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Greener approach for the extraction of copper metal from electronic waste

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A R T I C L E I N F O

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A B S T R A C T

Technology innovations resulted into a major move from agricultural to industrial economy in last few decades. Consequently, generation of waste electronic and electrical equipments (WEEE) has been increased at a significant rate. WEEE contain large amount of precious and heavy metals and therefore, can be considered a potential secondary resource to overcome the scarcity of metals. Also, presence of these metals may affect the ecosystem due to lack of adequate management of WEEE. Building upon our previous experimental investigations for metal extraction from spent catalyst, present study explores the concept of green technology for WEEE management. Efforts have been made to recover base metal from a printed circuit board using eco-friendly chelation technology and results were compared with the conventional acid leaching method. 83.8% recovery of copper metal was achieved using chelation technology whereas only 27% could be recovered using acid leaching method in absence of any oxidant at optimum reaction conditions. Various characterization studies (energy dispersive X-ray analysis, scanning electron microscopy, X-ray diffraction, inductive coupled plasma spectrophotometry) of Printed Circuit Board (PCB) and residues were performed for qualitative and quantitative analysis of samples. Significant metal extraction, more than 96% recovery of chelating agent, recycling of reactant in next chelation cycle and nearly zero discharge to the environment are the major advantages of the proposed green process which articulate the transcendency of chelation technology over other conventional approaches. Kinetic investigation suggests diffusion controlled process as the rate determining step for the chelate assisted recovery of copper from WEEE with activation energy of 22 kJ/mol.

1. Introduction

Environmental management of hazardous wastes has become a major concern across the globe due to uncontrolled dumping of hazardous wastes into ecosystem in a cavalier manner. Significant potential risks associated with these hazardous wastes to the ecosystem are increasingly recognized. Nearly, 1.3 billion tonnes (1.2 kg/capita/day) of waste are generated every year across the globe (Hoornweg and Bhada-Tata, 2012), which will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of solid waste (2.2 billion tonnes per year) by the year 2025. Globally, solid waste management costs are also estimated to increase from today's annual $205.4 billion to about $375.5 billion in 2025. Developing countries such as China and India face a rapidly increasing amount of solid waste, from domestic generation and illegal imports. In addition, the lack of national regulation and/or lax enforcement of existing laws are promoting the growth of a semi-formal or informal economy in industrializing countries. Improperly managed solid waste poses hazardous effects on human health and the environment. Uncontrolled dumping and improper waste handling may cause water contamination, increasing possibilities of flooding due to blocked drainage canals, greenhouse gas emission and consequently climate changes. Therefore, a strong need is felt to adapt the green innovative approaches for minimizing the global environmental impacts of solid wastes.

1.1. Greening the 'Waste'

This paper deals with the concept of "Greening the waste" which refers to a shift from less-preferred waste treatment (acid/alkali leaching, pyrometallurgical methods) and disposal methods (incineration, landfilling) toward greener technologies following the "Four R's" i.e. Reduce, Reuse and Recycle and Recovery. "Greening the waste" strategy is to move upstream in the waste management hierarchy as shown in Fig. 1, based on the internationally recognized approach of Integrated Solid Waste Management (ISWM) (ISWM, 2011). This concept includes

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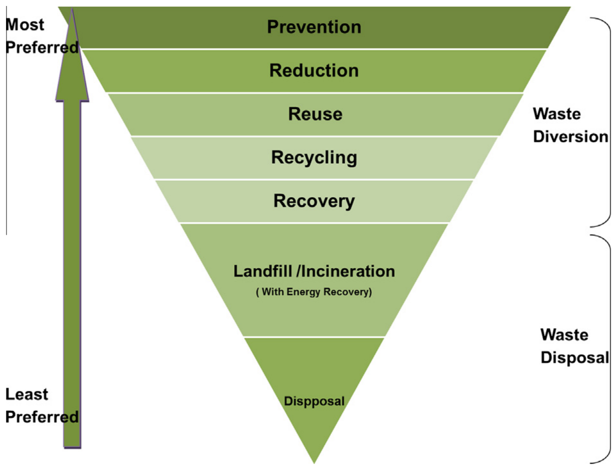

Fig. 1. Waste management hierarchy.

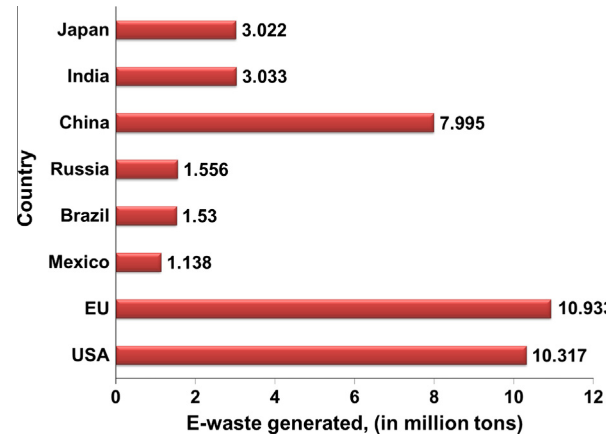

Fig. 2. Global generation of WEEE in year 2012. *Source:* StEP initiative, http://www.step-initiative.org/overview-world.html.

resource conservation and optimization, waste reuse and recycling, energy recovery, landfill avoidance and acquisition of novel green approaches for waste management. In this paper, "Greening the waste" concept has been explored in order to generate substantial economic, environmental and social benefits using waste electrical and electronic equipments (WEEE).

2. WEEE management

Revolutionary innovations in the functionality of information and communication technology certainly marked a new era of human civilization in past two decades. Though, negative shades of this revolution can also not be disregarded. With the rapid development and technology innovations, the useful life of consumer electronic products has been foreshortened. Thereof, generation of waste electronic and electrical equipments (WEEE) has been increased at a significant rate. According to the Basel Action Network, WEEE can be defined as:

> "A *broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users*".
>
> [Puckett and Smith, 2002]

WEEE contains valuable and hazardous metals which require special handling and recycling methods to minimize environmental contamination and hazardous effects on human health.

Globally, generation of WEEE is predicted to grow up to 65.4 million metric tons by year 2017 which is 34% higher than that of in year 2012 (Bidwell, 2013). It is also estimated that e-waste from old computers would raise by 500% and that of discarded mobile phone would be nearly 18 times higher by year 2020 than year 2007 levels in India (UNEP, 2010). Cobbing (2008) approximated production of almost 10 million tonnes of e-waste globally only from computers, mobile phones and television sets in year 2015. Hence, WEEE can be regarded as the most riotous solid waste stream which is growing at the rate of 3–5% annually (Tuncuk et al., 2012). Fig. 2 demonstrates the production of WEEE in different countries for the year 2012 which clearly demonstrates Europe and USA as the largest producer of e-scrap. Developing countries such as China and India are also moving at a fast pace in the technological world which can be estimated with the growing amount of WEEE in these countries.

Another sincere concern is the complexity of WEEE due to wide range of electronic products which differentiates WEEE from other solid waste on the basis of their chemical and physical properties (Yla-Mella et al., 2004). WEEE contain large amount of metals, particularly Cu, Al, and Fe, mixed with various types of plastics and ceramics which reflects WEEE as a potential secondary resource to overcome the scarcity of metals. Nevertheless, presence of these metals may affect the ecosystem due to lack of adequate management of WEEE. Environmental effects of WEEE disposal are drawing increasing attention from the scientific community. Increasing number of research publications related to WEEE management has been analyzed for last 15 years by collecting the data from Scopus library (http://www.scopus.com). Scopus library enumerates that approximately 1221 reports have been published related to WEEE management out of which 584 are research articles, 124 are review article and 411 are conference papers. Also, more than 90 publications every year in the last decade (http://www.scopus.com) clearly illustrate the increasing concern of researchers toward economic potential and environmental consequences of WEEE.

Several initiatives have been made by the government and non-governmental organizations (NGOs). WEEE directive have made it mandatory for manufacturers to follow the concept of 'Greener Electronics' (Chen et al., 2011; Pant, 2010). The Restriction on the use of Hazardous Substances (RoHS) directive prohibits the use of Pb^{2+}, Cd^{2+}, Hg^{2+}, Cr^{6+}, polybrominated biphenyls (PBBs), and polybrominated diphenyl ethers (PBDEs) in new electronic devices (Chen et al., 2011). Incineration, landfilling and export to overseas are not allowed in recent years for WEEE management due to strict environmental legislations. Thus, environmental concerns and presence of reusable metals/components trigger the need to recover heavy and precious metals from WEEE, before disposing off these scrap material into the ecosystem. Some world initiatives for the WEEE management have been listed here in Table 1.

Incineration, landfilling and export to overseas are not allowed in recent years for WEEE management due to strict legislations. Thus, environmental concerns and presence of reusable metals/components trigger the need to recover heavy and precious metals from WEEE, before disposing off these scrap material into the ecosystem. Recovery of metals from WEEE using conventional hydrometallurgical and pyro-metallurgical processes is widely reported in literature; however, environmental consequences and high energy requirement are the major limitations which inhibit their use at large scale. Pyro-metallurgical methods are energy intensive and liberates hazardous dioxins which itself become secondary pollution possibility (Khaliq et al., 2014; Cui and Zhang, 2008). Hydrometallurgical treatment of WEEE often uses cyanide, halide, thiourea and thiosulfate as leaching agent to extract

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