Recovery of Metals from Waste Printed Circuit Boards Using Low-Temperature Ammonium Chloride Roasting

This study focused on the development of an effective and environment-friendly method to extract valuable metals from waste printed circuit boards (PCBs) using low-temperature solid-state chlorination followed by the water/HCl leaching method. Low-temperature roasting methods have several advantages over traditional hydrometallurgical and pyrometallurgical processes. High amount of metals can be recovered using this technique with high selectivity, low energy consumption, and low cost. In the present work, both chemical and thermal pre-treatment was used to process the polymeric fraction. Dimethyl formamide (DMF) was used in chemical pre-treatment to dissolve the brominated epoxy resin (BER) from PCBs surface. More than 97% of the BER was separated using DMF at 140 °C. Similarly, through thermal pre-treatment, the polymeric fraction of the shredded PCBs was converted into oil and combustible gases. However, it was observed that the thermal pre-treatment method has more advantages compared to chemical pre-treatment. The yield of solid residuals through thermal pre-treatment was observed to be 77 wt.% solid residues, 5 wt.% liquid, and 18 wt.% gas under the optimized process condition of 500 °C temperature and 30 min of pyrolysis time. The metal-rich pyrolysis residue (T-PCBs) was roasted in presence of NH_4Cl as a chlorinating agent to recover metals. The effect of process parameters like temperature, NH_4Cl dose, and time was investigated to optimize the roasting process. Ammonium chloride at higher temperatures breaks into HCl and NH_3, among which HCl reacts with metals to form metal chlorides. After completion of the chlorination reaction, the obtained residue was allowed to cool down and subsequently leached with a suitable solvent. Herein, water was used as a solvent for efficient extraction of base metals, whereas HCl solution was used for extraction of base as well as precious metals. Characterization techniques such as XRD and FESEM-EDS provided evidence for the successful conversion of metal into metal chlorides. This proposed method resulted in the extraction of 93% Cu, 100% Ni, 100% Zn, and 100% Pb using the water leaching technique when T-PCBs was chlorinated at 300 °C for 4 h with NH_4Cl dose of 3 g/g. Similarly, 98% Cu, 86% Ag, and 76% Au were extracted using HCl when T-PCBs was chlorinated at 260 °C for 2.5 h with NH_4Cl dose of 2 g/g. Ultimately, cementation methods were employed for individual separation of metals from leached solution. Further, a three-step cementation technique was employed for the separation of Au, Ag, and Cu using Ag, Cu, and Fe as sacrificial metals, respectively. Finally, all the reagents used in the process were recovered in the form of NH_4Cl and $Fe(OH)_2$. Overall, this study demonstrated that low-temperature solid-

state chlorination could represent a promising approach for the recovery of metals from waste PCBs using a closed-loop process.