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REVIEW ARTICLE

Review on Microbial remediation of Heavy metals from E-waste

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ABSTRACT: E-waste is an end of the life span of electric or electronic appliances which contain the complex heavy metals. It is causing severe health concerns for millions of people around the world, mostly in the developing nations of India, Africa, Europe, etc. More of these wastes are ending up in dumping yards and recycling centers, cause a new challenge to the environment. In general electronic gadgets are intended to make our lives happier and simpler, but their toxicity, removal and recycling becomes a health horrendous. Many research papers have been reported on microbial remediation of heavy metals present in E-waste. The pioneer work was reported on 1998, bio-dissolution of spent nickel batteries using *Thiobacillus ferroxidans,* which is the first step to recycle and discarded batteries by using microbes as eco-friendly method. This review paper provides an insight in to the bioremediation of heavy metals from E-waste by potential microorganisms, in an eco-friendly way and provide pathway for current researchers.
Keywords: E-waste (Electronic and electric) waste, Bioremediation, Heavy metals, *Thiobacillus ferroxidans*.

INTRODUCTION

The revolution brought by information and communication in twentieth century brought enormous changes in the way we organize our lives, our economies, industries and institutions (Devendra S Verma, 2014). In most of the developing and underdeveloped countries, e-waste is dumped directly into the soil without any treatment; often due to weak environmental regulations and financial problems. For profitable recovery of materials and sustainable environment, the efficient recycling of electronic waste is very necessary, and is still regarded as a major challenge for today's society (Shubham Gupta, 2014).

According to Centre of Science and Environment's latest reports, every year our country is producing 3, 50,000 tonnes of e-waste, 5,0000 tonnes of electronic waste is imported but only 19000 tonnes is rejected. Out of total e-waste 10 states contribute about 70% of e-waste, leading states are- Maharashtra, Tamil Nadu, Andhra Pradesh, Uttar Pradesh. E-waste is highly complex to handle due to its composition. It is made up of multiple components some of which contain toxic substances that have an adverse impact on human health and environment if not handled properly and mixed with municipal waste.

Electronic wastes can cause widespread environmental damage due to the use of toxic materials in the manufacture of electronic goods (Mehra, 2004). H azardous materials in one form or the other are present in such wastes primarily consisting of electronic equipment. Even though it is hardly known, E-waste contains toxic substances such as Lead and Cadmium in circuit boards, lead oxide and Cadmium in monitor Cathode Ray Tubes , cables and polyvinyl chloride cable insulation that releases highly toxic dioxins and furans when burned to recover Copper from the wires.

All electronic equipment contains printed circuit boards which are dangerous because of their content of lead. The microorganisms for remediation of complex or co-contaminated system, they must possess tolerance and detoxification abilities towards different types of pollutants. These properties help them prolong and bioremediation in complex and mixed polluted systems like e-waste.

Microbes possessing such novel properties can be either isolated from natural contaminated sources (soil contaminated with e-waste or leachate from e-waste landfill sites), or obtained through engineering processes. Such microbes, individually or as consortia, can be used for decontamination of e-waste. Certain microorganisms with their unique tolerance mechanisms are able to grow and degrade or transform toxicants into nontoxic forms. (Amrik Bhattacharya, 2016).

Categories of E-waste

It can be categories on the basis of hazardous and non- hazardous waste and more than one thousands e- waste comes under this category (Wath *et al.,* 2010). According to the European Union electrical and electronic equipment available on the market have divided e-waste types into ten categories such as Large household Appliances, Small household appliances, IT and telecommunications

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,Equipment, Consumer equipment, Light equipment, Electrical and electronic tools, Toys, leisure, and sports, Equipment, Medical devices, Monitoring and control Instruments, Automatic dispensers.

Techniques used to handle E-waste

There are basically four ways in which e-waste has been treated till date. But none has been found to be fully satisfactory. The first and most common one has been storing e-wastes in landfills, but it is replete with all the dangers of leaching. The hazardous effects are worse in the older or less stringently maintained landfills or dumpsites. The second method commonly used has been to incinerate or burn the goods, but this process releases heavy metals such as lead, cadmium and mercury into the atmosphere. The third and the fourth methods are reusing and recycling of E-wastes. They have been preferable because they increase the lifespan of the products and therefore imply less waste over time. These are the four different and common method used to handle the waste all over the world. Each method has its own drawbacks and limitations. (Bikashdev Chhura, *et al.,* 2015). To facilitate take the edge off e-waste problems, there are investigations in term of the quantity, character and potential environmental and human health impacts of e-waste and broad research into e-waste management.

Table: 1.Microbial Remediation of Heavy metals present in E-waste

S.No	Metals	Source of Metals Studied	Microorganism	Bioremediation Process/Methods	Reference
1.	Cu	Cu- rich e-waste	*Acidithiobacillus ferroxidans, Acidithiobacillus thiooxidans Aspergillus niger*	Bioleaching	Saidan and M.Valix, 2006
2.	Cu	Waste Printed circuit board (PCB)	Bacterial consortium enriched from natural acid mine drainge	Bioleachning	Yun Xiang, *et al.,* 2010
3.	Au, Ag	PCB	-	Manual	Chatterjee, *et al.,* 2009
4.	Cr, Pb, Cu	Solid & Liquid Waste	*Staphylococcus saprophyticus,*	Biosorption	Ashok kumar, *et al.,* 2011
5.	Ni	PCB	mesophilic chemolititrophic bacterial culture of *A. ferrooxidans and A. thiooxidans*	Bioleaching	Anna Mrazikova, 2014
6.	Au	E waste	*Chromobacterium violaceum, Pseudomonas fluorescens, Pseudomonas aeruginosa* and *Escherichia coli.*	Bioleaching	Chang jin Liang, *et al.,* 2011
7.	Cu, Al, Zn	PCB	Mixed culcture of Acidophilic Bacteria	Bioleachning	Nengwu Zhu, *et al.,* 2011
8.	Cu, Ni, Al, Zn	Electronic scrap	*Acidithiobacillus ferroxidans Acidithiobacillus* thiooxidans	Bioleaching	Willner, *et al.,* 2013 and Kavitha, 2014.
9.	Cu, Ni, Al, Zn	Electronic scrap	*Acidithiobacillus ferroxidans, Acidithiobacillus thiooxidans*	Bioleaching	Brandl, *et al.,* 2001
10.	Cu, Ni, Sn, Pb, Zn, Al	Electronic scrap	*Aspergillus niger Penicillium simplicissimum*	Bioleaching	Brandl, *et al.,* 2001
11.	Cu	PCB	*Acidithiobacillus ferroxidans*	Bioleaching	Tao yang, *et al.,* 2009
12.	Cu	Printed wire	*Acidithiobacillus*	Bioleaching	Jingwei wang *et*

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		boards	*ferroxidans, Acidithiobacillus thiooxidans A. ferroxidans + A. thiooxidans*		*al.,* 2009
13.	Ni, Cu, Al, Zn, Pb, Sn	Electronic scrap	*Sulfobacillus thermosulfidooxidans*	Bioleaching	Ilyas, *et al.,* 2007
14.	Cu, Al, Zn, Ni	Electronic scrap	*Thermosulfidooxidans sulfobacillus + Thermoplasma acidophilum*	Column Bioleaching	Ilyas, *et al.,* 2010
15.	Au	Printed electronic circuits	*Chromobacterium violaceum*	Bioleaching	Faramarzi, *et al* 2004
16.	Li, Co	Lithium batteries	*Acidithiobacillus ferroxidans*	Bioleaching	Joanna willner, 2013
17.	Li, Co	Lithium batteries	*Acidithiobacillus ferroxidans*	Bacterial leaching	Debaraj Mishra, *et al.,* 2008
18.	Ag, Au, Pt	Jewellery waste, automobile catalytic converter, electronic scrap	*Chromobacterium violaceum, Pseudomonas fluorescens, Pseudomonas plecoglossicida*	Biomobilization	Brandl, *et al.,* 2008
19.	Ni,Co, Cr &Mn	Ores	*Acidithiobacillus ferroxidans*	Biomining	Barrie Johnson, *et al.,* 2013
20.	Zn, Ni, Pb	PCB	*Acidithiobacillus ferroxidans*	Bioleaching	Joanna willner, 2012
21.	Ni, Cd	Spent Ni - Cd batteries:	*Acidithiobacillus ferroxidans*	Bioleaching	O.Velgosova, , *et al.,* 2012 and O.Velgosova, *et al.,* 2014
22.	Cu, Au, Zn, Fe	E waste	*Chromobacterium violaceum, Pseudomonas aeruginosa, Pseudomonas fluorescens*	Bioleaching	Jatindra Kumar Pradhan, *et al.,* 2012
23.	Au, Cu, Ni	Cellular phone PCBs and Computer gold finger motherboards	*Aspergillus niger MXPE6 + Aspergillus niger MX7,*	Bioleaching	Jorge Enrique Madrigal-Arias, *et al.,* 2014
24.	Cu, Zn, Ni	PCB	*Acidiphilium acidophilum*	Bioleaching	Rivero Hudec, *et al.,* 2009
25.	Cu, Cd, Pb	Electroplating industrial effluent samples	*Bacillus sp, Pseudomonas sp. Micrococcus sp.*	Biosorption	Johncy Rani, *et al.,* 2010
26.	Ni, Au, Cu	Nickel powder, PCB scrap	*C. violaceum, P. fluorescens, B. megaterium*	Microbial mobilization	Mohammad Faramarzia, *et al.,* 2004
27.	Pb, As, Cd, Ni, Cu, Zn, Al, Co, Mn	Mine Waste Disposal Sites	*Sulfobacillus* sp. *Sulfidobacillus* sp. *Acetobacter acidophilum*	Biosorption	Petrisor, *et al.,* 2002

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			Alcaligenes entrophus Pseudomonas putida		
28.	Cd	E waste	*Pseudomonas aeruginosa JN102340*	Biosorption	Kumar, 2014
29.	Pb	E waste	*Aspergillus fumigatus*	Biosorption	Rajesh kumar Ramasamy, *et al.*, 2011
30.	Cd	E waste	*Aspergillus sp.*	Biosorption	Ramasamy Rajesh Kumar, *et al.*, 2012
31.	Mn	E waste	*Helminthosporium solani*	Biosorption	Savitha, *et al.*, 2010
32.	Ni , Cd	Bio-dissolution of spent Nickel-Cadmium batteries	*At. ferrooxidans*	Bioleaching	Cerruti, *et al.*, 1998
33.	Ni , Cd	Spent Nickel-Cadmium batteries	*Indigenous acidophilic thiobacilli*	Bioleaching	Zhu *et al* , 2003
34.	Ni , Cd	Spent Ni-Cd battery	*At. ferrooxidans, & At. thiooxidans*	Bioleaching	O. Velgosova, *et al.*, 2010
35.	Cu	PCB of waste Computer	*Acidithiobacillus ferroxidans*	Bioleaching	Choi, *et al.*, 2004
36.	Cu, Pb, Zn	Printed wire boards	*Acidithiobacillus ferroxidans,+ Acidithiobacillus thiooxidans*	Bioleaching	Wang, *et al.*, 2009
37.	Cu, Ni, Zn	PCB	*Acidithiobacillus thiooxidans Acidithiobacillus ferrooxidans*	Bioleaching	Liang, *et al.*, 2010
38.	Ag	Waste photographic films	*Bacillus subtilis ATCC 6633*	Enzymatic Method	Nakiboglu, *et al.*, 2001
39.	Ag	Waste X-ray film	*Conidiobolus coronatus*	Enzymatic Method	Shankar, *et al.*, 2010
40.	Ag	X-ray films	*Bacillus sphaericus*	Enzymatic Method	Singh, *et al.*, 1999
41.	Ag	Lith Film	*Bacillus* sp. B21–2	Enzymatic Method	Masui, *et al.*,2004
42.	Cr, Cu, Ni, Co, Cd, and Zn	Dumping municipal soil area	*Pseudomonas* spp. *Bacillus* spp	Resistance	Ersoy Sevgi, *et al.*, 2009
43.	Cd	Contaminated site	*Pseudomonas aeruginosa* S22	Resistance	El-Sayed, *et al.*,2008
44.	Uranium	Mine waste	*Pseudomonas aeruginosa*	Biosorption	Michael Z. and Hu,*et al.*,1996
45.	Hg, Pb, Ag, ZN, Cu,	Industry waste	*Bacillus* species	Bioaccumulation	Meghraj Hookoom, *et al.*,

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					2013
46.	Ar, Pb, Cd	E waste	*A.Thioxidans, Micrococcus roseus, T. ferrooxidans, Aspergillus fumigates, A. niger*	Bioleaching	Stephen , Macnaughtont, 1999,and Shuchi Patel *et al.,* 2014
47.	Cr, Ur, Cd, Pb	Industrial waste	*Bacillus sphaericus, Myxococcus Xanthus, Pseudomonas aeruginosa, Streptoverticillium Cinnamoneum, Rhizopus arrhizus, Saccharomyces cerevisiae*	Biosorption	Hu, *et al.,* 1996, Atkinson, *et al.,* 1998; Ahalya *et al.,* 2003 and Shuchi Patel etal, 2014
48.	Cr, Ur, Pb	Heavy metal presenting waste	*Bacillus circulans , Bacillus megaterium, Deinococcus radiodurans , Micrococcus luteus, Aspergillus niger, Monodictys pelagic*	Bioaccumulation	Demirba , 2001; Srinath, *et al.,* 2002, Malik, 2004; Juwarkar, Yadav, 2010 and Shuchi Patel, *et al.,* 2014
49.	Ur, Cr, Cd	Heavy metal presenting waste	*Anaeromyxobacter sp. Clostridium sphenoides Halomonas sp. Serratia sp. Fusarium oxysporum Rhizopus oryzae*	Biotransformation	Lovley and Coates, 1997; Francis, 1998; Malik, 2004 and Shuchi Patel, *et al.,* 2014
50.	Cu	Electronic Waste	*Acidithiobacillus* bacteria	Bioleaching	Saidan, *et al.,* 2012
51.	Au	Cellular phone Printed circuit board	*A. niger* MXPE6 and *A. niger* MX7	Bioleaching	Madrigal-Arias, 2015
52.	Cu	Printed circuit board	*S. thermosulfidooxidans*	Bioleaching	Rodrigues, *et al.,* 2015
53.	Ni, Cu, Al, Zn	Electronic scrap	*S. thermosulfidooxidans* and acidophilic heterotrophy (code A1TSB)	Bio solubilization	Tang, *et al.,* 2016
54.	Pb	E waste landfill	*Bacillus licheniformis*	Biosorption	Gayatri, *et al.,* 2017

Ar-Arsenic,Pb- Lead, Cd-Cadmium,Cr- Chromium, U-Uranium, Ni- Nickel, Cu-Copper, Al-Alumnium, Zn-Znic, Sn-, Co-cobalt, Mn-Manganese, Ag-Silver, Fe-Ferrous, Pt-Platinum, Li-Lithium, Au- Gold

CONCLUSION

E-Waste containing toxic metals which need to be remediated efficiently from contaminated surroundings. To reduce the toxic metals effect on environment and living beings. Biological methods one of the potential methods to minimize the toxicity associated with e-waste contaminants in sustainable way. So we need to spread the awareness of proper handling of E-waste such as reduce, reuse and safe recycle process.

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CONFLICTS OF INTEREST

"The authors declare no conflict of interest".