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# A combination of hydrometallurgical and pyrometallurgical processes for efficient recovery of group 11 (Cu, Au, and Ag) from WPCBs

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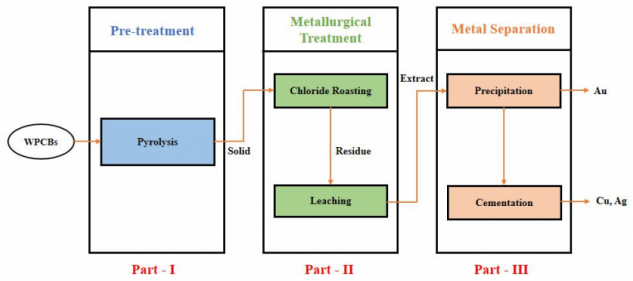
## PURPOSE OF THE ABSTRACT

Recently, e-waste management is becoming a global issue due to its high rate of generation, hazardous constituent, low recycling rate, and high intrinsic values. E-waste contains a variety of metals, including base metals (Cu, Ni, Zn, Al, Fe, Pd, Sn), precious metals (Au, Ag, Pd, Pt), and rare earth metals (Y, Eu, Ce, Gd, La) [1,2]. Out of all these metals, group 11 metals (Cu, Au, and Ag) are cumulatively worth ~ 53% of the total value of e-waste; however, the combined weight of these metals is a mere ~ 5% of the total e-waste [3]. The concentrations of Cu, Au, and Ag are rich in waste printed circuit boards (WPCBs) compared to other components of e-waste. PCBs are extensively used in various areas of electric and electronic equipment and consist of 6% of the total amount of e-waste generated every year. Therefore, espying at the market value of the group 11 metals, recovery of these metals are of greater interest from high-grade e-waste such as WPCBs. The existing popular routes for recycling metals from WPCBs are mainly hydrometallurgical and pyrometallurgical processes and the metal recovery operations mostly take place in a multistep mode, which may include recovery of base metals, precious metals, or both [4]. Currently, strong mineral acids accompanying a suitable oxidant are preferred for the extraction of base metals from WPCBs. Additionally, cyanide leaching, thiosulphate leaching, and thiourea leaching are reported to be mostly used for the extraction of precious metals. Similarly, pyrometallurgical processes such as smelting, roasting, incineration have been extensively used for the recovery of metals from WPCBs. Presently, the generation of toxic effluents, high lixiviant consumption, hazardous emissions, and high energy consumptions are major hiccups in hydrometallurgical and pyrometallurgical processes [5].

Herein, we developed an environment-friendly closed-loop process for recovery of group 11 metals from waste WPCBs using NH4Cl roasting, which operates in a low-temperature range compared to conventional pyrometallurgy processes. Low-temperature roasting methods have several advantages over traditional hydrometallurgical and pyrometallurgical processes. The high amount of metals can be recovered using this technique with high selectivity, low energy consumption, and low cost. Initially, before the chloride roasting process, pyrolysis of WPCBs was done to convert a polymeric fraction into oil and gases. Therefore, to avoid the emission of toxic gases during the roasting process, pyrolysis of WPCBs was done to get rid of flame retardants and to convert polymeric fractions into oil and gas. Thereafter, the calculated amount of chlorinating agent was thoroughly mixed with pyrolyzed WPCBs and roasted in a heating chamber. NH4Cl at higher temperatures breaks into HCl and NH3, among which HCl reacts with metals to form metal chlorides. Subsequently, a suitable environment-friendly solvent was used for the efficient dissolution of metals. The flowsheet of the process is shown in Fig. 1. Various process parameters such as roasting temperature, time, chlorinating agent dosage, and

concentration of solvent were varied to optimize the process. The effect of roasting temperature on the recovery of metals is shown in Fig. 2. It can be seen that with an increase in temperature up to 260 °C the extraction efficiency of Cu, Au and Ag increases. Subsequently, there is no further increase in extraction yield, which confirms 260 °C as optimum temperature for the roasting process. Approximately, 97% of Cu, 85% of Ag, and 76% of Au were extracted by varying temperatures. After the successful dissolution of metal chlorides, a combination of precipitation and cementation methods was used to separate out Cu, Au, and Ag from leached solution.

## FIGURES



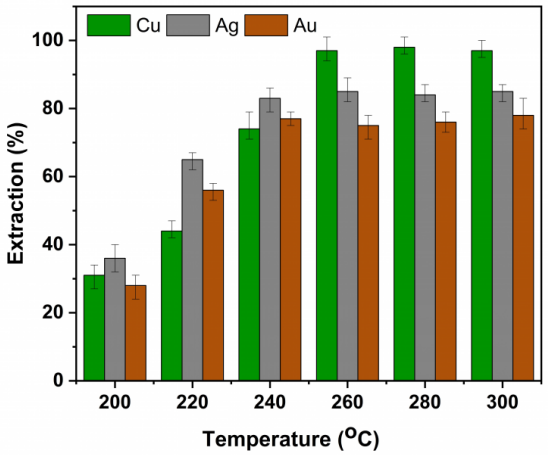




**FIGURE 1**
Flowsheet of the process
Fig. 1

**FIGURE 2**
Effect of temperature on recovery of Cu, Au, and Ag
Fig. 2


## KEYWORDS
Low-temperature roasting | Leaching | Environment-friendly | Metal separation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