and nickel (Ni). Discarded electric and electronic devices and particularly printed circuit boards (PCB) are a very promising secondary source of metals. Recovery of metals is conventionally carried out by pyrometallurgical and hydrometallurgical methods, which have their own drawbacks and limitations. To this end, we present the proof-of-concept of a novel technology to biologically treat and recover metals from WEEE. In this work, discarded PCB is characterized, a novel metal biorecovery technology is given, and its future techno-economic and environmental sustainability analysis is analyzed.

1. Methodology

Characterization of PCB has been carried out by digesting the ground waste material (<0.5 mm) in nitro-hydrochloric acid, in a microwave system. The concentrations of Cu, Fe, Al, and Au were analyzed by ICP-MS (Perkin Elmer, USA). Cu and Au are selected as metals of interest. Due to distinct chemical behavior of base and precious metals, a two-step leaching process is considered. In the first step, Cu is leached out using pure cultures of chemolithotrophic *Acidithiobacillus ferrivorans* (DSM 17398) and *Acidithiobacillus thiooxidans* (DSM 9463) and a constructed co-culture of the two microorganisms. In the subsequent step, Au is bioleached by pure cultures of *Pseudomonas putida* and *Pseudomonas fluorescence* that is grown in nutrient broth supplemented with glycine. For the techno-economic studies, three alternative case studies for chemical, biological and hybrid treatment of electronic waste for metals recovery are drafted. Two-step recovery of metals was simulated in industrial scale processes. Ex ante life cycle assessment methodology is used to use of their environmental sustainability was assessed.

2. Results and discussion

Results showed high concentrations of the metals (Cu 171.8 - 230.07 mg/gr, Au 0.022 – 0.307 mg/gr) in the discarded circuit boards from various devices (Table 1).

Table 1: Metal concentrations of discarded printed circuit boards(PCB)

	Desktops	Computer parts	Desktops without components	Laptops	Mobile phones
Cu	176.7 ±23.6	93.0 ±7.2	163.6 ±13.0	176.1 ±18.6	230.1 ±10.0
Fe	52.1 ±7.0	2.4 ±0.2	23.3 ±2.6	37.8 ±5.7	38.3 ±3.1
Al	36.0 ±1.6	15.4 ±4.1	19.4 ±6.6	19.8 ±2.4	10.3 ±4.3
Au	0.021 ±0.003	0.031 ±0.005	0.002 ±0.002	0.029 ±0.002	0.32 ±0.003

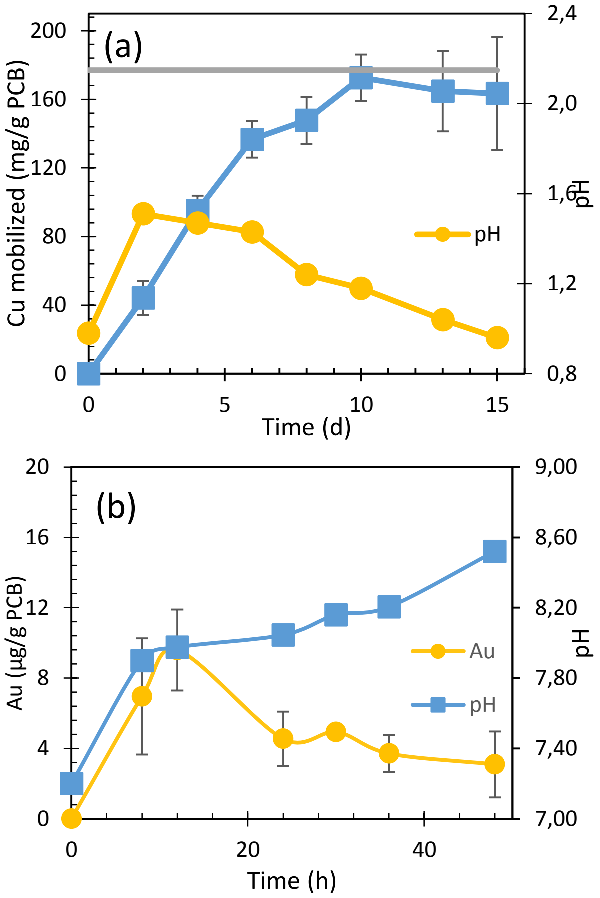

Figure 1: Bioleaching of (a) copper (Cu) and (b) gold (Au) from PCB.

Cu was bioleached from discarded circuit boards with a high (>98%) efficiency with mixture of A. ferrivorans and A. thiooxidans at 1% (w/v) pulp density in batch reactor (Figure 1a). Maximal Cu bioleaching efficiency was achieved at about 7 days. These results showed that bioleaching of Cu from waste PCB is feasible at ambient conditions with a mixture of iron- and sulfur-oxidizing acidophilic consortium. Gold (Au) was bioleached from discarded circuit boards at a (>44%) efficiency with Pseudomonas putida at 0.5% (w/v) pulp density in batch reactors (Figure 1b). Generated cyanide was decomposed by the bacteria. The techno-economic studies of the three alternative cases showed that the average value of metal recovery of 1 kg of discarded PCB is 11.83 EUR, and the metal recovery process is feasible with a future plant of 82,000 ton/year processing capacity. The potential revenues were calculated to be 5.03, 9.64 and, 9.26 EUR/kg board, respectively, for the biological, chemical and hybrid alternatives, due to difference in process efficiencies. Accordingly, the return of investment was 2.4, 4.2, and 5.1 years for biological, chemical and hybrid alternatives. Sustainability assessment revealed that biological treatment of base metals in acidophilic consortium is more advantageous than chemical leaching, however, in case of gold leaching, chemical leaching was more sustainable than biological leaching.

3. Conclusions

Using a two-step approach, copper and gold are removed from PCB with an efficiency of 98.4% and 44.0%, respectively. The pre-growth strategy contributed to maintain optimal bioleaching conditions and cell viability. Copper bioleaching with Acidithiobacillus ferrivorans and Acidithiobacillus thiooxidans was feasible at pH 1.0 - 1.6 and ambient temperature (23 ± 2°C). Gold bioleaching with Pseudomonas putida and Pseudomonas fluorescens was effective however the metal removal efficiency by biogenic cyanide is lower compared to chemical cyanide. There is need for further research aiming to enhance bacterial cyanide production, as well as increase the chemical stability of the free cyanide in solution. Techno-economic assessment showed that biological leaching of metals is slower thus less financially feasible than the conventional routes. Environmental sustainability assessment of the technology showed the hotspots of the technology. There is need to improve the environmental profile before the technology could be scale up for industrial application.

References

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