Open Access, Peer Reviewed, Referred Research Journal
© RUT Printer and Publisher
Print & Online available on https://jbsd.in
ISSN: 2229-3469 (Print); ISSN: 2231-024X (Online)
Review Article

Global electronic waste treatment, challenges and management: a short review

Rajesh M. Jorgewad[†], Pooja V. Deshpande[1], Darshani S.Chopade[2,] Manoj Mehta[3]

[†, 1, 2]Department of Biotechnology Engineering, KIT's College Of Engineering (Autonomous), Kolhapur, Maharashtra, India 416 234.
[3]Mahalaxmi E Recyclers Pvt. Ltd. Kolhapur 416 234.
[†]Corresponding author: E-mail: rajeshgudmalwar001@gmail.com , Tel: 9923957189

Article Info

Received: 14-01-2021,
Revised: 16-03-2021,
Accepted: 27-03-2021

Keywords: Bioleaching, e-waste, e-waste management, PCBs, pretreatment, recovery of metals

Abstract

With increasing advancements in technologies and rising demand of electrical & electronical equipments, large amount of e-waste is being produced every year. Due to which management of e-waste is becoming a serious problem. Based on literature, PCBs are known to be metal rich component of e-waste. Hence with economical and environmental point of views, recovery of metals from PCBs is gaining a big attention. This paper gives the brief description about e-waste, its constituents, problems associated with e-waste management along with various methods for recovery of metals from these PCBs; among them Bioleaching proven to be the widely accepted and known technique. And also, the importance of Bioleaching is discussed with the significance of pretreatment given to the PCBs. Finally, along with rules and regulations for e-waste management in India, limits and necessity of robust process for e-waste management and recovery of metals from PCBs is highlighted.

INTRODUCTION

Electronics Company is one of the vast and quickly increasing fabrication companies around the world. Speedy development integrated with quick product degeneration is resulting into scrap electronics that is currently the quickest growing waste flow within the manufacturing world. This amount of E-Waste from these electronics companies is growing at devastating proportions. E-waste is defined as the old and discarded obsolescent electronic devices like personal computers, notebook computers, Television sets, Digital Video Disc players, fridges and cold storages, cell phones, etc. that is thrown away by their native customers. Hence, E-waste is produced out of nearly costly and necessarily long-lasting products which are utilized for information processing, telecom media, or entertainment in individual homes and companies(Wath *et al.*, 2011).

E-waste differs by both parameters i.e. chemical and physical from other kinds of urban or manufacturing waste which includes both expensive and dangerous components that needs exclusive operation and recovering techniques to null the surrounding contagion and detrimental consequences on human well being (Robinson, 2009).

With fast technological advancements and market enlargement, the quantity of electric & electronical devices has increased promptly during past 10 years. According to the data collected from United Nations (UN), 1.4 crores tons of electric waste was produced in 1992, which rose to 2.4 crores tons in the year 2002, and further more increased threefold, to 4.77 crores tons in 2016. A huge quantity of electrical and electronic waste (WEEE) has been generated because of constant technological advancements and the enhancement of life style of the people. As per the configurations that are abundant in variety of metals, discarded Printed Circuit Boards (PCBs) known to be the most expensive element amidst electrical and electronical waste (Hao *et al.*, 2020). Using various processes one can retrieve reusable components and essential materials, specifically Copper and other valuable metals. But, because of shortage of facilities, high worker prices, as well as strict environment related laws, wealthy countries are inclined to not reprocess electronical waste. Rather, they either landfill, or export to comparatively poverty-stricken countries, where e-waste could be reprocessed utilizing primary methods giving less concern to the safety of labor and to the environment (Robinson, 2009).

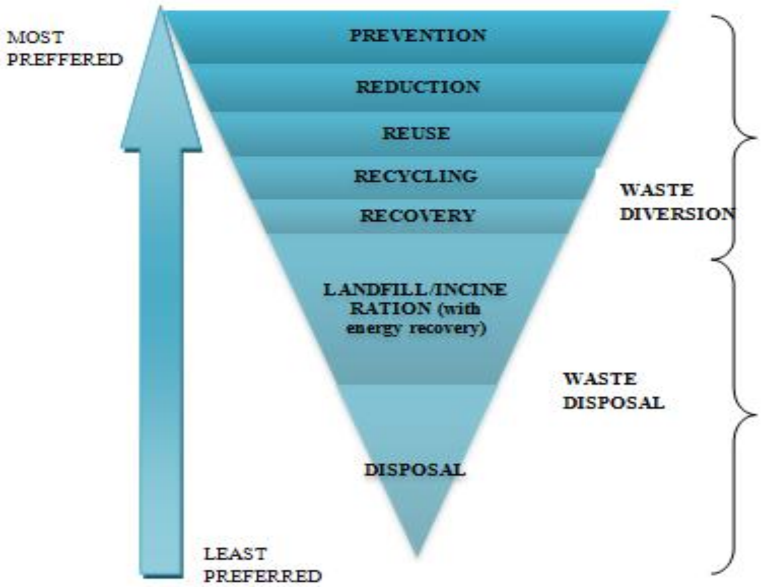

Figure 1: Hierarchy of waste management(Jadhao *et al.* 2016)

THE CONTENTS OF PCB:

The constituent of precious substances and dangerous components in waste PCBs is crucial to evolve fruitful and environmentally sound recovery approaches. Waste PCBs include nearly 60 types of components comprising 30% of plastic materials, 30% of ceramic components as well as 40% of metal fractions that are present into the silkscreen, connecting components, metal coats, solder mask and into the polymer stratum (Pinho *et al.*, 2018).

Metals such as base metals and valuable metals are dispersed into metal coats, connecting components, complicated composites of metals and multi-part alloys (Cui and Forssberg 2003). As a consequence of the presence of precious metals, these discarded PCBs become major secondary metal reservoir. Furthermore, these PCBs also constitute huge amount of dangerous parts that includes Brominated Flame Retardant (BERs), Poly-Brominated Biphenyl (PBB), heavy metal elements (for instance, Chromium, Mercury, Cadmium), as well as rare earth metals (examples are Tantalum, Cerium), that has adverse effects on the surrounding environment in addition to health of the humans. The composition of metals in PCBs is majorly based on the categories, manufacturing procedures, and the duration of the devices. Depending on the types (most important element), these metals constitutes ~38% Fe, ~27% Cu, ~19% Al, ~3% Pb, ~2% Ni, ~0.3% Ag, ~0.05% Au, and ~0.02% Pd. Amidst these, the reprocessing of valuable metals gets highest recognition due to the higher economic rate. Statistics information indicated that the yearly utilization of Silver, Gold, Palladium and Platinum were approximately 7554, 327, 44 and 4 tons (Cayumil *et al.*, 2016). Another characteristic of electronic waste which could impact on recovery of metals is considered to be the galvanic corrosion of Copper accompanied by other metal elements that are present between the wastes. This technique also known as cementation, includes the thermo-chemical interrelation between the metals in which metals with more anodic reduction power has an inclination to reduce, while the ones with potentially lesser standard could oxidize then dissolve favorably. Hence, the metal contact with lesser electrode powers consist a potential that could restrain the specific copper leaching from e-waste. The latest surveys of cementation of metals disclose, along with the above characteristic; variety of other characteristics inclusive of solution temperature, concentration and pH of solution, as

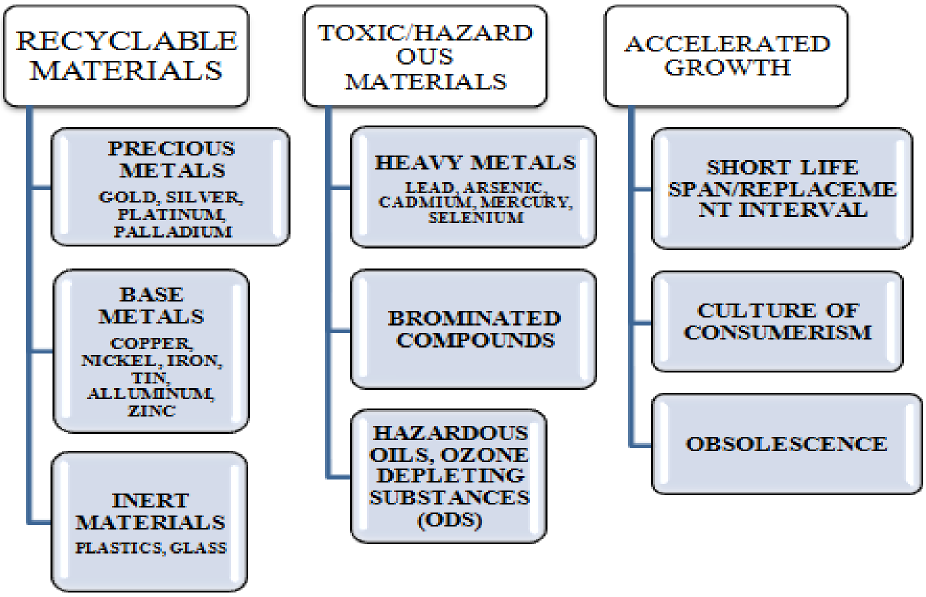

Figure 2: Properties of E-waste different than municipal or industrial waste flow(Saldaña-Durán *et al.* 2020)

well as DO concentration, leaching elements with time can also impact specific deletion or favorable metal dissolution (Hong and Valix 2014).

CONSEQUENCES OF E-WASTE

Huge quantities of e-waste have been generated in past years as consequences of the advancement in computer technology and telecommunications. Recently, it has been discovered that e-waste generation is increased up to 5 crores per annum. The quantity of e-waste recovered is barely of 20% the overall generation. The e-waste components that have been discarded impart approx. 70% the total poisonous substances to the surroundings. Hence, e-waste recovery is required to prevent adverse effects on the environment (Islam *et al.*, 2020).

Worldwide, the production of WEEE was estimated to increase up to 65.4 MMT until year 2017 that was 34% more than in year of 2012. Also it has been predicted, e-waste due to discarded computers may increase with 500%; whereas, due to discarded mobile phone it may increase approximately 18 folds greater until year of 2020 than that in year of 2007 proportions within India. It is approximated that the e-waste of nearly 1 crores tonnes would be generated universally barely through cell-phones, TV sets and computers in 2015. Therefore, waste electrical devices could be considered as the major uncontrollable solid form waste flow that is increasing with the rate approx. 3–5% yearly (Jadhao *et al.*, 2016).

The unenclosed e-waste (comprising poisonous materials) dumping in the water resources and land filling results into pollution of the ground water. This ground water also gets polluted due to dripping of toxic substances originated from discarded e-waste. Also when Cd containing plastic materials and BFR plastic is land filled both Cd and PBDE may reach to the ground water levels. These poisonous materials get combined within soil which in turn passes into the veins of plants. These plants are when eaten as food by the population, they may get affected by hazardous diseases and then resulting into severe respiratory problems (Islam *et al.*, 2020). Precious metals can be retrieved by e-waste utilizing pyrometallurgical, hydro-metallurgical and bio-metallurgical techniques. Pyro-metallurgical technique comprises incineration of the matrix and detection of the required metals. The efficiency of this technique depends on capital invested.

Safe and sound handling of electronic and electrical waste (e-waste/WEEE) is turning into the significant drawback of several of the nations globally. Improper and poor management of e-waste is harmful to the surroundings as well as to health of the humans due to its toxic materials. Many nations around the globe are currently troubled to tackle with this new rising danger. Mitigation of e-waste stream using eco-friendly design and new production is raising more attentiveness.

Table 1: The metal proportion and commercial prices for waste PCBs (values in /ton)(Yu, *et al.* 2009)

Metal	Content (%)	Metal Price($/Kg)	Potential Value	Value (%)
Cu	9.7	3.6	349.2	4.8
Al	5.8	1.7	98.6	1.35
Fe	9.2	0.4	36.8	0.51
Ni	0.69	10.5	72.5	0.99
Pb	2.24	1.2	27	0.37
Sn	2.15	13	279.5	3.84
Ag	0.06	315	189	2.6
Au	0.023	24.434	5620	77.17
Pd	0.01	6100	610	8.38
Total	29.87	-	7282	-

Eco-friendly management of E-waste in advancing and economically poor countries is lacking or terribly restricted. Tackling with the illegal and poor recovery methods is considered to be an complicated social and environmental issue(Herat and Agamuthu 2012).

VARIOUS METHODS FOR DISMANTLING OF E-WASTE

The common dismantling processes in few developing countries embody physical dismantling, overheating, and open flaming, that unheeded the characteristics analysis of waste PCBs and was harmful to surroundings and human well-being(H. Wang *et al.* 2011). For instance, some harmful components would be produced throughout overheating method because of the greater melting point of lead-free solders (270–280 °C)(J. Wang and Xu 2014).

With the rise of WPCBs, the in depth application of these ways was restricted due to high value, components waste, and surroundings pollution. After that, semi-automatic and automatic disassembling machine was manufactured to increase the potency of dismantling process. A versatile automation unit, that might verify the helpful and the hazardous parts by equating the form and tag with the information of the maker and also the remaker, was designed correspondingly(Ly 2002).

Alternate three-component dismantling machine removes parts by dissolution of solder mask after which outer drives like impact else pulsation are applied, for getting rid of materials(Islam *et al.*, 2006). The disassembling potency may reach up to 90%(Lee *et al.*, 2012). Nevertheless, the prices of semi-automatic as well as automatic machines are higher because of their complex frameworks. Additionally, ionic liquid also is being utilized to open the solder junctions because of its convenient thermal solidity(Hao *et al.* 2020).

PROCEDURES FOR THE RETRIEVAL OF THE PRECIOUS METALS FROM PCBs

Hydrometallurgical process:

In hydrometallurgical techniques, precious metal containing PCBs are initially leached out into the acid or basic suspensions, which are then, concentrated using different processes such as cementation, precipitation and extraction by solvents. Processing ways that may be utilized to extract metals from waste PCBs are alike ancient techniques utilized to extract metal from its primitive minerals. But, complicated characteristic of e-waste serves these methods difficult equated with original minerals (Kavitha, 2014).

Pyrometallurgical process:

During the pyrometallurgical technique, PCBs are dissolved with many flux materials as the residue formats. As liquefied substance comprising precious metals come in contact with liquefied metal reservoir the precious metals solubilize and gather together. These liquefied metals could be named as collector metals. After this, the precious metals which have been extracted should then be managed to segregate and clarify them. Several metals such as Pb, Cu etc., may be recovered by using pyrometallurgical technique.

Dismantling and Granulation process:

Nowadays, disassembling and granulation methods are being used commercially to segregate different kinds of metals and constituents. Commercial scale granulation equipments are used for grinding components up to 5 cm. The granulating machines are utilized for the reduction of plastic materials, non-iron as well as heterogeneous components.

Fractionating plants can be used to recover metal from e-squander by mechanical way. Rising speed and retarding instruments used in the fractionating mills for recovering the components as showed by their bodily characteristics.

Supercritical water oxidation (SCWO):

Another procedure for recuperating Au, Ag, and Pd by discarded PCBs of cell phones is through Supercritical Water Oxidation (SCWO) pretreatment integrated with I-I leaching procedure can be used. The PCBs were first pretreated with supercritical water, followed by diluting using hydrochloric acid leaching (HL) method to recover copper, which showed approximately 100% leaching potency, eventually the end slag was treated with the I-I leaching process to recuperate Au, Ag, and Pd. This pretreatment technique for waste PCBs, as well as for poisonous organic matters like BFRs in waste PCBs can be reduced effectively using SCWO technique(Xiu, *et al.* 2015).

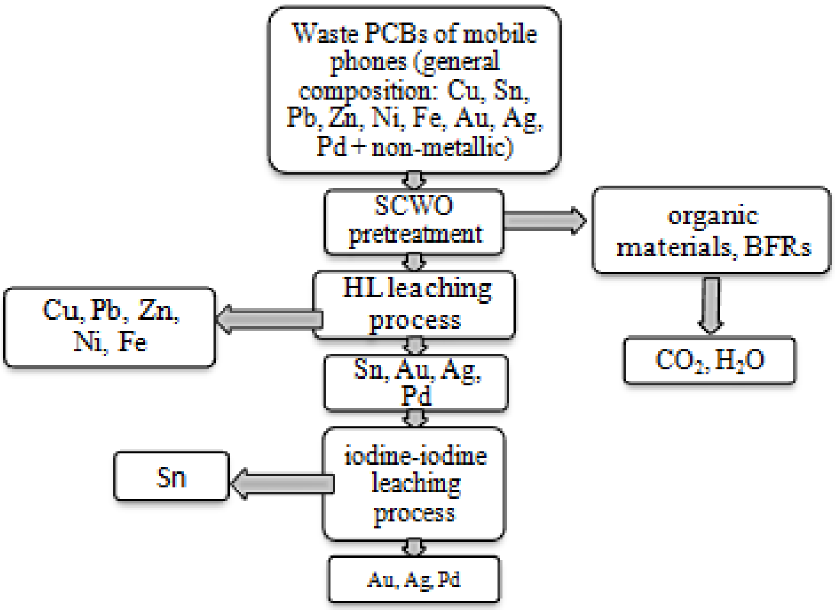

Figure 3: Schematic diagram showing Au, Ag and Pd recovery from waste PCBs (Xiu *et al.*, 2015)

Bio Leaching:

In this technique, different species of bacteria have been used for leaching of metals from PCBs. Leaching technique using microbes employs a natural potential of microbes to convert metals which are there in the waste in a solid format to a dissolved format. Besides this, the potentiality of metals bioleaching in basic environment (inclusive of cyanegenic bacteria), using acidophilic micro-organisms and carrying out biological action of leaching in acidic conditions act as an important factor in the bio-hydro-metallurgical processes. Prime categories of bacteria that are mostly used in the recovery of metals include consortia of acidophilus and chemoautotroph micro-organisms like *Leptospirillium ferrooxidans*, *Acidothiobacillus thiooxidans*, *Acidothiobacillus ferrooxidans*, as well as heterotrophic, such as *Sulfolobus* sp. Additionally, fungus like *Penicillium* sp. as well as *Aspergillus niger* are typical cases of some eukaryotic microbes that are utilized in bioleaching processes for recovery of metals from industrial waste streams.

FUNDAMENTALS OF MICROBIAL LEACHING TECHNIQUE

Biological leaching is one of most commonly practised technique for metal extraction from E-waste. Various lithotrophic and organo-trophic microorganisms are noted to mobilize the different constituents from solids commonly by forming inorganic and organic acids(Krebs et al. 1997). The utilized microbes have the natural potential to transform metals into soluble system. Normally, 3 groups of micro-organisms are embodied in bioleaching that includes autotrophic as well as heterotrophic bacteria and heterotrophic fungus (Arshadi and Mousavi, 2014), (Zhu *et al.*, 2011). Major autotrophic bacterial leaching is performed by chemolithotrophic as well as acidophilic bacteria that are able to fix carbon dioxide and acquire energy from Fe ion or reduced S compounds oxidation.

These microbes used in autotrotrophic bioleaching consists of sulphur oxidising bacteria (for example *Acidithiobacillus thiooxidans*, before known as *Thiobacillus thiooxidans*), ferrous and sulphur oxidising bacteria (i.e. *Acidithiobacillus ferrooxidans*), and ferrous oxidising bacteria (i.e. *Leptospirillum ferrooxidans*) (Xin *et al.*, 2009). Subsequently, sulphur and ferrous oxidation by above mentioned bacteria, metal sulphides are dissolved and suddenly pH is lowered in the solution, which increases the solubilisation of other metal compounds(He *et al.*, 2010).

Heterotrophic bioleaching is described as microbial leaching process during which the microbes require natural C sources for energy reserve to continue the bioleaching operation and also for the growth(Meshkini *et al.*, 2013). In this category of leaching, the metabolic outcome from the organic carbon react with metals(Jain Nalini *et al.*, 2010). For example, heterotrophic organisms are able to release organic acids, like acetic, citric and oxalic acids which would be suitable for metals dissolving in the pH range of 4 to 6. Heterotrophic microbes with unique leaching capacity are commonly familiar as filamentous fungi which include *Aspergillus* sp. and *Penicillium* sp. whereas bacteria such as *Chromobacterium violaceum* are also capable of bioleaching. Commonly, fungus work efficiently between pH range from 2 to 8 with temperature ranging from 20–40°C(Habibi, *et al.* 2020).

In the bioleaching technique, the metal recycling is associated with its reactivity, and stronger the metal reactivity, the quicker and effortless will be the bioleaching process. Additionally, the alkaline component of waste PCBs (direct consumption) and the oxidization of Fe^{2+} (indirect consumption) use H^+. Therefore, addition of acid is to balance the pH of leaching solution and contribute to enhance the leaching potency indirectly by assuring the iron cycle progress well(Yang *et al.*, 2014).

Biosorption, an alternate aspect of bioleaching, is a method to retrieve metals through the leach liquor. This process has basis of the variety of physicochemical reactions (such as ion exchange, chelation, coordination, complexation) amongst the ions of metals and the charged surface classes of microorganisms(Ghosh *et al.* 2015).

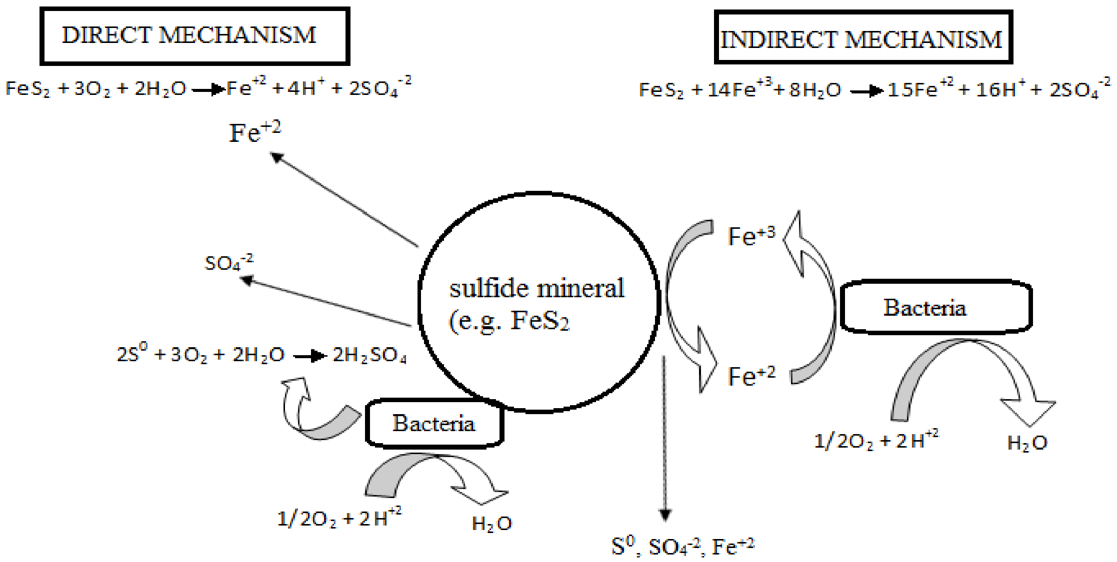

Figure 4: Bacterial mechanism for metal sulfide(Mishra and Rhee 2014)

Figure 4 shows the bacterial operation for metal sulfide solubilization. During the direct process, bacteria bind directly to the sulfide ore surface and with the help of oxygen and carbon dioxide, bacteria solubilize metal ions to the solution phase and sulfide is converted to sulfate. In the indirect process, bacteria utilize O_2 and CO_2 which oxidize Fe^{+2} ions (energy source) to Fe^{+3} ions, which solubilize metal ions. Later liberating metal ion, Fe^{+3} is afresh recouped to form Fe^{+2}(Mishra and Rhee 2014).

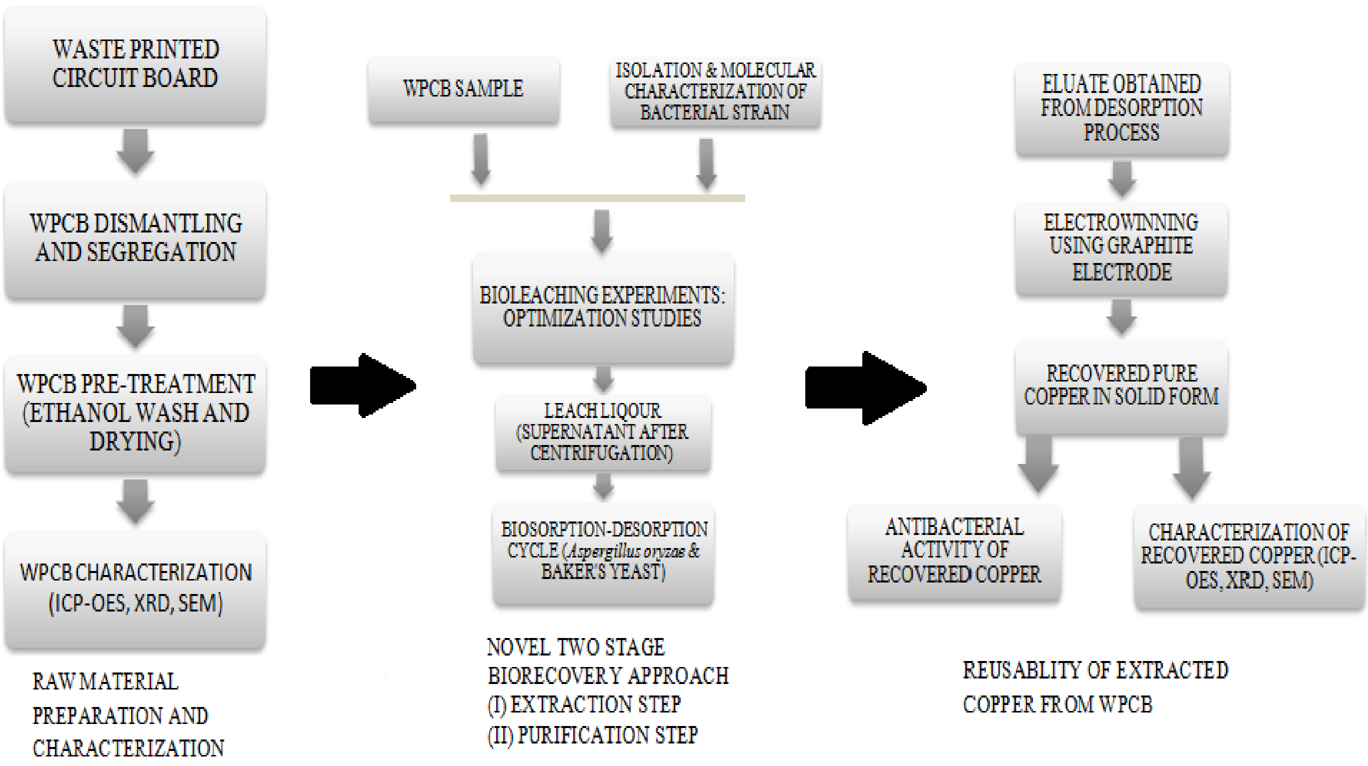

Figure 5: Schematic representation of unique hybrid two step biological recovery of Cu from waste PCB(Sinha *et al.* 2018)

Consortium of *At. ferrooxidans* and *At. thiooxidans* bacteria was capable of leaching out beyond 90% each of Copper, Zinc, Nickel, & Aluminum at PCB pulp density from 5 g/L to 10 g/L at temperature 30°C. According to Lead and Tin, precipitation of these metals was detected like PbSO4 whereas Tin precipitates possibly like SnO. Experiments indicated that bacterial growth was hindered. To obtain more amount of metal solubilization, two-stage leaching procedure has been developed in which growth of biomass is segregated from the process of leaching of metal. Results showed that Cu, Pb and Zn were solubilized greater than the amount 88.9% with less than 0.035 cm of the screen fractions of the samples selected with 5 days of leaching period. Elevated amounts of Pb, Zn and Al conversion in solution were attained using consortium of acidophilic bacteria during bioleaching process. Approximately 88.2% Aluminum, 91.6% Zinc, 86% Lead were leached within 96 h. In the course of e-waste bioleaching utilizing a static procedure at temperature 45°C, leached out concentration was approximately 80.9% Nickel, 88.9% Copper, 79.1% Aluminum, and 83.1% Zinc. Lead as well as Tin was found to be in the precipitate forms(Willner 2012).

Usually 3 types of procedures such as acido-lysis, redoxo-lysis and complexo-lysis have been used for e-waste bioleaching. During acido-lysis, the hydronation of atoms of oxygen occurs which envelopes surface of metal compounds. Protons that have been produced of organic acid through heterotrophs (gluconic, succinic, oxalic, malic, acetic, formic, pyruvic and citric acids) which also includes inorganic acids produced by bacteria such as sulfuric acid that shows acido-lysis ability(Glombitza and Reichel, 2014). Redoxo-lysis is nothing but the mechanism of solubilization of metal by using redox reactions. Through redoxo-lysis, transfer of energy required for growth of microbes takes place by transfer of electron. During the redoxo-lysis process of acidophilic microbes under anaerobic conditions, Fe ions are recuperated with the help of enzymes, in which H or S atoms play as the donor of electron(Glombitza and Reichel 2014), (Minier *et al.*, 2018). Complexo-lysis, another process by fungi is important in the recovery of valuable metals using cyanobacteria. During de-carboxylation reaction of glycine, cyanide is released in the microbial growth phase of late stationary(Lu and Xu, 2017). Many cyanide-releasing bacteria possess the capability of detoxifying cyanide which forms β-cyanoalanine through reaction of β-cyanoalanine synthase enzyme. Thus making this process gain attraction during the case when less hazardous cyanide is present in the streams of waste-water (Baniasadi, M., *et al.,* 2019).

Bioleaching is a cost-efficient process of recycling valuable crystals from solid leftovers with the help microbes. This work intensified eco-friendly as well as safe microbial leaching technology for recovering of Pb acid power units using *Cupriavidus sp*. The microbes first reacted with Pb powders of acidic batteries by sub-culturing with 5% (in w/v). Subsequently the extractions of Pb through particular microbes were enhanced. The ideal functioning variables attained through various trial processes include pH 6, temperature for the incubation 29-32°C, and density of pulp with 2–3% (in w/v). Hench the utmost extraction efficacy observed with these ideal functioning environments are almost 67% by utilizing locally obtained *Cupriavidus sp.* (Prabhakar *et al.,* 2019).

IMPORTANCE OF PRE-TREATMENT OF PCB:

The PCBs cannot be directly exposed to microbial culture as it may result into zero metal leaching because of the chemical layer which is also known as solder mask coated on the surface of PCBs. Usually epoxy is utilized for the chemical coat. This chemical layer does not allow microbes to pierce through it and hence the microbes fail to react with metals. Removing of this chemical coat makes it easier to use large PCB pieces for the bioleaching. With consideration of this, various types of chemical and reagents have been used for removal of the solder mask and it is noted by many researches that 10 M NaOH shows better results. Hence, PCB can be submerged for whole night in a 10 M NaOH which are then cleaned underneath the running tap water. Then these PCBs are washed with freshly prepared distilled water till all the sodium hydroxide layer is completely detached from the surface of PCBs (about 5 times) which can be tracked by detecting change in cleaned water pH. Neutral value of pH of this cleaned water ensures absolute detachment of sodium hydroxide layer. These cleaned PCBs can be then used further for bioleaching process(Adhapure *et al.* 2014).

Finely crushed, washed as well as unwashed samples of PCBs can be used during bioleaching studies. Washed PCB is developed by making suspension of 10 g of PCB in 100 ml of saturated suspension of sodium chloride. This suspension is then mixed gently about 10 min which then left standing until heavy particles settle at the bottom. Then the floating substance is removed and the heavier part that is settled at bottom is segregated, cleaned and dried out to obtain constant weight. Use of not washed PCBs or metal-non-adapted microbial cells may result into recouped metal bioleaching rates, the earlier being extremely serious. Increased rates are obtained when washed PCBs are exposed to bioleaching with metal-adapted microbes. This may occur because of the reason that when the microbes are adapted to bear rising masses of metal ions by cyclic subculture with media containing metal ions, there occurs anatomical modifications which induces bacteria for survival with higher metal ion concentration into the media in the course of bioleaching(Ilyas *et al.* 2007).

VARIABLES THAT AFFECTS THE POTENTIALITY OF BIOLEACHING TECHNIQUE:

Different variables have shown an impact on bio-oxidation efficacy and also on the activity of microbes. They can be classified as follows:

Microbiological variables of leaching conditions such as microbial diverseness, population mass, microbial actions, tolerance for metal ions, oxidizing capability of microbes, and so on can affect the efficiency of bioleaching process(Demergasso *et al.,* 2005). In regard of the oxidation capability of microbes, this feature has an important role in the bioleaching process. Although, the efficiency of bioleaching technique not always rise with the rise in the oxidizing capability of the bacteria(Jafari *et al.,* 2019).

Physico-chemical variables of bioleaching conditions such as temperature, pH, redox power, potential energy of water, content of oxygen and accessibility, and so on are another class of variables that may impact the efficiency of the process. Consider the following example; redox power is a vital factor of physicochemical variables in process of bioleaching. The action of microbes in the suspension is easily tracked through ORP measurement(Mousavi *et al.* 2008), where it shows positive interaction in between the existence of oxidants in the medium such as Fe^{3+} & oxygen while negative interaction in between the existence of reducers such as carbon and hydrogen (Lombardi and Garcia, 2002).

During bioleaching interactions, biological oxidation changes Fe^{2+} to Fe^{3+} which in turn modifies the value of ORP and induces the bioleaching reactions.

In between all the above mentioned variables, temperature pH, diversity of microbes, population mass, size of the grain, method of leaching, density of pulp as well as mixing rate are monitored using an operator, although other variables like oxidation-reduction power, potential energy of water, content of oxygen and accessibility, microbial actions and metal ion tolerance can't be monitored precisely. Hence such variables show impact on the process at various times of the operation.

ELECTRICAL WASTE MANAGEMENT WITHIN INDIA

Commercially e-waste can be managed by utilizing 4 staged processes that include inventory control, production-operation control, volume recuperation and retrieve & reuse. In the inventory control stage, constituents utilized during the making of electronic gadgets are restrained and thus quantity of waste generation is recuperated. Also the e-waste quantity can be reduced through following 2 routes– in the first place, by making review over purchases of material as well as control processes and then after that, through the inventory trailing method. During the production-operation control stage, e-waste is reduced through enhancement of operational and maintenance procedures, through modifying materials utilized in making of product as well as through modifying present process to develop the product. During third stage, i.e. during volume recuperation, the methods are used for segregating the hazardous component from non-hazardous component of waste which subsequently reduces the amount of e-waste. Reduction into e-waste can be attained through separating the e-waste at origin. At the end, during the retrieval & reuse stage, waste can be recycled. Thus the environment is conserved, since the recycling procedure converts the dangerous materials into different products that are meant to dispose off (Sastry and Ramachandra Murthy, 2012). The volume of e-waste can be reduced at huge amount by recovering as well as reutilizing products. This helps in preserving the energy as well as creating the surrounding free of poisonous materials(Joseph 2007).

The several measures have been conducted from the Indian Government to control e-waste which are listed as follows:

- E-Parisara – it is known as the first technical plant which was initiated for e-waste recycling to reduce contaminants of e-waste and to also retrieve metals.
- Earth Sense Recycling Pvt. Ltd. – this industry was initiated to manage biomedical wastes in year 2000 which now also handles every sorts of waste control, also includes e-waste.
- Trishyiraya Recycling India Private Limited – this industry was authorized through the Indian Government which is involved in the recycling of the e-waste.
- Plug - into E-cycling – e-cycling is described as recycle and recovery which helps into the reduction of greenhouse gases emission in the environment.
- Installing e-Bins over Bengluru City – e-bins have been equipped around the city to make everyone aware regarding e-waste(Jhariya, *et al.* 2014).

The several parameters that are troublesome in e-waste management are production of e-waste in huge extent; absence of regulations for inhibiting children involvement into various procedures while treating e-waste; harmful effects on environment and human health; insufficiency in the recognition of ill-effects of e-waste amongst individuals; import of e-waste from different nations to recycle inside the India; as well as huge capital expenditure in e-waste recycling plants(Kaushik and Herat 2020). In India E-waste control procedures deal with no. of problems which should be looked over.

RULES & REGULATIONS FOR E-WASTE HANDLING WITHIN INDIA:

E-waste control and operating regulations are for managing as well as handling e-waste during several steps of collection and treatment of same. These regulations has been reported underneath the Environment (Protection) Act in year 2010 (Notification no: S.O. 1035) for minimizing the impacts of e-waste on the environment. Basel Convention, by the UNs, was devised on 5th May, 1992 which offered a contract amongst the countries to control and manage harmful substances beyond the borderlines. With respect to the Basel Convention, reprocessing of e-waste is a strategy of discarding the materials (Babu *et al.*, 2007). The rules for protecting the surroundings and human health from harmful effects of e-waste are indicated in Table 3.

Table 2: Different levels for recycling the e-waste (Kaushik and Herat 2020)

Sr. No.	Level of treatment	Processes	Output	Role of technology	Main technologies
1.	Primary	Decontamination, dismantling, disassembly and sorting	Waste is separated into decontaminated waste, like plastic, PCB, and harmful waste like batteries, mercury switches, etc.	Low	Typically a manual process
2.	Secondary	Hammering, shredding, separation of waste streams and CRT treatment	The material output can be categorized into glass, plastic, contaminated plastic stream, ferrous metal stream and non-ferrous metal stream	Medium	Electromagnetic, eddy current, density separation, and variable vortex technology Splitting technology in CRT treatment like Ni-chrome wire cutting, thermal shock, laser cutting and diamond wire method
3.	Tertiary	Pulverization, and advanced separation, leaching for metal recovery and energy recovery	Plastics, ferrous metals, precious group of metals such as gold and platinum and other metals like gold and other metals like aluminum and lead and energy recovered from contaminated plastic stream	High	Plastic separation using skin floatation technology and electrostatic separation PGM recovery using smelting, electrochemical process and Haber's process

Table 3: Regulations that prevent e-waste hazards to the surroundings as well as to the health of the humans (Wath *et al.* 2010)

Sr. No.	Laws	Content	Effective from year
1.	Environment (Protection) Act, 1986 (Amendment 1991)	Empowers Central Government to take measures to protect and improve environment quality.	1986
2.	Hazardous Waste Rules, 2008 (Amendments 2009)	Provides stipulations on management, disposal and transboundary movement of solid waste of hazardous nature.	2008
3.	Batteries (Management and Handling) Rules, 2001	Responsibility for safe disposal and recycling of lead acid batteries	2001
4.	National Environmental Tribunal Act, 1995	Provide for strict liability for damage arising out of accidents caused from handling of hazardous substances.	1995
5.	The Air (Prevention and Control of Pollution) Act	Provide for prevention, control and abatement of air pollution in India	1981

DISCUSSION

Due to the advancements in technology, the problem of e-waste is increasing tremendously. Traditionally, many methods have been used around the world as well as in India. However, there is no precise solution or a standard procedure to reduce e-waste. Pyrometallurgical techniques have many drawbacks including negative impacts on environment as well as on the health of the workers who carry out this process. Whereas, hydrometallurgical process cannot be used at larger scale since the chemical reagents used are not recyclable and are toxic when exposed into the environment.

Also the present methods of e-waste control in India deals with many challenges such as the difficulty in inefficient laws, insufficient and hazardous conditions of illegal recycling procedures, negligible awareness of consumers and unwillingness from the stakeholders to mark the issues. Thus, subsequently hazardous substances enter the waste flow with no special precautions to prevent the known harmful effects on the environment and human well-beings as well as reservoirs are wasted when economically precious substances are dumped.

Therefore, there was a constant urge to find out a procedure which is cost-effective and also does not harm to the environment. Biotechnology has been the most attractive and encouraging field which can be used for extraction of precious metals from e-waste since it has less adverse effects on environment with higher specificity for the targeted elements as well as economically cheaper than the other methods. Bioleaching process has number of advantages as compared to the ancient methods such as less operating rates, reduced volume of chemical and/or biological constituents containing sludge to be controlled and high potency in detoxification of effluents.

CONCLUSION

This article reviews on the ill-effects of the e-waste, various processes that have been used till now for the recovery of metals from e-waste, a descriptive information about use of bioleaching process as well as variables that affect the efficiency of bioleaching. Also the importance of pre-treatment to the WPCBs using NaOH solution is discussed. In addition, rules and regulations for the management and control of e-waste in India and their insufficiency at various points of implication have also been reviewed.

The e-waste has been widespread around the world. The excessive generation of E-waste makes this necessary to search for eco-friendly techniques for the retrieval of metals. A considerable amount of damage has already been caused due to e-waste generation within the poor nations and negatively impacting the health of the country people.

Hence safe and sound management and control of E-waste is becoming very necessary for the sake of quality of environment and human health. The development of bioleaching technique has gained much attention from recent years. The improvement in efficiency of bioleaching process and utilization of appropriate consortium of micro-organisms are the main challenges in the path of recovering the metals from e-waste. Also, process of bioleaching of E-waste must be a robust process so that it can be performed anywhere without the requirement of the laboratories. Also for it to be successful to use at large scale process must be more efficient and the commercial establishment must be done.

Finally, the restrictions and regulations on open burning and dumping of e-waste creating awareness of ill-effects of e-waste amongst the citizens as well as workers working in these field is very much necessary.

ACKNOWLEDGEMENT

We are very much thankful to Mr. Manoj Mehta, Managing Director, Mahalaxmi E-Recycler, Kolhapur for their immense support and guidance.

AUTHOR'S CONTRIBUTION

P.V.D. and D.S.C. (B.E. Students) conducted the research and wrote the manuscript.

R.M.J. (Ph.D, Assistant Professor) wrote, revised and approved the manuscript.

REFERENCES

Adhapure N, Dhakephalkar P, Dhakephalkar AP, Tembhurkar VR, Rajgure AV and Deshmukh AM, 2014. Use of Large Pieces of Printed Circuit Boards for Bioleaching to Avoid 'precipitate Contamination Problem' and to Simplify Overall Metal Recovery. *Methods X*, (**1**): 181–186.

Arshadi M and Mousavi SM, 2014. Simultaneous Recovery of Ni and Cu from Computer-Printed Circuit Boards Using Bioleaching : Statistical Evaluation and Optimization. *Bioresource Technology*, **174**: 233–242.

Babu BR, Parande AK and Basha CA, 2007. Electrical and Electronic Waste: A Global Environmental Problem. *Waste Management and Research*, **25** (4): 307–318.

Baniasadi M, Vakilchap F, Bahaloo-Horeh N,

Mousavi SM and Farnau S, 2019. Advances in bioleaching as a sustainable method for metal recovery from e-waste: A review. *Journal of Industrial and Engineering Chemistry,* **76**: 75-90.

Cayumil R, Khanna R, Rajarao R, Mukherjee PS and Sahajwalla V, 2016. Concentration of Precious Metals during Their Recovery from Electronic Waste.*Waste Management*, **57**: 121–130.

Cui J and Forssberg E, 2003. Mechanical Recycling of Waste Electric and Electronic Equipment : A Review. *Journal of Hazardous Material,* **99**: 243–263.

Demergasso C, Galleguillos P, Escudero L, Alvarez V, Castillo D and Casamayor E, 2005. Molecular Characterization of Microbial Populations in a Low-Grade Copper Ore Bioleaching Test Heap. *Hydrometallurgy,* **80** (4): 241–253.

Ghosh B, Ghosh MK, Parhi P, Mukherjee PS and Mishra BK, 2015. Waste Printed Circuit Boards Recycling: An Extensive Assessment of Current Status. *Journal of Cleaner Production,* **94**: 5–19.

Glombitza F and Reichel S, 2014. Metal-Containing Residues from Industry and in the Environment : Geobiotechnological Urban Mining. *Advances in biochemical engineering/biotechnology,* **141**: 49–107.

Habibi A, Kourdestani SS and Hadadi M, 2020. Biohydrometallurgy as an Environmentally Friendly Approach in Metals Recovery from Electrical Waste: A Review. *Waste Management and Research,* **38** (3): 232–244.

Hao J and Wang Y, 2020. Metal Recovery from Waste Printed Circuit Boards: A Review for Current Status and Perspectives. *Resources, Conservation and Recycling,* **157**: 104787.

He Z, Zhao J, Gao F, Hu Y and Qiu G, 2010. Monitoring Bacterial Community Shifts in Bioleaching of Ni – Cu Sulfide. *Bioresource Technology,* **101** (21): 8287–8293.

Herat S and Agamuthu P, 2012. E-Waste: A Problem or an Opportunity? Review of Issues, Challenges and Solutions in Asian Countries. *Waste Management and Research,* **30** (11): 1113–1129.

Hong Y and Valix M, 2014. Bioleaching of Electronic Waste Using Acidophilic Sulfur Oxidising Bacteria. *Journal of Cleaner Production,* **65**: 465–472.

Ilyas S, Anwar MA, Niazi SB and Ghauri MA, 2007. Bioleaching of Metals from Electronic Scrap by Moderately Thermophilic Acidophilic Bacteria. *Hydrometallurgy,* **88** (1–4): 180–188.

Islam A, Ahmed T, Awual MR, Rahman A, Sultana M, Aziz A, Monir MU, Teo SH and Hasan M, 2020. Advances in Sustainable Approaches to Recover Metals from E-Waste-A Review. *Journal of Cleaner Production,* **244**: 118815

Jadhao P, Chauha G, Pant KK and Nigam KDP, 2016. Greener Approach for the Extraction of Copper Metal from Electronic Waste. *Waste Management,* **57**: 102–112.

Jafari M, Abdollahi H, Shafaei SZ, Gharabaghi M, Jafari H, Akcil A and Panda S, 2019. Acidophilic Bioleaching: A Review on the Process and Effect of Organic–Inorganic Reagents and Materials on Its Efficiency. *Mineral Processing and Extractive Metallurgy Review,* **40** (2): 87–107.

Jain N and Sharma DK, 2010. Biohydrometallurgy for Nonsulfidic Minerals — A Review. *Geomicrobiology Journal,* **21**(3): 135-144.

Jhariya MK, Sahu KP and Raj A, 2014. E-Waste, A New Challenge to the Environmentalists Nature Environment and Pollution Technology. *Nature Environment and Pollution Technology,* **13**(2): 333–338.

Joseph K, 2007. Electronic Waste Management in India–Issues and Strategies. *Eleventh International Waste Management and Landfill Symposium,* Pp 1–9 .

Kaushik PR and Heart S, 2020. Current State of E-Waste Management in India. *International Journal of Environment and Waste Management,* **25**(3): 322–339.

Kavitha AV, 2014. Extraction of Precious Metals from E-waste. *Journal of Chemical and Pharmaceutical Sciences,* **3**: 147–149.

Krebs W, Brombacher C, Bosshard PP, Bachofen R and Brandi H, 1997. Microbial Recovery of Metals from Solids. *FEMS Microbiology Reviews,* **20** (3–4): 605–617.

Lee J, Kim Y and Lee JC, 2012. Disassembly and Physical Separation of Electric / Electronic Components Layered in Printed Circuit Boards (PCB). *Journal of Hazardous Materials,* **241–242**: 387–394.

Li J, Tian B, Liu T, Liu H, Wen X and Honda S, 2006. Status Quo of E-Waste Management in Mainland China. *Journal of Material Cycles and Waste Management,* **8**(1):13–20.

Lombardi AT and Garcia O, 2002. Biological Leaching of Mn, Al, Zn, Cu and Ti in an Anaerobic Sewage Sludge Effectuated by *Thiobacillus Ferrooxidans* and Its Effect on Metal Partitioning.” *Water Research,* **36** (13): 3193–3202.

Lu Y and Xu Z, 2017. Precious Metals Recovery from Waste Printed Circuit Boards : A Review for Current Status and Perspective. *Resources, Conservation & Recycling,* **113**: 28–39.

Shabani MA, Irannajad M, Azadmehr AR and Meshkini M, 2013. Bioleaching of Copper Oxide Ore by *Pseudomonas Aeruginosa*. *International Journal of Minerals, Metallurgy, and Materials,* **20** (12), 1130–1133.

Hubau A, Minier M, Chagnes A, Joulian C, Perez C and Guezennec AG, 2018. Continuous Production of a Biogenic Ferric Iron Lixiviant for the Bioleaching of Printed Circuit Boards (PCBs) Hydrometallurgy

180: 180–191.
Mishra D and Rhee YH. 2014. Microbial Leaching of Metals from Solid Industrial Wastes. *Journal of Microbiology*, **52** (1): 1–7.
Mousavi SM, Yaghmaei S , Vossoughi M , Roostaazad R , Jafari A, Ebrahimi M , Chabok OH and Turunen I, 2008. The Effects of Fe(II) and Fe(III) Concentration and Initial PH on Microbial Leaching of Low-Grade Sphalerite Ore in a Column Reactor. *Bioresource Technology*, **99** (8): 2840–2845.
Pinho S, Ferreirab M and Almeida MF, 2018. A Wet Dismantling Process for the Recycling of Computer Printed Circuit Boards. *Resources, Conservation & Recycling*, **132**: 71–76.
Prabhakar A, Mishra S and Das AP, 2019. Isolation and Identification of Lead (Pb) Solubilizing Bacteria from Automobile Waste and Its Potential for Recovery of Lead from End of Life Waste Batteries . *Geomicrobiology Journal*, **36** (10): 894-903.
Robinson BH, 2009. E-Waste: An Assessment of Global Production and Environmental Impacts. *Science of the Total Environment*, **408** (2): 183–191.
Saldaña-Durán CE, Bernache-Pérez G, Ojeda-Benitez S and Cruz-Sotelo SE,2020. Environmental Pollution of E-Waste: Generation, Collection, Legislation, and Recycling Practices in Mexico. *Handbook of Electronic Waste Management, Butterworth-Heinemann*, Pp 421–442.
Ch V Ramachandra Murthy. 2012. Management of E-Waste in the Present Scenario. *International Journal of Engineering and Technology*, **4** (5): 543–547.
Sinha R, Chauhan G, Singh A, Kumar A and Acharya S, 2018. A Novel Eco-Friendly Hybrid Approach for Recovery and Reuse of Copper from Electronic Waste. *Journal of Environmental Chemical Engineering*, **6** (1): 1053–1061.
Wang H, Han M, Yanga S, Chena Y, Liu Q and Ke S, 2011. Urinary Heavy Metal Levels and Relevant Factors among People Exposed to E-Waste Dismantling. *Environment International*, **37** (1): 80–85.
Wang J and Xu Z, 2014. Disposing and Recycling Waste Printed Circuit Boards : Disconnecting , Resource Recovery , and Pollution Control. *Environmental Science Technology*, **49**(2), 721–733.
Wath SB, Dutt PS and Chakrabarti T, 2011. E-Waste Scenario in India, Its Management and Implications. *Environmental Monitoring and Assessment*, **172** (1–4): 249–262.
Wath SB, Vaidya AN, Dutt PS and Chakrabarti T, 2010. A Roadmap for Development of Sustainable E-Waste Management System in India. *Science of the Total Environment*, **409** (1): 19–32.
Willner J, 2012. Leaching of Selected Heavy Metals from Electronic Waste in the Presence of the *At . Ferrooxidans* Bacteria. *The Journal of Achievements in Materials and Manufacturing Engineering*, **55** (2): 860–863.
Xin B, Zhang D, Zhang X, Xia Y, Wu F, Chen S and Li L, 2009. Bioresource Technology Bioleaching Mechanism of Co and Li from Spent Lithium-Ion Battery by the Mixed Culture of Acidophilic Sulfur-Oxidizing and Iron-Oxidizing Bacteria. *Bioresource Technology* **100** (24): 6163–6169.
Xiu FR, Qi Y and Zhang FS, 2015. Leaching of Au, Ag, and Pd from Waste Printed Circuit Boards of Mobile Phone by Iodide Lixiviant after Supercritical Water Pre-Treatment. *Waste Management* **41**: 134–141.
Yang Y, Chen S, Lib S, Chena M, Chena H and Liu B, 2014. Bioleaching Waste Printed Circuit Boards by *Acidithiobacillus Ferrooxidans* and Its Kinetics Aspect. *Journal of Biotechnology* **173** (1): 24–30.
Yu J, Eric W and Meiting J, 2009. Review and Prospects of Recycling Methods for Waste Printed Circuit Boards. *IEEE International Symposium on Sustainable Systems and Technology*, Pp 1-5.
Zhu N, Xiang Y, Zhang T, Wu P, Dang Z, Li P and Wu J, 2011. Bioleaching of Metal Concentrates of Waste Printed Circuit Boards by Mixed Culture of Acidophilic Bacteria. *Journal of Hazardous Materials*, **192** (2): 614–619.

How to cite this article

Rajesh M. Jorgewad, **Pooja V. Deshpande, Darshani S.Chopade, Manoj Mehta, 2021.** Global electronic waste treatment, challenges and management: a short review. *Bioscience Discovery*, **12**(2):83-95.

Google Scholar citation: https://scholar.google.co.in/citations?user=vPzEyC8AAAAJ&hl=en