Preface

In the present era of rapid development in technology, the growth of sophisticated instruments is lucidly visible. Rapid advancement in technology on even the smallest equipment has led to the decrease in the life of the electrical and electronic equipment (EEE). On one front, the demand for better electronic equipment and gadget shows no sign of abating, whereas on the other side, e-waste generation has drastically increased. The world production of e- waste was 62.0 MT in the year 2022 with annual growth of 3–5%. Being caught up by the growth of consumers' base and increased supply of greater variety of such WEEEs, the pile up of the e-waste becomes the spotlight for the researchers across the globe to handle it properly.

The e-waste generated all over the world has around 3% fraction accounted as waste printed circuit boards (WPCBs). WPCBs contain metals (40%); base metals (copper, iron, tin, and zinc), precious metals (platinum, gold, silver), and hazardous metals (cadmium, lead, and mercury) along with 30% polymers (polystyrene (PS), and epoxies with halogenated flame retardants (HFRs)), 30% ceramics (SiO_2, Al_2O_3, etc.). Therefore, the recycling of waste PCBs is very essential for recovering these metals, maintaining the circular economy, and also for protecting our environment.

The existing hydrometallurgical methods are mainly utilized for the recovery of copper, gold, silver. Though, many metals such as nickel, zinc etc. posing contaminations to these recovered metals. This work is a complementary method to make it possible to remove these contaminations for the complete recovery of metals with high purity. Therefore, the present work entails applying Polymer Inclusion Membrane (PIMs) to complement a distinct hydrometallurgical route of electronic waste (e-waste) recycling to recover trace metals otherwise ignored.

Additionally, this work also focuses on ultrasonic pre-treatment technique for the separation of metallic fractions from milled WPCBs. The limitations such as higher working temperature, longer duration for separating metallic fractions, relatively costly, and generation of fume or toxic gases during existing pretreatment route of WPCBs promote working on newer environmental and cost friendly route to make recycling of WPCBs viable at industrial scale. The present study was therefore undertaken initially to separate metallic fractions from the WPCBs by some greener route. Therefore, direct ultra-sonication of hammer milled WPCBs was done for separating metal rich powder. 99.30% of WPCBs were milled within 7 min at optimized feed rate ($3kg.h^{-1}$). The proposed pre-treatment route doesn't involve any organic or toxic solvent to separate the metallic fractions. Further, hydrometallurgical route (nitric acid leaching in first stage and sodium bromide in acidic conditions in second stage) has been applied for the metal ions recovery from the metallic powder. Our goal was therefore to optimize the leaching conditions that would facilitate a two-stage metal separation process, with the predominant base metals separated first and precious metals second. Hence, Response Surface Methodology (RSM), a statistical modelling technique to study the effect of parameter optimization have been used to optimize the leaching parameters. 98.96% and 99.50% of copper and nickel were leached out with 3.5 M HNO_3 from the ultrasonically cleaned metallic fractions at optimized parameters; time:180 min; temp: 30 $^{\circ}$C; stirring speed: 500 rpm; pulp density: 50 g/L.

Further, polymer inclusion membrane route has been used for recovery of metal ions from the leach liquor. Therefore, two newer kind of polymer inclusion membrane containing 5-nonylsalicylaldoxime (ACORGA M5640) and tetra butyl ammonium nitrate (TBAN) carrier have been synthesized and characterized to check its possibility to be used it in metal purification from the WPCBs leach liquor. The possible challenges associated with membrane fabrication have also been studied and highlighted.

50% polyvinyl chloride (PVC)/ 50% (ACORGAM5640) PIMs have been used for the recovery of nickel from the raffinate of solvent extraction stage. Effect of carrier concentration of carrier, pH on nickel recovery on nickel recovery, concentration of stripping agent etc. have been studied thoroughly. Similarly, the gold recovery from second stage leach liquor was done using cellulose triacetate/TBAN (50-50%) based PIMs. The effect of carrier concentration, effect of stripping agents and transport studies have been performed to check the feasibility of this route. 99.77% nickel was selectively recovered from SX raffinate using PIMs containing 50% of ACORGA M5640 at the optimized parameters; pH of feed phase; 7.5, strip phase;1M HNO_3. 99.35% gold was selectively recovered from stage-2 leach liquor using PIMs containing 50% of TBAN at the optimized parameters; pH of feed phase; 0.75, strip phase;1M NaOH. The stability and extraction efficiency of ACORGA M5640 and TBAN based PIMs were found constant up to seventh cycle, and sixth cycle respectively. This work demonstrated the feasibility of PIMs for the selective and quantitative nickel and gold separation from the WPCBs leach liquor.

The proposed work is categorized into 7 chapters followed by scope of future work, references, and publications details are presented. The background of electronic waste, waste printed circuit boards and its recycling, polymer inclusion membranes and a detailed literature survey is presented in **Chapter 1.** Subsequently, **Chapter 2** describes in detail about various materials used and methods employed for synthesis of PIMs and recovery of target metals. The results and discussion of this study is extended into four chapters from **Chapter 3-6**. Finally, the major conclusion of this research work is given in **Chapter 7**.