

Recycling E-waste Metals and Polymers for Recovery of Value-Added Materials

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Electronic waste (e-waste) is one of the fastest increasing waste streams worldwide due to unprecedented growth of the electronics industry, rapid obsolescence and subsequent disposal of electronic devices. Printed circuit boards (PCBs), the central component of electronic devices, are highly complex. PCBs are an important resource of metals, and contain substantial amounts of copper, tin, lead and precious metals in concentrations considerably higher than in their corresponding ores. The high value and limited reserves of minerals containing these metals makes their urban mining from waste PCBs very attractive. However, these also contain significant quantities of hazardous and toxic materials, which can result in high levels of pollution when such waste is landfilled or processed inappropriately.

The aim of this project was to investigate the recycling of electronic waste at high temperatures towards the recovery of metals and other valuable materials, with specific focus on the extraction of copper from waste PCBs. Phase separation behaviour of various components under inert atmosphere and loss of metals in the polymeric/ceramic residue was also investigated, aimed at maximising the recovery of materials, while generating minimal secondary by-products and toxic emissions during the recycling process.

These objectives were successfully achieved. Key findings are described below:

1. Investigations on the recovery of copper from waste PCBs under inert atmosphere at high temperatures

There were two key features of this investigation, namely the use of an inert atmosphere and high temperatures that were generally above the melting point of the main metallic constituent copper. This investigation has shown that these conditions led to the separation of solid residues in two clearly-formed phases: the metallic phase and the carbonaceous/slag phase. The metallic phase was found to be in the form of red and white droplets. Analysis of red droplets showed that these were predominantly copper, but also contained tin and lead in small concentrations, while the white droplets were formed mainly of tin and lead, with smaller proportions of copper. The phase behaviour of tin and lead plays an important role in enhancing copper purity, as these metals tend to separate from copper upon cooling to room temperature. This study has led to the formation of a copper rich metallic phase (~83 wt.% - ~92 wt.%) from waste PCBs.

These findings have been published in two journal papers:

Cayumil R, Khanna R, Ikram-UI-Haq M, Rajarao R, Hill A and Sahajwalla V (2014) "Generation of copper rich metallic phases from waste printed circuit boards" *Waste Management* Vol. 34(10), pp. 1783-1792.

Khanna R, Cayumil R, Mukherjee PS and Sahajwalla V (2014) "A novel recycling approach for transforming waste printed circuit boards into a material resource" *Procedia Environmental Sciences* ed. L. Beesley Vol. 21, pp. 42-54. International Conference on Urban Environmental Pollution, Beijing, China Nov. 17-20, 2013.

2. Studies on the recovery of carbon resources from waste PCBs during high temperature pyrolysis

High temperature pyrolysis of waste PCBs under inert conditions also resulted in the generation of a carbon rich/slag residue. Very limited affinity between carbon and copper led to a clear separation of these two phases. The formation of slag was due to the presence of refractory oxides in waste PCBs, and after the heat treatment these elements got separated from the metallic phase due to their poor wettability and high stability as oxides at the operating temperatures 800-1350 °C. The use of argon as a flowing gas prevented the combustion of carbons present in polymers, minimising the loss of carbon in the gaseous fraction. A significant proportion of solid carbon remained stable within the non-metallic product. Carbon recovery of 32 wt. % was achieved at 1150 °C in polymer rich PCBs; this is amongst the highest levels achieved in similar investigations on polymeric waste. Negligible quantities of metals were present in the residual carbonaceous/slag phases obtained at temperatures \geq 1150 °C.

This study has shown that significant carbonaceous resources could be produced from the recycling of waste PCBs. Carbons produced during waste PCB recycling can find application as a valuable carbon resource.

This research has been published:

Sahajwalla V, Cayumil R, Khanna R, Ikram-ul-Haq M, Rajarao R, Mukherjee PS and Hill A (2015) "Recycling polymer rich waste printed circuit boards at high temperatures: Recovery of value-added carbon resources" *Journal of Sustainable Metallurgy*, Vol. 1, pp. 75-84.

Outcomes and impact of this investigation

The generation of copper rich metallic phases and a carbon rich fraction has demonstrated the successful use of high temperature pyrolysis for the recovery of valuable materials waste circuit boards. This process has effectively concentrated copper into small droplets and significantly reduced the volume of material for further processing and management.

This study has shown that recycling of waste PCBs under controlled conditions (800 °C – 1350 °C, inert conditions) would result in a significant recovery of valuable metals and carbons. This approach also produced minimal level of secondary wastes as well. These results have the potential to make a positive impact on the environment through effective waste management of electronic waste and resource recovery.