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Review

Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes

Muammer Kaya

Mining Engineering Department, Eskişehir Osmangazi University, Eskişehir, Turkey

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ABSTRACT

This paper reviews the existing and state of art knowledge for electronic waste (e-waste) recycling. Electrical and/or electronic devices which are unwanted, broken or discarded by their original users are known as e-waste. The main purpose of this article is to provide a comprehensive review of e-waste problem, strategies of e-waste management and various physical, chemical and metallurgical e-waste recycling processes, their advantages and disadvantages towards achieving a cleaner process of waste utilization, with special attention towards extraction of both metallic values and nonmetallic substances. The hazards arise from the presence of heavy metals Hg, Cd, Pb, etc., brominated flame retardants (BFRs) and other potentially harmful substances in e-waste. Due to the presence of these substances, e-waste is generally considered as hazardous waste and, if improperly managed, may pose significant human and environmental health risks.

This review describes the potential hazards and economic opportunities of e-waste. Firstly, an overview of e-waste/printed circuit board (PCB) components is given. Current status and future perspectives of e-waste/PCB recycling are described. E-waste characterization, dismantling methods, liberation and classification processes are also covered. Manual selective dismantling after desoldering and metal-nonmetal liberation at −150 μm with two step crushing are seen to be the best techniques. After size reduction, mainly physical separation processes employing gravity, electrostatic, magnetic separators, froth floatation, etc. have been critically reviewed here for separation of metals and nonmetals, along with useful utilizations of the nonmetallic materials. The recovery of metals from e-waste material after physical separation through pyrometallurgical, hydrometallurgical or biohydrometallurgical routes is also discussed along with purification and refining. Suitable PCB recycling flowsheets for industrial applications are also given. It seems that hydrometallurgical route will be a key player in the base and precious metals recoveries from e-waste.

E-waste recycling will be a very important sector in the near future from economic and environmental perspectives. Recycling technology aims to take today's waste and turn it into conflict-free, sustainable polymetallic secondary resources (i.e. Urban Mining) for tomorrow. Recycling technology must ensure that e-waste is processed in an environmentally friendly manner, with high efficiency and lowered carbon footprint, at a fraction of the costs involved with setting multibillion dollar smelting facilities. Taking into consideration our depleting natural resources, this Urban Mining approach offers quite a few benefits. This results in increased energy efficiency and lowers demand for mining of new raw materials.

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E-mail address: mkaya@ogu.edu.tr

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List of abbreviations

Flame retardants and by-products of e-waste treatment processes

BFR	brominated flame retardant
PBDE	polybrominated diphenyl ethers
TBBPA	tetrabromobisphenol-A
HBCD	hexabromocyclododecanes
PBB	polybrominated biphenyls
PXDD/Fs	mixed halogenated dioxins and furans
PBDD	polybrominated dioxins
PCDD	polychlorinated dioxins
CFC	chlorofluorocarbon
Fs	furans
PVC	polyvinylchloride

E-waste terminology

3R	reduce, reuse and recycle
EEE	electric and electronic equipment
WEEE	waste electrical and electronic equipment
EoL	end-of-life
RoHS	restriction of hazardous substances
EPR	extended producer responsibility
ARF	advanced recycling fee

Components/parts of electric and electronic equipments

EC	electronic component
IT	information technology
CD	compact disc
DVD	digital versatile disc
CRT	cathode ray tube
LCD	liquid crystal display
TV	television
PCB	printed circuit board
CPU	central processing unit

Metallurgy

DSX	direct solvent extraction
SSX	synergistic solvent extraction
VMS	vacuum metallurgy separation
TBP	tribromophenol

Characterization equipments

AAS	atomic absorption spectrophotometer
ICP–OES	inductively coupled plasma spectrometer
ICP–MS	inductively coupled plasma mass spectrometer
XRD	x-ray diffraction
XRF	x-ray fluorescence
SEM	scanning electron microscope
TGA	thermo gravimetric analysis

General

PGM	platinum group metals
IMC	inter metallic compound
CCL	copper-clad plate
SMD	surface mounted device
THD	through-hole device
LOI	loss of ignition
TBE	tetrabromoethane

1. Introduction

E-waste comprises of waste electric and electronic equipments (WEEE/EEE) or goods which are not fit for their originally intended use. Such EEEs may be TVs, telephones, radios, computers, printers, fax machines, DVDs, CDs, washing machines, refrigerators, dryers, vacuum cleaners, etc. Fig. 1 shows the composition distribution of e-waste. Half of the e-waste is coming from electrical appliances and the rest from electronic goods. Fig. 2 shows the four sources of e-waste. Small/large home appliances, hospital medical equipments, government office machines (information technology (IT) and telecom equipments) and private sector offices and industrial equipments and machines are main source of e-waste. Consumer and lighting equipments; electrical and electronic tools; entertainment devices; toys and sports equipments and monitoring and controlling equipments are also important source of e-waste. EEEs can become e-waste due to rapid advancement in technology; development in society; change in style, fashion and status; greater demands on EEE; nearing the end of their useful life and not taking precaution while handling them. The replacement of EEE becomes