ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Methodological review on recovery of gold from E-waste in India

P. Prasanna Natesh[a]*, S.Govindaradjane[b], S.Pradeep Kumar[b]
[a]* Environmental Engineering, Pondicherry Engineering College, Puducherry
[b]Dept of Civil Engineering, Pondicherry Engineering College, Puducherry

ABSTRACT

Electronics industry is one of the fastest growing manufacturing industries in India. But the increase in sales of electronic goods and their rapid obsolescence has resulted in generation of electronic waste (E-Waste).E-Waste is among the most rapidly growing problem in the world and about 50-80% of this waste is being exported to developing countries, especially Asia and Africa. E-Waste contains lots of heavy metals and also precious metal, in which Gold, Silver and Platinum are present.Gold has vast industrial application, high market value and extensively used precious metal. The sanctuary value attributed to gold during international political and economic crises and limited resource of this metal may explain the recent increasing gold values. This paper mainly deals about gold which is present in E-Waste, current status of E-Waste generation in India and various methodologies used for the recovery of gold. The methodologies such as Pyro-metallurgy, Hydrometallurgy and Bio-hydrometallurgy technologies are analysed, and also the evaluation of recovery efficiency of gold from E-Waste.

Keywords: E-Waste, Methodologies, Gold recovery, Precious metal, Recovery efficiency

INTRODUCTION

The industrial revolution followed by the advances in information technology during the last century has radically changed people's lifestyle. Although this development has helped the human race,and also it leads to globalization market and increased contamination due to the above said fact, the waste generated from waste electrical and electronic equipment (WEEE) creates new problems as they contaminate the environment and ultimately affect human health. The technical process acquired during this century has posted new challenges in the management of electronic waste. For example, personal computers.

Electronic waste contains a wide range of metals 50% of which constitutes of iron and steel followed by 21% plastics, 13% nonferrous metals and 16% other constituents like rubber, concrete and ceramics. E waste is classified as hazardous if the elements like lead, mercury, arsenic, cadmium, selenium, and hexavalent chromium and flame retardants are present beyond permissible quantities (Hageluken, 2006; CPCB, 2007; Pant, 2010), many of which are toxic and create serious problems if not handled properly (Chatterjee, 2008). The processing of such E-waste could cause immediate risks to human health and environment (Li et al., 2008) by releasing substantial quantities of toxic heavy metals and organic compounds to the workplace environment (surrounding soils, and drainage water) (Shen et al., 2009; Yang et al., 2009; Zheng et al., 2008).

Table.1.Metals present in various type of WEEE's

Equipment	Lead	Nickel	Aluminium	Iron	Copper	Silver	Gold	palladium	Reference
	Metals present in %					Metals present in ppm			
Printed Wiring board	26	29	29	29	22	-	0.04	-	Scharnhorst et al. (2005)
PCB scrap	2-3	2	7	12	16	280	110	-	CPCB (2007)
PC board scrap	1.5	1	5	7	20	1000	250	110	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
PC main board scrap	2.2	1.1	2.8	4.5	14.3	639	566	124	Legarth et al. (1995) and Cui and Zhang (2008)
TV board scrap	1	0.3	10	28	10	280	17	10	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
Mobile phone scrap	0.3	0.1	1	5	13	1340	350	210	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
Portable audio scrap	0.14	0.03	1	23	21	150	10	4	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
DVD player scrap	0.3	0.05	2	62	5	115	15	4	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
Calculator Scrap	0.1	0.5	5	4	3	260	50	5	Bandyopadhyay (2008), Hageluken and Art (2006) and Hageluken (2006)
TV Scrap	0.2	0.04	1.2	-	3.8	27.1	27.1	27.1	Kang and Schoenung (2005) and Cui and Zhang (2008)
PC Scrap	6.3	0.85	14.17	20.47	6.93	189	16	3	Kang and Schoenung (2005) and Cui and Zhang (2008)

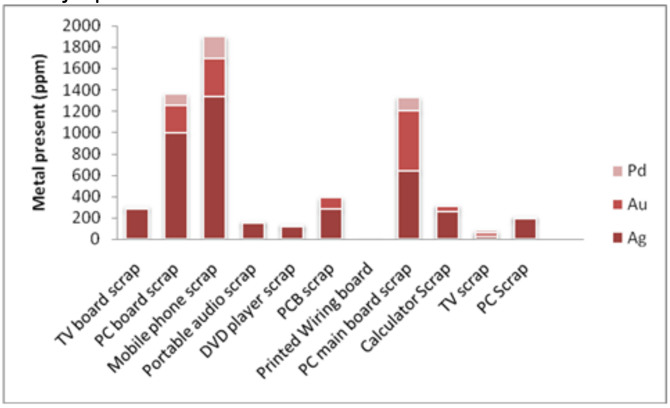

Fig.1.Precious metals present in various WEEE

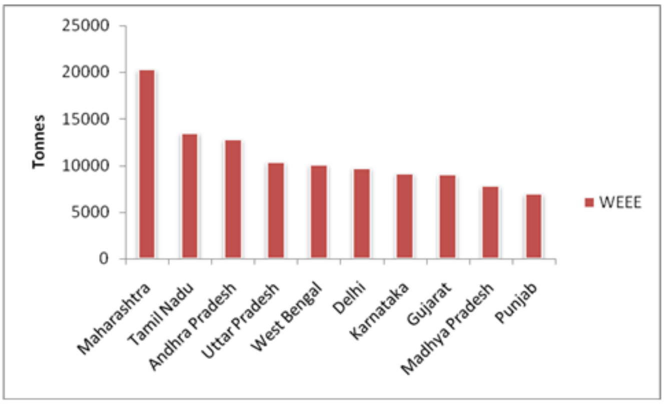

Fig.2.WEEE generation in top ten Indian states

Various metals present in WEEE are summarized in Table 1. Among these metals gold is a comparatively exceptional precious metal with a singular beauty and is treasured because of its color. Besides, as an extraordinary ductile and malleable metal, it is still cosmic demand in jewelry, high-tech industries and medical applications, because of their unique physical and chemical properties (Ramesh et al., 2008; Spitzer and Rodnei, 2004). During the last four decades, considerable quantities of gold have been used by the electronic and electrical industries in view of its excellent electrical conductivity, low contact electrical resistance for inserting connections and outstanding corrosion resistance (Baba, 1987). Growing demand for gold makes it crucial to recover the gold from the inevitably increasing waste products (Syed, 2006). Thus the gold component has become a candidate for recovery (Khalemskii et al., 1998; Leao and Ciminelli, 2000; Li, 1998; Zhao et al., 1999).

Table.2.WEEEgenerating in Indian states (IRGSSA, 2005)

States	WEEE (Tonnes)	States	WEEE (Tonnes)
Andaman and Nicobar Island	92.2	Lakshadweep	7.4
Andhra Pradesh	12780.33	Maharashtra	20270.59
Arunachala Pradesh	131.7	Madhya Pradesh	7800.62
Assam	2176.7	Manipur	231.7
Bihar	3055.6	Meghalaya	211.6
Chandigarh	359.7	Mizoram	79.6
Chhattisgarh	2149.9	Nagaland	145.1
Dadra and Nagar Haveli	29.4	Orissa	2937.8
Daman and Diu	40.8	Pondicherry	284.2
Delhi	9729.15	Punjab	6958.5
Goa	427.4	Rajasthan	6326.9
Gujarat	8994.3	Sikkim	78.1
Haryana	4506.9	Tamil Nadu	13486.24
Himachal Pradesh	1595.1	Tripura	378.3
Jammu and Kashmir	1521.5	Uttar Pradesh	10381.11
Jharkhand	2021.6	Uttarakhand	1641.2
Karnataka	9118.74	West Bengal	10059.36
Kerala	6171.8	**Total**	146180.7

Table 2 shows the amount of wastes generated by each state in India. In all Indian states Maharashtra is the highest producer of WEEE. After that Tamilnadu and Andhra Pardesh takes place. Figure 2 reveals the top ten E-waste generator states. From table 1&2, it is obviously comes to know that 128.285mg of gold which is present in per kg of E-waste and the total WEEE generated by Indian state is 146180.7 tonnes. From the above said facts, it is correlated that 18.7527 tonnes of gold can be present in 146180.7 tonnes of WEEEand 18.5652 tonnes of gold can be recovered because the recovery efficiency of the gold is 99% (MoEF and CPCB, 2008).

Recovery methodology for gold:

Pyro-metallurgy: In this process, the crushed gold containing scraps are burned in a high temperature by incineration, smelting in a plasma arc furnace or blast furnace, dressing, sintering, melting and reactions in a gas phase at high temperatures has become a conventional method to recover gold from ores and secondary spent materials since three decades and impurities are removed in some way, they may be volatilized by a chemical reaction or by heat, or may be converted to slags which rise to the surface of molten metal, or sludges which sink to the bottom (Hoffmann, 1992; Lee et al., 2007; Sum, 1991). As a traditional technology, pyro-metallurgy has been used for recovery of gold from spent materials. However, it has encountered some challenges from environmental considerations. Consequently, state of the art smelters are highly dependent on investments (S. Syed, 2012).

Hydrometallurgy: The main steps in hydrometallurgical processing consist of a series of acid or caustic leaches of gold containing material. The solutions are then subjected to separationand purification procedures such as precipitation of impurities, solvent extraction, adsorption and ion-exchange to isolate and concentrate the metals of interest. Consequently, the solutions are treatedby electro-wining, cementation, chemical reduction, or crystallization for gold recovery (Sadegh et al., 2007). Today, attentions have been removed to hydrometallurgical process for recovery of gold from secondary sources because most of the gold produce in the world is recovered by hydrometallurgical techniques. Cyanide leaching of gold has been used by the mining industries for more than 100 years. However, a series of environmental accidents at various gold recoveries around the world has precipitated widespread concern over the use of cyanide. Based on a critical comparison of various leaching methods from the economic points of view, feasibility and environmental impact, it is concluded that leaching of gold by thiourea and other potential leachants may be the most realistic substitute. These leaching should be taken into consideration due to a rapid reaction with gold, as well as less environmental impact compared with cyanide (S. Syed, 2012).

Table.3.Types of hydrometallurgical techniques for gold recovery

Sl.No	Types of hydrometallurgical Techniques	pH	Metals to beextracted/recovered	Reagents concentration	Reference
1	**Chemical leaching**				
i	Cyanide leaching	9-10	Au, Ag, Pd, Pt	~1%	Cui and Zhang (2008) and Belfer and Binman (1996)
ii	Thiourea leaching	1-2	Au and Ag	~10–12 g/L	Zhong et al. (2006), Cui and Zhang (2008), Johnson et al. (2008) and Wu et al. (2009)
iii	Halide leaching chlorine iodine	6 3-10	Au	High	Cui and Zhang (2008)
iv	Thiosulphate leaching	9–10	Au	0.1–0.14 M	Cui and Zhang (2008), Ha et al. (2010) and Ji et al. (2011)
2	**Using Acid**				
i	Sulfuric acid		Cu Zn, Ni, Pb, Cd and Cr	100 mL or 15%	Baba et al. (2010), Bayat and Sari (2010) andYang et al. (2011)
ii	Hydrochloric acid		Au, Cu, Ag and Pa	4 or 0.2–5 M	Liu et al. (2011) and Baba et al. (2010)
ii	Aqua-regia	below 1	Au	50–100 mL	Sheng and Etsell (2007)
iv	H_2SO_4 and HNO_3		Ni, Cd, Pb and Ag	50–100 mL	Nnorom and Osibanjo (2009) and Nnorom et al. (2010)
v	Sodium hypochlorite (along with acid or alkali)	6	Au	6 mL/L of NaClO	Li et al. (2011)
3	**Hydrometallurgical etching**				
i	$FeCl_3$, $CuCl_2$ and HCl.		Precious metals (e.g. Au)	100 g/L	Barbieri et al. (2009)
ii	Organic solvent		Fe, Cu, Al Ni, Au, Ag		Lee et al. (2009)

Bio-hydrometallurgy: There are two main areas of bio-hydrometallurgy for recovery of gold, namely bio-oxidation and bio-sorption. Bio-oxidation has been successfully applied in recovery of gold from metallic sulfides, which are the major bearing minerals of gold, and spent electronic materials, by the use of bacterially assisted reactions. The extraction of gold is industrially produced in significant proportions by this way (Morin et al., 2006). Bio-sorption process is a passive physico-chemical interaction between the charged surface groups of micro-organisms and ions in solution, in which living as well as dead organism can be used.

Bio-hydrometallurgy has been one of the most capable technologies in gold metallurgical processing. Bio-oxidation has been used for recovery of gold from spent materials. However, limited researches were carried out on the bioleaching of gold from secondary sources. Research in biosorption of gold from leaching solutions has received great deal of attention in the recent years using various potential biosorbents. Compared to conventional methods of recovery, a biosorption based process offers a number of advantages including eco-friendly, easy operation, low costs and minimization of chemical or biological sludge. It was reported that living or dead biomass including bacteria, fungi, yeast, and algae has been used for recovery of gold from wastewater. It should be pointed out here that biomass of all groups has been immobilized by encapsulation or cross-linking to improve the stability and other physical/chemical properties (S. Syed, 2012).

Table 4 Various microorganisms used for gold recovery

Sl.No	Microorganism	Species
1	Bacteria	Pseudomonas aeruginosa, Stenotrophomonas maltoplia, Plectonema boryanum,
2	Fungi	Verticillium luteoalbum, Trichothecium sp
3	Actinomycetes	Rhodococcus sp
4	Yeast	Yarrowia lipolytica
5	Algae	Calothrix pulvinata, Anabaena flos-aquae, Leptolyngbya foveolarum, Laminaria japonica

CONCLUSION

The presence of metals and precious metals in WEEE are discussed and it is clearly given that the amount of gold which is present in WEEE per kilogram and its recovery from total WEEE generated in India are also discussed. The recovery methodology and its various application have also discussed.

REFERENCES

Baba, H, An efficient recovery of gold and other noble metals from electronic and other scraps. Conserv. Recycl. 10 (4), 1987, 247–252.

Bandyopadhyay, A., 2008. A regulatory approach for E-waste management: a cross national review of current practice and policy with an assessment and policy recommendation for the Indian perspective. International Journal of Environment and Waste Management 2 (1-2), 2008.

Barbieri, L., Goivanardi, R., Lancellotti, I., Michelazzi, M, A New environmentally friendly process for the recovery of gold from electronic waste. Environmental Chemistry Letters, 8 (2), 2009, 171–178.

Bayat, B., Sari, B, Comparative evaluation of microbial and chemical leaching processes for heavy metal removal from dewatered metal plating sludge. Journal of Hazardous Materials 174 (1–3), 2010, 763–769.

Chatterjee, P, Health costs of recycling. British Medical Journal 337, 2008, 376–377.

CPCB, Draft guidelines for environmentally sound management of electronic waste, 2007, 10–25

Cui, J., Zhang, L, Metallurgical recovery of metals from electronic waste: a review. Journal of Hazardous Materials 158, 2008, 228–256.

Hageluken, C. and Art, S., 2006. 'Recycling of E-scrap in a global environment – chances and challenges: umicore precious metals refining'. Indo–European training workshop, 4–5 and 8–9 May 2006, Bangalore and New Delhi.

Hageluken, C., 2006. Improving metal returns and eco-efficiency in electronics recycling – a holistic approach for interface optimisation between preprocessing and integrated metals smelting and refining. IEEE International Symposium on Electronics and the Environment, 218, 23.

Hoffmann, J.E, Recovering precious metals from electronic scrap. J.Miner.Metall.Mater. Soc. 44 (7), 1992, 43–48.

Johnson, D.B., Okibe, N., Wakeman, K., Yajie, L, Effect of temperature on the bioleaching of chalcopyrite concentrates containing different concentrations of silver. Hydrometallurgy 94 (1–4), 2008, 42–47.

Kang, H., Schoenung, J, Electronic waste recycling: a review of US infrastructure and technology options. Resources, Conservation and Recycling, 45, 2005, 368–400.

Khalemskii, A.M., Payvsov, S.A., Kadnikov, S.A., Talanov, A.G., Tumashov, Y.S, Recovery of Au and Ag from material containing non-ferrous metals and Fe including leaching by KCNO method. Russian Patent, RU 2109826 Cl, 1998, 2.

Leao, V.A., Ciminelli, V.S.T, Application of ion exchange resins in gold hydrometallurgy. A tool for cyanide recycling. Solvent Extr. Ion Exch. 18 (3), 2000, 567–582.

Lee, J.C., Song, H.T., Yoo, J.M, Present status of the recycling of waste electricaland electronic equipment in Korea. Resour. Conserv. Recycl. 50 (4), 2007, 380–397.

Lee, J.C., Yoo, J.M., Jeomg, J.K., Jha, M.K, Novel pre-treatment process for liberation of metals from waste printed circuit boards using organic solution, Patent Publication No.: WO/2009/064063, 2009.

Legarth, J.B., Altisng, L., Baldo, G.L, Sustainability issues in circuit board recycling. IEEE International Symposium on Electronics and the Environment, 126, 1995, 31.

Li, J., Huang L., Xu X., 2011. Experimental research of leaching gold from waste printed circuit board by sodium hypochlorite method, Chinese Journal of Environmental Engineering 2 DOI CNKI:SUN:HJJZ.0.2011-02-045.

Li, S, Recovery of gold from gold-bearing waste materials containing organic substances, Huangiin, 19 (5), 1998, 42–43.

Li, Y., Xu, X., Liu, J., Wu, K., Gu, C., Shao, G., Chen, S., Chen, G., Huo, X, The hazard of chromium exposure to neonates in Guiyu of China. Science of the Total Environment, 403, 2008, 99–104.

Liu Y, Su G, Zhang B, Jiang G, Yan B, Nanoparticle-based strategies for detection and remediation of environmental pollutants. Analyst 136, 2011, 872–877.

MoEF and CPCB, 2008. Guidelines for Environmental Sound Management of E-waste, pp. 72

Morin D, Lips A, Pinches T, Huisman J, Frias C, Norberg A, Forssberg E, Bio-MinE - integrated project for the development of biotechnology for metal-bearingmaterials in Europe. Hydrometallurgy 83, 2006, 69–76.

Nnorom, I.C, Osibanjo, O, Toxicity characterization of waste mobile phone plastics. Journal of Hazardous Materials, 161 (1), 2009, 183–188.

Nnorom, I.C, Osibanjo, O, Okechukwu, K., Nkwachukwu, O., Chukwuma, R.C, Evaluation of heavy metal release from the disposal of waste computer monitors at an open dump. International Journal of Environmental Science and Development, 1 (3), 2010, 227–233.

Pant, D, ElectronicWaste Management, Lambart Academic Publishing, 2010, 3–16.

Ramesh, A., Hasegawa, H., Sugimoto, W., Maki, T., Ueda, K, Adsorption of gold (III), Platinum(IV) and palladium(II) onto glycine modified crosslinked chitosan resin. Bioresour. Technol. 99, 2008, 3801–3809.

S. Syed, Recovery of gold from secondary sources-A review. Hydrometallurgy 115-116, 2012, 30-51

Sadegh, M., Safarzadeh, M.S., Bafghi, D., Moradkhani, A review on hydrometallurgical extraction and recovery of cadmium from various resources. Miner. Eng, 20(3), 2007, 211–220.

Scharnhorst,W., Althaus, H.J., Classen, M., Jolliet, O., Hilty, L.M., The end of life treatment of second generation mobile phone networks: strategies to reduce the environmental impact. Environmental Impact Assessment Revision 25, 2005, 540–566.

Shen C, Chen Y, Huang S,Wang Z, Yu C Qiao, M Xu Y, Setty K, Zhang J, Zhu, Y Lin Q, Dioxin-like compounds in agricultural soils near E-waste recycling sites from Taizhou area, China: chemical and bioanalytical characterization. Environment International 35, 2009, 50–55.

Sheng, P.P., Etsell, T.H., 2007. Recovery of gold from computer circuit board scrap using aqua regia. Waste Management and Research 25, 380–383.

Spitzer, M., Rodnei, B., 2004. Selective electrochemical recovery of gold and silver from cyanide aqueous effluents using titanium and vitreous carbon cathodes. Hydrometallurgy 74, 233–242.

Sum, E.Y.L, The Recovery of Metals from Electronic Scrap. J. Miner. Metall. Mater.Soc, 43 (4), 1991, 53–61.

Syed, S, A green technology for recovery of gold from non-metallic secondary sources, Hydrometallurgy 82, 2006, 48–53.

Takashima, M, Method for recovering aluminum from materials containing metallic aluminum. US Patent No. 5 855, 1999, 644.

Wu, J.B., Qiu, L.J., Chen, L.B., Chen, D.H., 2009. Gold and silver selectively leaching from printed circuit boards scrap with acid thiourea solution, Non-Ferrous Metals 4 (DOI CNKI:SUN:YOUS.0.2009-04-020).

Yang, Z.Z., Zhao, X.R., Qin, Z.F., Fu, S., Li, X.H., Qin, X.F., Xu, X.B., Jin, Z.X, Polybrominated diphenyl ethers in mud snails (Cipangopaludina cahayensis) and sediments from an electronic waste recycling region in south China. Bulletin of Environmental Contamination and Toxicology, 2009, 82, 206–210.

Zhao, J., Wu, Z., Chen, J.C, Separation of gold from other metals in thiosulfate solutions by solvent extraction. Sep. Sci. Technol, 34 (10), 1999, 2061–2068.

Zheng, L., Wu, K., Li, Y., Qi, Z., Han, D., Zhang, B., Gu, C., Chen, G., Liu, J., Chen, S., Xu, X., Huo, X, Blood lead and cadmium levels and relevant factors among children from an E-waste recycling town in China. Environmental Research, 108, 2008, 15–20.