EDITORIAL

Metal Recovery from Electronic Waste in the Framework of the Circular Economy

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Electronic and electrical waste or e-waste is rapidly emerging as a leading waste category, constituting approximately 8% of municipal waste. In 2019, around 53.6 million metric tons of e-waste were generated. Projections indicate a surge up to nearly 74 million metric tons of e-waste by 2030. Recycling and recovery of metals and other constituents from e-waste have become pivotal issues, raising significant environmental and socioeconomic concerns.

In terms of composition distribution, half of the e-waste originates from electrical appliances, with the remaining coming from electronic goods. The primary sources of e-waste include home and hospital medical equipment, information technology and telecom equipment, private sector, and industrial machines. Additionally, lighting equipment, electrical and electronic tools, entertainment devices, as well as monitoring and controlling equipment contribute significantly to the e-waste stream.

According to the US Environmental Protection Agency, a mere 15% of e-waste undergoes recycling, with most of these electronics being disposed directly in landfills or through incineration. Only 1.5% of the total e-waste is recycled through formal recycling sectors employing environmentally friendly methods. The remaining portion of e-waste is handled by the informal recycling sector worldwide.

Hence, the recycling of valuable metallic and non-metallic materials from e-waste is imperative in numerous developed and developing countries. Given the global demand for valuable metals in the production of new electronic and electrical equipment (EEE), e-waste is increasingly recognized as a secondary source. In 2022, approximately $60 billion worth of high-value raw materials present in e-waste were either discarded in landfills, incinerated, or subjected to crude recycling techniques. E-waste is indeed a repository of valuable resources, encompassing numerous heavy metals and hazardous materials. It represents both an appealing secondary source of metals and an environmental pollutant due to its content. Notably, e-waste comprises at least 57 valuable elements from the periodic table, offering opportunities for urban mining and job creation.

The heterogeneous composition of e-waste includes metals, glass, plastics, and ceramics. It contains precious metals such as gold, silver, palladium, platinum, as well as hazardous materials like mercury, arsenic, nickel, copper, lithium, among others. Additionally, e-waste contains non-hazardous materials like iron and steel, along with rare earth metals such as tantalum and indium.

Toxic metals and materials present in e-waste have adverse effects on the entire ecosystem. Workers, including women and children, in the informal e-waste sector are exposed to these toxins, leading to health complications such as an increased risk of cancer and DNA damage. Direct disposal and improper recycling practices contribute to contamination of air, soil, surface water, and groundwater.

Among the hazardous substances found in electronic equipment, mercury is employed in liquid crystal displays, switches, batteries, and gas discharge lamps. Approximately 22% of the global mercury production is used in the electronics industry annually. Rechargeable batteries, old TVs, printed circuit boards (PCBs), cathode ray tubes, personal computers, and floppy discs also contain hazardous elements like lead, cadmium, lithium, nickel, barium, chromium, and others. Chlorofluorocarbons (CFCs) are found in cooling units and insulation foams. Liquid crystals, used in various displays, consist of substances considered hazardous.

Lead causes damage to the human nervous system, blood system, and kidneys, affecting the brain development of children. Chromium induces asthmatic bronchitis and damages the respiratory system. Cadmium has toxic and irreversible effects on human health, accumulating in the kidneys and liver, and causing neural damage. Mercury leads to chronic damage to the brain and respiratory system. Burning plastics produces dioxins, causing reproductive and developmental problems, immune system damage, and interference with regulatory hormones.

E-waste has primarily undergone recycling through mechanical and chemical processes. Various studies, encompassing physical, chemical, and biological approaches, are conducted for effective e-waste treatment. However, each recycling method shows shortcomings, such as high capital costs in mechanical processes and the generation of toxic gases and liquid waste in chemical processes. Consequently, there is a pressing need to develop sustainable and cost-effective methodologies for e-waste management, ensuring environmental protection, human health safety, and the economic growth of nations.

In recent decades, techniques like pyrometallurgy, hydrometallurgy (i.e., leaching processes), and biometallurgy have emerged for recovering value-added products from e-waste. Hybrid methods combining pyro- and hydrometallurgy have also been developed to maximize recovery efficiency.

Pre-treatment, a crucial step before each of these processes, is essential for enhancing metal recovery from e-waste. Particularly before leaching processes, pre-treatment of e-waste is vital for improving dissolution efficiency and reducing energy consumption. Physical or mechanical techniques, including dismantling, shredding, crushing, sieving, separation (i.e., screening, gravity, magnetic, electrostatic, and density separation), as well as chemical techniques like pyrolysis, supercritical fluids, and various solvent systems, constitute pre-treatment.

Thermo-chemical processes, notably pyrolysis and plasma treatment, play significant roles in e-waste treatment. Pyrolysis involves the thermal degradation of materials in the absence of air. Studies on e-waste pyrolysis have been conducted, with notable implementation by Jectec in Japan. The plasma process, recognized for its high temperature and environmentally friendly nature, has demonstrated success in the recovery of metals from mobile phone waste.

Pyrometallurgical processes, involving the heating of e-waste at high temperatures in smelters, are widely employed for metal recovery globally. This method leaches non-ferrous and valuable metals from e-waste, including gold and copper from waste e-waste. However, the challenge lies in recovering pure desired metals from the complex mixture of metals, non-metals, and alloys present in e-waste. Multiple companies have adopted a pyrometallurgical approach, although it requires higher capital costs compared with hydrometallurgical processes.

Hydrometallurgical methods for metal recovery from e-waste are modified versions of traditional methods used for metal extraction from primary ores. After physical pre-treatments, leaching is conducted using acid, alkaline, or other solvents to extract metals in the form of soluble salts. Metal isolation from the solution containing impurities is achieved through processes like adsorption and solvent extraction, with final purification through electrorefining or chemical reduction. Hydrometallurgy has proven to be cost-effective, efficient, predictable, and energy-conserving, yielding high metal purity and facilitating easy management processes compared with pyrometallurgy. Despite its advantages, limitations such as the use of acidic, alkaline, and flammable solvents have somewhat reduced the significance of hydrometallurgy.

Industrial applications of new green approaches are deemed essential for sustainability. Currently, innovative green approaches aim to replace highly polluting solvents with eco-friendly solutions. Amongst the new sustainable approaches proposed, solar-powered and cost-effective photoactivated processes have proved to allow the recovery of pure elements (e.g., metals) from the leaching solutions.

Biometallurgical processing of e-waste is an emerging and promising area where microorganisms are employed to extract metals from various sources. This method includes biosorption and bioleaching. Recently developed techniques, such as bioelectrochemical and phytoremediation, have exhibited remarkable recovery efficiencies. The bioleaching process has been explored for the recovery of gold, aluminium, copper, nickel, zinc, and lead from e-waste. Collectively, biometallurgy consumes less energy, incurs lower operational costs, and achieves high efficiency rates.

The concept of circular economy (CE) integrated into e-waste management plays a vital role in the economy. Overall, this integrated approach reduces waste, improves valuable material recovery, minimizes occupational hazards, and creates jobs, thereby formalizing the recycling industry. Directives introduced by the European Commission restrict the use of hazardous materials in electronic and electrical equipment manufacturing, promoting sustainable production with reduced environmental impact.

CE in e-waste management promotes designing and manufacturing EEE, reducing e-waste generation, urban mining of secondary resources, and employing secondary materials for manufacturing industries. This approach may boost a green economy by creating jobs at every product life-cycle stage, requiring advanced technologies like bioleaching, and encouraging investments in environmentally sound technologies. In developing countries like India, e-waste poses a significant challenge due to a lack of proper recycling techniques, involvement of the informal sector, inadequate knowledge, and financial support. Therefore, the systematic incorporation of CE in e-waste management may stimulate a sustainable economic growth, extend product end-of-life, and address future climate change commitments.

Eventually, last but not least, it is noteworthy that consumer behaviour in the product lifecycle is a critical parameter of CE. Decision-making and user behaviour during purchase, consumption, and disposal of metal-containing e-waste are essential for the implementation of product reuse, repair, and recycling. Initiatives and awareness campaigns should be launched to improve consumer behaviour, fostering communication between consumers, retailers, and urban local bodies to promote the CE.