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Extraction of gold from electronic scraps: a biohydrometallurgical process overview

D P Krishna Samal[1], Lala Behari Sukla[1,*], Archana Pattanaik[1], Debabrata Pradhan[1]

[1]Biofuels and Bioprocessing Research Center, Institute of Technical Education and Research, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar-751030, India

*corresponding author e-mail address: ***lalabeharisukla@soa.ac.in*** | 6603724593

ABSTRACT

The explosive growth in the electronics industries has revolutionized modern human life. This has resulted in the enhanced electronic wastes (E-wastes) generation which affects adversely on the global environment. The E-wastes are the end life electronics devices like computers, televisions, VCRs, stereos, copiers, mobile phones, and fax machines, generally discarded without following the standard procedure established by the environmental protection agencies of different countries. They are assembled of different materials which compose various toxic metals and organic compounds; therefore, there is the risk of environmental leaching problems when discarded as such without precaution. There are different policies and steps established for the E-wastes management and the recovery of valuable metals from them is one of the suitable steps. They contain different valuable metals like copper, silver, gold, palladium, rhodium and harmful substances like beryllium, cadmium, mercury, and lead. Gold is a precious metal, which can be recovered by applying conventional techniques such as pyro- and hydro- metallurgy. However, environmental risks are always associated with the above techniques. Bio-hydrometallurgy technique has potential to overcome the issues related to the conventional techniques. Different microorganisms help directly or indirectly in the dissolution reactions of gold from the E-wastes. Acidophilus microorganisms, such as *Chromobacterium violaceum*, *Acidithiobacillus thiooxidans*, *Acidithiobacillus ferrooxidans*, *Aspergillus niger*, *Penicillium simplicissimum* and many more, have proved their gold dissolution properties. However it is a slow process compared to that in the conventional techniques, which should be addressed comprehensively.

Keywords:*E-waste; Gold; Bio-hydrometallurgy; Cyanidation.*

1. INTRODUCTION

Technology has certainly moved beyond just being a communication network. Therefore different leading industries around the globe are moving fast towards the technical sector to unlock the new opportunities and for the further socio-economic development. As a result of the fastest expansion of different electronic based industries and their products, the generation of different industrial scraps and the end life electronic devices (e.g. E-wastes), has reciprocated. This escalated E-wastes generation creates problems and ambiguity for their suitable disposal [1,2]. Worldwide the annual E-wastes generation is nearly 50 million tonnes and this figure will definitely be increasing in the future. The common E-wastes are old computers, televisions, VCRs, stereos, copiers, mobile phones, fax machines and etc. They contain different toxic substances like beryllium, cadmium, mercury and leads, which are dangerous upon contamination to different resources of the environment [3]. According to the recent report by the United States Environmental Protection Agency (USEPA) only 18% of the E-wastes have been recycled and the rest are disposed of as landfill [4]. In India, the regulations established for the E-waste management are followed by few organizations.

Although this ever increasing E-waste is complex in nature, it is also a rich secondary source of different metals like iron, gold, silver, and copper. These metals can be recovered and brought back into the production cycle. Gold is a precious metal present in the E-wastes, which has been recovered by the application of the traditional techniques such as pyro- and hydro- metallurgy. Yet these techniques require high energy, emission of dioxins and furans cause damage to environment [5,6]. They have the disadvantage of smelting, deterioration of environment due to high heat production and toxic gas emission. In order to overcome the adverse issues related to the traditional techniques, different level of research works have been carried out for the recovery of metals from E-wastes, especially valuable metals like gold, silver, and copper using the traditional techniques [7,8]. Hydrometallurgy has proved better to the pyrometallurgy in terms of toxic gas emission and energy intensiveness [9-11]. It uses different chemical reagents like cyanide, halide, thiosulphate, and thiourea for the gold recovery from the E-wastes. However, it has the high risk of toxic sludge production [12-15]. It involves oxidative leaching gold [16].

Since different natural microorganisms have properties to produce a natural oxidizing environment in the suitable condition, bioleaching of gold from the E-wastes has emerged as the promising alternative technology to the traditional hydrometallurgy techniques. Since the last two decades, bioleaching has become the key emerging filed for the dissolution of metals in a cost-effective and eco-friendly manner [17-19]. The recovery of gold from the E-wastes with the help of different microorganisms like bacteria and fungi is now under demand because of their easy handling, rapid adaptation to metals and enhanced metal dissolution by the metabolites. About 10-1000gm gold/tonne is present as the urban E-wastes, which can prove to be a suitable secondary resource of gold if recovered by the bioleaching technique [16,20].

2. E-WASTES POLLUTION AND HEALTH ISSUES

Any broken or unwanted electronic appliances, such as computers, entertainment electronics, mobile phones, and other electronic items, have been discarded called E-wastes. Their amount increases year by year atan alarming rate. Majority of the E-wastes contain hazardous metals such as lead, cadmium and mercury. They cause harm to the environment and living organisms [21,22]. The list of harmful metals and their adverse effects are summarised in Table 1.

Table 1. Hazardous metals in E-wastes and their health effects [23].

Sources of E-wastes	Metals present	Health issues	References
Relays; switches; PCBs	Mercury	○ Chronic damage to brain ○ and central nervous system	[24,25]
Solder in PCBs; glass panels; gaskets in computer monitors	Lead	○ Skin damage ○ Nervous system damage ○ Affects circulatory system ○ Affects kidney	[26-28]
Chip resistors and semiconductors; rechargeable computer batteries	Cadmium	○ Causes neural damage	[24,28-30]
Interior or CRT screens	Zinc	○ Cytotoxicity ○ Ischemia ○ Trauma	[29]
Data tapes; Floppy disks	Chromium	○ Multiple organ failure ○ Carcinogenic, ○ Lead oxidative stress	[24,25,28]
Light emitting diode	Arsenic	○ Affect breathing ○ Cardiovascular disease ○ Increase rate of cancer	[25,31]
Motherboard	Beryllium	○ Carcinogenic ○ Skin diseases	[24,28]

3. CYANOGENIC MICROBES

Cyanidation is widely used as one of the control technology for the recovery of gold. All the cyanogenic microbes can produce cyanide ions that dissolve gold in between their metabolic activities [32,33].

Cyanide is formed by several microorganisms including bacteria such as *Pseudomonas fluorescens*, *Pseudomonas aeruginosa*, *Chromobacteriumviolaceum*, *Pseudomonas plecoglossicida*, *Pseudomonas polycolor*, *Pseudomonas syringae*, *Pseudomonas putida*, *Bacillus megaterium*, *Rhizobium leguminosarum*, *Anacystisnidulans*, *Escherichia coli* fungus *Marasmiusoreades*, *Gloeocercosporasorghi*, *Stemphylium loti*, *Clitocybe sp.* and algae *Chlorella vulgari.* Although all these microbes havebeen reported as cyanide producing microbes but *Pseudomonas fluorescens*, *Pseudomonas aeruginosa*, *Chromobacteriumviolaceum*, *Pseudomonas plecoglossicida* have been reported in gold leaching from E-waste [34].

Cyanogenic microbes are commonly moderately thermophillic in the alkaline conditions. In the early stationary phase, cyanide is formed as secondary metabolites under some specific conditions abundant cyanide is obtained [35,36]. The metabolic activities of cyanogenic microbes are affected by various physiological parameters such as pH, pulp density, nutrient as well as other metal ions which act as catalysts. Compounds of sulphide and sulphate consume cyanide and are called as cyanide consuming compound or cyanide killer. So for enhancing gold leaching, researchers are now aimed to develop the suitable condition for the growth of bacteria and significant cyanide formation. Cyanide forming microbes are known but the mechanism of formation of hydrogen cyanide (HCN) is not known for many years [37].

*Chromobacteriumviolaceum*is a gram-negative facultative anaerobes abundantly found in most tropical and subtropical areas [32]. It can grow in both aerobic and anaerobic conditions as it utilizes energy source in both oxidative and reductive ways [38]. HCN is generally produced in aerobic condition when four electrons produced by HCN synthase (operon present in genome of bacteria *HCN A*, *HCN B*, and *HCN C*) are transferred to oxygen in the respiratory chain but this reaction occurs under the low oxygen concentration [32]. *C. violaceum*has β-cyanoalanine synthase help in detoxifying the cyanide during the late stationary phase [39].*C. violaceum*has been shown to mediate gold dissolution when it grow as the single-species biofilms on ultra-flat gold foils [40-42].

Pseudomonas fluorescens is a gram-negative bacteria. It has higher growth rate and leaching efficiency due to its metal resistance ability. It produces cyanide at the end of exponential growth phase by the oxidative decarboxylation of glycine. It can release cyanide up to 300 μM [43]. But the toxicity level of cyanide produced by it is very high resulting in the damage of the bacteria cells. Due to considerable tolerance to the metal toxicity, a mixed culture of cyanogenic strains were used for the extensive gold bioleaching. Mixed strains of *Pseudomonas aeruginosa* and *C. violaceum* have shown higher leaching efficiency than the individual culture and other mixed culture [44]. Mixed culture of *P. aeruginosa*and *P. fluorescens* also have efficiently leached gold due to the higher cyanide production [45]. Table 2 summarises the gold leaching rate by different microorganisms in both pure and mixed culture conditions.

Some chemoautotrophic bacteria have natural ability to use either organic or inorganic compounds energy sources for the growth. Chemoautotrophic bacteria use CO_2 as carbon source, and Fe^{2+} and S^{2-} as an energy source for the growth and produce Fe^{3+} and SO_4^{2-} as metabolites which facilitate the metal dissolution. Different biotic factors such as inoculums size and characteristics shape, and abiotic factors such as growth of microbes, environmental conditions, temperature, pH, aeration rate, oxygen concentration, and type of E-wastes affect the microbial activities in the gold bioleaching [46-48].

Table 2. Gold leaching rate by different microorganisms.

Microorganism name	Gold leached ($mg.L^{-1}.day^{-1}$)
Chromobacteriumviolaceum	0.716
Pseudomonas fluorescens	0.25
Pseudomonas aeruginosa	0.539
Pseudomonas aeruginosa + Pseudomonas fluorescens	0.513
Pseudomonas aeruginosa +Chromobacteriumviolaceum	0.72
Chromobacteriumviolaceum+ Pseudomonas fluorescens	0.651

4. PRINCIPLE OF EXTRACTION MECHANISM OF GOLD

Extraction of gold from the E-wastes by using cyanogenic microbes follows the indirect leaching mechanism. It involves the metabolic activity of *HCN synthase* to produce HCN by the associated enzymes followed by the reactions of cyanide with gold [39,49,50]. The direct growth of microorganisms in the presence of E-wastes is not suitable due to the presence of toxic chemicals cadmium, mercury and lead in them.

In recent years, the gold bioleaching is an emerging field from the E-wastes. Gold leaching by *Chromobacteriumviolaceum*involves following techniques such as (a) one-step bioleaching; (b) two-step bioleaching; (c) spent-medium leaching. The two-step bioleaching process is believed to be appropriate for the increase leaching efficiency. In this process microbes are allowed to grow under optimized cultural conditions to produce a high amount of cyanide in the first step. Then the cultured media having cyanide is separated and brought in contact with the E-wastes in the second step. However, the spent-medium leaching has recovered gold more efficiently than the two-step bioleaching process. The spent-medium has the significant advantage of continuous or fed-batch culture of microbes resulting in the maximum cyanide production [51-54].

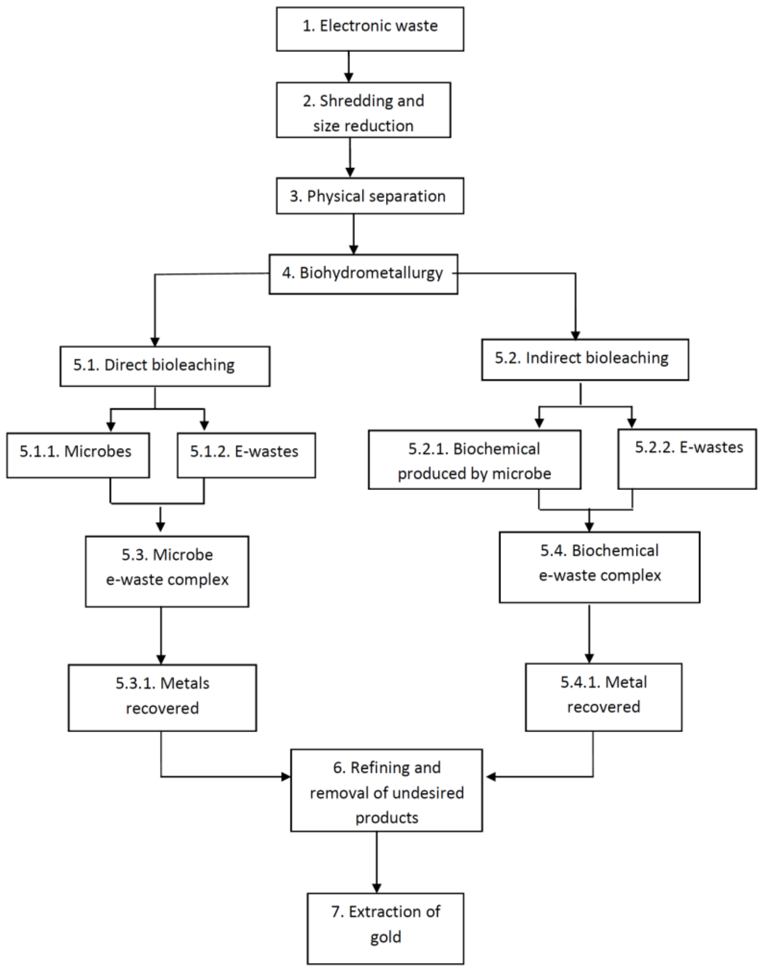

Figure 1. Methodology of extraction of gold from E-scarps by microorganisms.

5. METHODS OF GOLD RECOVERY

Printed circuit boards are the hardware provides electronic connections to the mounted components, present in almost all electronic equipments. Several noble metals can be recovered by various procedures from the used electronic equipments and mobile phone printed circuit board (PCB) [55]. Gold is basically used in PCBs as solder or connection pads, phone battery and audio cables. The circuit of PCB board comprises of three layers such as gold, copper and nickel. The hydrochloric acid dissolves gold, nickel and copper easily. About 340 g of gold was obtained from one metric ton of PCBs [56].

Gold recovery by the bioleaching technique involves biosorption and biooxidation. Using microorganisms gold is extracted from metallic sulphides by the biooxidation method. This procedure is followed by most of the gold industries. Biosorption is a passive physico-chemical process in which there is a contact between microorganisms and ions in the solution. In this process, both dead and live microbes can be used. This process is eco-friendly, cost-effective and minimizes the chemicals or biological sludges. Figure1 shows a schematic methodology for the gold biorecovery from E-scarps.

6. CONCLUSIONS

Rapid developments in the electronic industries have led to expansion of e-waste stream across the board. It includes a large amount of toxic materials that cause threats to humans and environments. Dumping of those E-wastes has several disadvantages comprising of pollution of ground water, soil as well as disturbance in environmental norms. Bioleaching is an eco-friendly technique for the treatment of e-wastes. Numerous physiological reactions were carried out by different microbes for the production of various inorganic and organic acids which help in the dissolution of metals.*Chromobacteriumviolaceum*is one of the most efficient microorganisms for the recovery of gold in the bioleaching process. However, more intensive research work is needed for the proper implementation of the process on the commercial scale. This would definitely satisfy the theme “Waste to Wealth”.

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