Chapter- 4

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The tremendous rise in e-waste generation demands the development of an efficient recycling technology to claim the recovery of valuables present. In view of this, several thermal and hydrometallurgical techniques have been investigated by the researchers. Both these processes exhibit certain limitations that restrict their commercial applicability. A literature survey showed that Halogenated Epoxy Resin (HER) plays a key role in eco-friendly and economical recycling of WPCBs. The HER content forms toxic emission during thermal processing of WPCBs. Further, during hydrometallurgical processing, HER envelops the metal values which prevails the attack of acids and results in low recovery of metal and large effluent generation.

Present work reports a cost-effective and efficient technique for the dissolution of HER in solvent *dimethylacetamide* (DMA) and *dimethylformamide* (DMF). Dissolution of HER delaminates WPCBs and liberates metal values thus, need of tedious mechanical processing techniques is minimized. Liberation of metals also ensures that they are completely exposed to lixivant and thus better recovery may be expected.

The investigation showed that both solvents (DMA and DMF) readily dissolves the HER and results in the delamination of WPCBs. Effect variation of parameters showed that dissolution of HER increases with a rise in temperature and WPCB:solvent (w/v) ratios. Further, HER dissolution is found to be more prominent for relatively smaller size WPCBs. The studies showed that HER dissolution significantly rises once the temperature is higher than Glass Transition Temperature (T_g). This may be attributed to the reversible breakage of *Van der Walls'* bond of HER chain above T_g. The optimized parameters for the HER dissolution were found to be different in both solvent systems.

Thus, comparative study of the dissolution of HER under similar parameters has been carried out by using both solvents. Investigations showed that solvent DMA is relatively better. The chemical analysis of metal laminates obtained after dissolution of HER by DMF and DMA showed the presence of ~ 80% and 55% copper. It indicates that even after the liberation of metal laminates, significant HER is sticking to laminates in case of DMF. It has also been found that both solvents are completely recyclable after usage and exert minimal loss and negligible drop in the resin dissolution capability after recycling. The dissolved HER is also recoverable as a residue and thus, it may be disposed off safely.

The investigations have been extended to understand the mechanism of dissolution of HER in solvent DMA. The studies revealed that during the contact of DMA with WPCBs, hydrogen bond formation between the carbonyl moiety of DMA and hydroxyl moiety of HER takes place. This phenomenon has been found responsible for the dissolution of HER in solvent. In these studies, WPCBs of size 1 and 2.25 cm^2 have been used. In order to reduce the efforts in chopping of WPCBs and energy consumption, the large size WPCBs have also been treated with solvent DMA. The results showed that progressive increase in the size of WPCB requires longer processing times.

The effect of the DMA treatment on the leachability of copper has also been investigated by dissolving copper into sulphuric acid solution along with oxidants. To compare the leachability of copper from conventionally processed WPCBs, hammer milling experiments have also been performed. The processing parameters of the hammer mill have been optimized and it has been found that feed is quickly crushed to

fine size within 7 min time. After the milling, sieve analysis has been carried out and results revealed that +0.15 mm size WPCBs comprise more than 80% of the original copper content. The copper content of the hammer milled WPCBs (-1 mm) can be easily enriched to two times (~ 43 wt%) of original values by collecting the +0.15 mm size particles.

The leachability test of WPCBs obtained by hammer mill route and DMA treatment route showed that copper may be easily leached out after DMA treatment. DMA treatment results in ~98% copper recovery.

The present work thus reports a cost-effective and efficient process for the most successful liberation of metallic values from the WPCBs. At the same time, it also offers a relatively cleaner, less effluent generating and eco-friendly alternative to the conventional mechanical processing technique.

4.1 Suggestions for future work

In this thesis, the successful delamination of WPCBs by using organic solvent DMA has been investigated. The effect of the solvent treatment on the leachability of copper has also been investigated. The presence of other metallic values and the nonmetallic material of the WPCBs provide a vast scope for future work which can be carried out with different objectives. Based on the present studies carried out in this dissertation the following future work suggestion may be proposed-

- Investigation to study the effect of hydrogen/reducing gas on the composition of pyrolysis oil and gases.
- To study the effect of aspect ratio of WPCBs on the dissolution of HER
- Dissolution of HER by using synergistic solvent system of DMF and DMA
- Investigation of effect of pressure on the dissolution of HER in solvent system
- Post leaching recovery of copper to recover it in metallic or useful compound form
- Study of kinetics of leaching of copper from WPCBs and estimation of activation energy
- The techno-economic justification of proposed technique in order to investigate the actual economy of process
- Scale-up study of the proposed process to study the effect of various other constraints and limitation
- Development of mathematical models and simulations of the investigated process and their validation

Apart from these aspects, pyrometallurgical processing of the 'solvent treated WPCBs' may be performed and qualitative studies on the emissions may be carried out. Although a large number of investigations have been carried out in the field of WPCBs recycling, many possibilities still exist to explore the eco-friendly recycling.