Sustainable recovery of pure copper from waste printed circuit boards

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Abstract

Nowadays, the rapid growth of electrical and electronic gadgets associated with their short life span is leading to a significant increase in the production of electronic and electric waste (e-waste). Printed circuit boards (PCBs) with copper as the main metal are the core part of e-waste and are considered a secondary source to recover copper. Among the different technologies, bioleaching is a green and sustainable process that uses microorganisms to produce essential leaching agents for metal solubilisation which is purified by the electrowinning process. This work aims to implement a cost-effective bioleaching approach in a continuous stirred tank reactor (CSTR) for the recovery of pure copper, paving the way for process scale-up.

Methods and Materials

Waste computer PCBs from ICT Reverse© were pre-processed by cutting and blending to reach a powder size of around 78 μm. A continuous culture experiment by the bacterium *Acidithiobacillus ferrooxidans* was performed in a stirred tank reactor (STR) at 30 ℃ and a rotation speed of 140 rpm in 9k medium, with the pH adjusted at 1.7 using sulphuric acid. After filtration to remove bacteria, the produced Fe^{3+} and PCB powder were introduced into the reactor and the copper rich solution and residue powder were removed. The study investigated the effects of hydraulic time, temperature, and pH on copper leaching. Electrowinning was employed to recover pure copper from the solution, with stirring at 500 rpm using a carbon electrode as the anode and a stainless-steel sheet as the cathode with a current density of 0.0168 A/cm^2.

Result and discussion

The results revealed that leaching kinetic was faster in a sample with pH adjustment compared to a sample without pH adjustment (pH~ 3) and complete leaching (100%) was achieved with pH adjustment, whereas only 80% of copper was leached in the absence of pH control as the addition of proton to the leaching solution helps regenerate Fe^{3+} (Fig. 1a). High temperature (40 ℃) favoured the process compared to room temperature, where the leaching rate did not exceed 50%, confirming the thermal role in metal dissolution thermodynamics and the kinetics of the chemical reactions and mass transports (diffusive and convective types) (Fig.1b). In samples with longer hydraulic residence time (HRT) a higher dissolution of copper was observed, with 76.68% dissolution rate at an HRT of 48 compared to 84% rate at an HRT of 96 h, facilitated by a longer contact of the leaching agent with the waste (Fig. 1c). Approximately 70.85% of the copper was recovered by the electrowinning after 8 h and the theoretical mass of copper was compared to determine the efficiency (Fig. 1d).

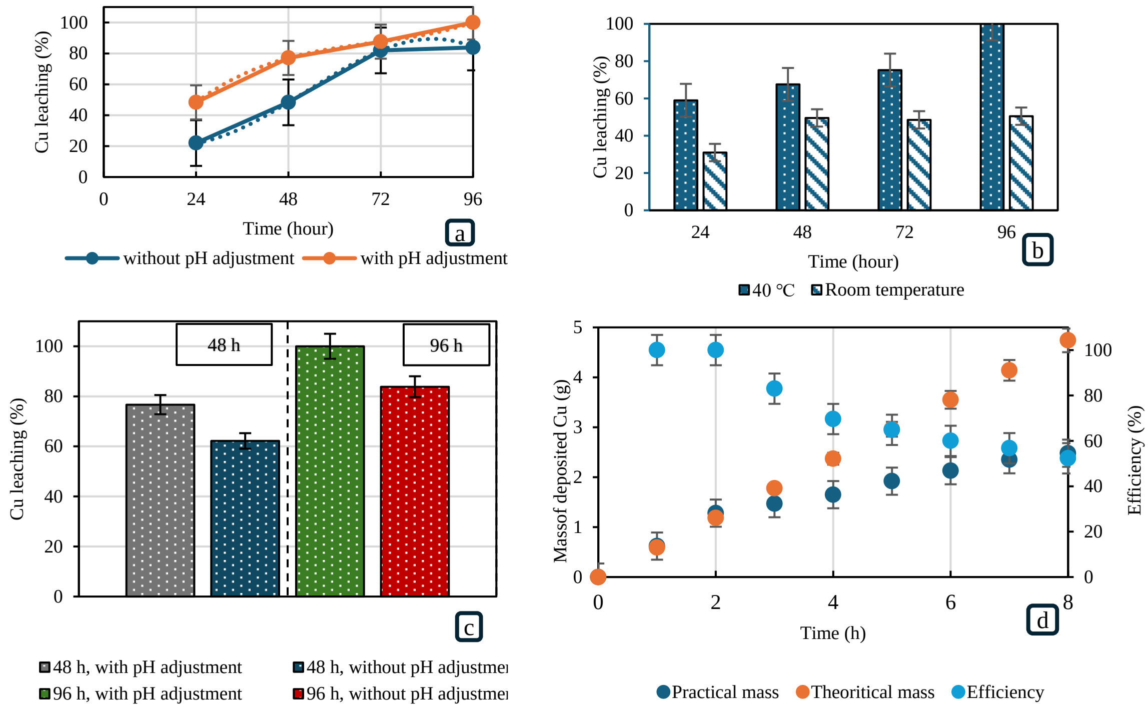

Fig. 1. (a-c) The effect of working parameters (pH, temperature and residence time) on copper leaching and (d) The mass of copper deposited on cathode surface (practical versus theoretical) and current efficiency over time.

Conclusion

This study represents bioleaching as a promising alternative to physico-chemical methods for metal recovery and improvement in handling high PCB loads (60 g/l) within the bioreactors for a practical achievement of a cost-effective and upscaled process. The parametric study highlighted the roles of pH, temperature and hydraulic residence time for a complete leaching of copper at reduced feed and energy costs. For the future study, the post-electrowinning solution containing Fe^{2+} will be recycled back to the bioreactor as a nutrient for the bacteria, thereby reducing material cost.

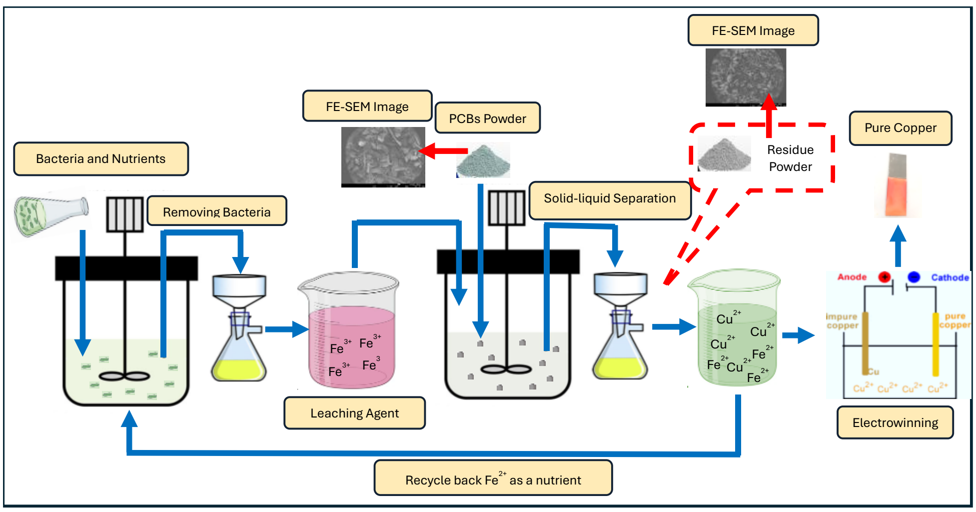

Figure. 2. Flowsheet of the process