Hydrometallurgical recovery of valuable metals from printed circuit boards of obsolete mobile phones

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By

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Chapter 4

MAJOR CONCLUSIONS AND SCOPE FOR FUTURE WORK

4. Major conclusions and scope for future work

4.1. Major conclusions of the present work

Growing societal and environmental awareness of the current (often illegal) practice in collecting and reprocessing waste electronics, combined with economic drivers, will lead to greater regulation in this industry and here the substantial body of academic literature will play an instrumental part in providing routes suitable for industrial scale-up that are based on sustainable chemistry principles. Current industrial processes rely heavily on pyrometallurgy, where the high throughput, minimal pre-treatment steps, combined with ability to handle heterogeneous material, render this economically attractive. While highly energy-intensive, its reliance on fossil fuels can be partially offset by using the plastic content of PCBs as fuel. Even so, substantial challenges remain in minimising the pollution generated through incinerating plastics. Hydro- and bio hydrometallurgy offer lower capital investment routes which, along with flexibility of scale, are attractive options for both developed and developing countries alike, provided they can compete with the economy of scale offered by pyrometallurgy, deal with the challenge of the highly complex feed stream, and limit the discharge of organic chemicals into the environment. With the potential to process low-grade material cheaply and under mild conditions, these routes are likely to make a positive impact, although life-cycle analyses would be required to fully appreciate their benefits or otherwise. However, it is clear that recovering valuable metals like gold from discarded household items such as mobile phones, is a compelling and growing field, with many promising avenues arising for sustainable chemical processes.

The present work demonstrated a metal leaching process that selectively dissolves copper and nickel from delaminated WPCBs to leave a gold-rich solid residue for the subsequent recovery of gold. Nitric acid was shown to offer superior leaching performance over sulfuric acid, and optimal conditions for the selective leaching of copper and nickel were achieved. Importantly, no gold was dissolved in the stage-1 leaching. Halide leaching at acidic conditions was shown higher leaching performance at optimal conditions for the selective leaching of gold.

The work has been extended to the selective recovery of copper and nickel from stage-1 leach solution and selective recovery of gold from stage-2 leach solution. This has shown that the use of the industrial extractant ACORGA M5640 is efficient for the quantitative recovery of copper and nickel from stage-1 leach liquor. As expected, the extraction of copper and nickel are pH dependent, with maximum extraction observed at optimized parameters. The extracted copper and nickel ions can be readily stripped, with maximum recovery observed for 4 M sulfuric acid (copper) and 0.5 M hydrochloric acid or 1.0 M nitric acid (nickel). The extraction efficiency of a recycled extractant layer after 5 cycles was performed to a similar standard as a fresh organic solution, with a slight volume loss attributed to phase separation. The separation of other minor elements (Cd, Pb, Sn and Cu) from the raffinate of nickel SX stage was also accomplished by adding zinc powder through cementation. The XRD analysis of separated residue proved the formation of impurities as complex precipitates. An organic tertiary amide was shown effective recovery of gold from stage-2 leach solution. The separation of silver from the raffinate of gold SX stage was also accomplished by adding copper powder through cementation

Recovery of elemental copper, nickel and zinc from pure solutions via electrowinning would be a well-established next step [206], whereas gold solutions could be subjected to standard reduction processes for the isolation of metallic gold or could be used to synthesize nanoparticles or catalysts to potentially increase the economic value [196]–[199].

Design of Experiment analysis validated the experimental data with the quantitative recovery of copper and nickel obtained at 190 min, 2.92 M nitric acid and 490 rpm stirring speed. In addition to the quadratic, 2FI model equations, fit statistics were also studied for the experimental conditions. The new optimization method RSM not only saves experimental time but also minimizes the use, and loss of chemicals inherent to conventional experimental processes. Kinetic studies show that the activation energies calculated for copper and nickel dissolution are within the expected range for a chemically controlled dissolution model.

Importantly, the leaching process optimized in this section avoids the need for high temperatures and reduces energy consumption and effluent generation, leading to the cleaner processing of obsolete mobile phone PCBs for the sequential separation of valuable metals, i.e. copper, nickel, zinc, gold and silver.

4.2. Scope for future work

In this thesis, the sequential separation of copper, nickel, gold, silver and zinc were observed using two-stage leaching, solvent extraction and cementation processes. Optimization of parameters in each stage was also investigated. The presence of WPCB components, non-metallic fraction, selection of a particular ligand leading to the vast scope of future work. Based on the present study carried out in this work the following future work suggestions may be proposed.

- Isolation of the refined metals as solids under sustainable boundaries is required.
- Recovery of minor elements and acid values from the raffinate of nickel SX stage.
- Recycling of separated solder fraction, batteries and other electronic components of obsolete mobile phones.
- A novel process development to recycle non-metal fraction from waste mobile phone printed circuit boards.
- Removal of components by hydrometallurgical route.
- Effective utilization of separated resin after delamination
- NMR study of the organic compounds during metal-ion separation
- Further refinement of the chemistry, including solvent choice, acid and reagent recycling, pH modulation, and isolation of the refined metals as solids under strict sustainability boundaries is required.
- An assessment of the materials balance and economic feasibility would also be the subject of future work.