Turning trash into treasure- The Bioleaching Solution

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Abstract— The escalating global discard of electronic devices has propelled the issue of e-waste disposal and recycling to the forefront. In the E-waste, presence of hazardous materials like lead, mercury, and cadmium, poses significant environmental and health risks if not managed properly. However, conventional recycling methods including open burning and acid baths worsen environmental degradation rather than mitigating it. Similarly, traditional metal extraction techniques like open-pit mining and smelting contribute to habitat destruction, air and water pollutions. To combat these challenges, bioleaching appears as a promising solution for recycling e-waste and extracting metals sustainably. Bioleaching involves the use of bacteria and other microorganisms to dissolve metals from ores or electronic waste, presenting a more environment friendly alternative to conventional methods. By harnessing microbial action, bioleaching offers a pathway to recover valuable metals such as copper from e-waste. Role of specific acidophilic bacteria in catalyzing metal extraction emphasizes the importance of perfecting environmental conditions for microbial activity. Furthermore, insights into mine water use for metal extraction underscores the comprehensive approach of bioleaching in waste management. Scaling up the bioleaching process for organic waste recycling requires optimization of microbial consortia, process engineering, and effective nutrient management. In conclusion, bioleaching is a sustainable approach to ameliorate the e-waste crisis and help in metal extraction from solid wastes and ores. By embracing bioleaching and advancing its technologies, we can move towards a circular economy, minimizing environmental impact while maximizing resource recovery.

Keywords: E-waste, bioleaching, sustain able, extraction.

I. INTRODUCTION

I.I. THE PROBLEM: DECODING THE DISPOSAL DILEMMA

The burgeoning issue of e-waste disposal and recycling arises from the escalating discard of electronic devices globally. E-waste harbours hazardous materials such as lead, mercury, and cadmium heavy metals, which, if not disposed properly, can pollute the environment [1, 2]. Recycling e-waste presents a multifaceted challenge due to the diverse materials used in electronic devices and the deficiency of efficient recycling infrastructure in many regions [3, 4]. This predicament causes significant environmental and health issues, underscoring the imperative for enhanced e-waste management practices on a global scale. Presently employed recycling methodologies worsen the problem rather than solving it [5- 7].

Open Burning: This method involves setting e-waste on fire to recover valuable metals, but it releases toxic fumes into the air, contaminating soil and water [5].

Acid Baths: Acid baths are used to dissolve metals from electronic components, posing risks to workers and the environment due to the corrosive nature of the chemicals involved.

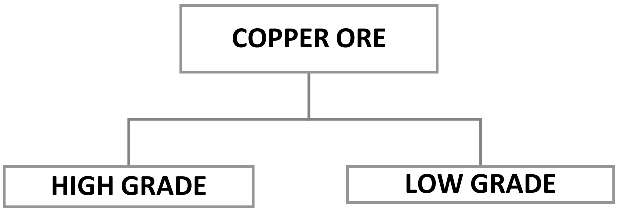
Manual Dismantling: This entails disassembling electronic devices by hand to extract valuable components, exposing workers to hazardous materials without adequate safety measures. Similarly, conventional metal extraction practices from e-waste compound environmental woes:

Open-Pit Mining: This technique involves excavating large open pits to extract metals from the earth's surface, causing deforestation, habitat destruction, soil erosion, and disrupting ecosystems, thereby harming biodiversity.

Acid Leaching: Acid leaching is a prevalent method used for metal extraction from ores or electronic waste, generating substantial amounts of acidic wastewater that can contaminate soil and water sources if not effectively managed. It also poses risks to workers' health and safety due to the handling of corrosive chemicals.

Smelting: In Smelting process, metal ores are heated at high temperature to extract the metal, requiring a significant amount of energy use and releasing pollutants such as sulphur dioxide and particulate matters into the air, leading to air pollution and climate change. Additionally, smelting can release heavy metals and other toxic substances into the environment if not controlled properly.

Overall, the current practices employed for recycling e-waste and extracting metals have drastic environmental impacts, polluting air and water, destruction of habitats and emission of greenhouse gases needs adoption of more sustainable practices [8].Most of the electronic devices consist of copper metal as it provides strength and support to the devices. Copper is a valuable metal which has been mined for centuries. It is typically extracted from ores. Copper ores are found in the Earth's crust [9].



High-grade copper ores, also known as copper-rich ores have high percentage of the metal. In high-grade copper ores, smelting and electrolysis are used to extract the metal. Low-grade ores have low percentages of the metal in them. BIOLEACHING AND PHYTOMINING are the two techniques that are used to extract copper from low-grade ores or e- wastes [10].

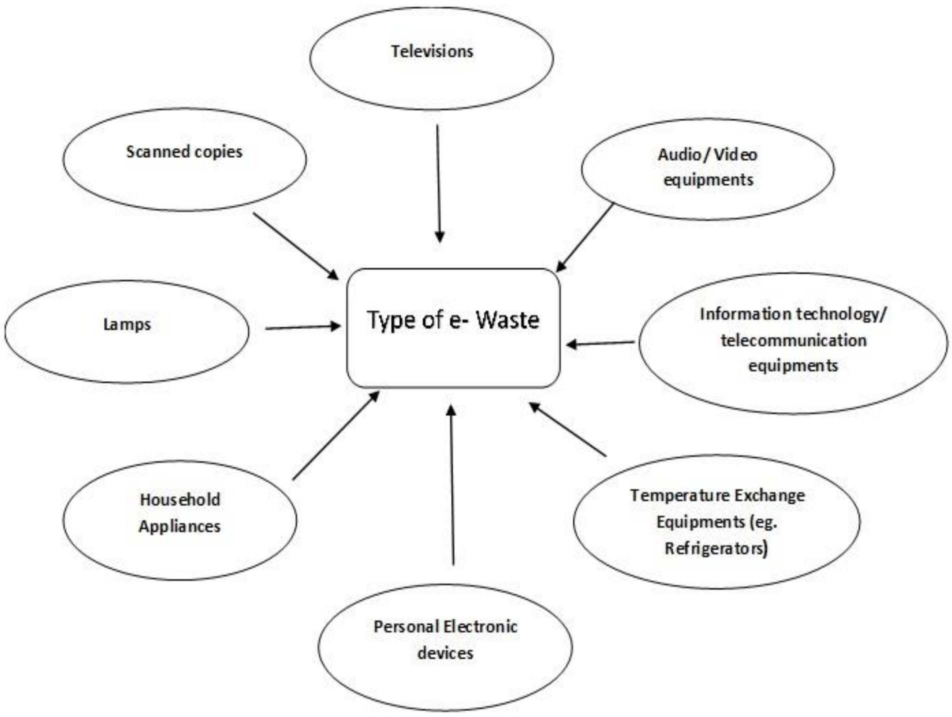


Fig.1 Chart for different types of sources for e- waste

I.II. THE BIOLEACHING SOLUTION

Biohydrometallurgy or bioleaching is a sustainable technology that employs the metabolic activities of microorganisms (fungi, bacteria, archaea) for the solubilization of metals from mineral concentrates, or e- waste [11, 12]. Bioleaching involves the use of bacteria and other microorganisms while Phytomining involves use of plants [13]. Bioleaching is used on metal concentrates or e-wastes. Bacteria feed on the metal concentrates for their growth by breaking the weak copper-sulphur bonds in ores. Biological and chemical decomposition of the metal concentrates by bacteria form a solution rich in copper ions called the leachate [14]. Since the leachate is abundant in the copper ions, the extraction of copper is done from the leachate. For the recovery of pure copper, the leachate is added with scrap iron and an electrolysis process is conducted for the ores or e-waste [15]. Chemical reactions involved in copper extraction may be -

$$sulphides\ (FeS, CuFeS_2) \rightarrow\ H_2SO_4$$

$$CuFeS_2 + 4H_2SO_4 \rightarrow CuSO_4 + FeSO_4 + 4H_2O + 2SO_2$$

$$CuSO_{4(aq)} + Fe_{(s)}\ \rightarrow Cu_{(s)} + FeSO_{4(aq)}$$

Obviously, Metal extraction through bioleaching requires less energy, in fact, it is a simple, effective and environment friendly process [6,16].

I.II. THE BACTERIAL MAGIC

In a bioleaching bioreactor, bacteria like Acidithiobacillus ferrooxidans play a crucial role in extracting copper from ores[17]. These bacteria thrive in the bioreactor's controlled environment which typically maintains optimal conditions vis-à-vis temperature, pH, and nutrient levels. When the ore containing metal sulphides like chalcopyrite ($CuFeS_2$) is introduced into the bioreactor, the bacteria begin their action [18]. They produce enzymes that catalyse the oxidation of metal sulphides, converting them into soluble metal sulphates. In the oxidation process electrons are released which the bacteria utilise to generate energy. As a result, copper initially locked within the insoluble mineral structure, is released into the solution in the form of soluble copper sulphate. This makes the copper accessible for subsequent extraction processes [19]. The bioreactor ensures that the bacterial activity proceeds efficiently, leading to the effective leaching of copper from the ore. As per different literatures members of the genus Acidithiobacillus are prominent and well-studied organisms for the bioleaching of metals due to their outstanding tolerance to heavy metal toxicity and low nutrient requirements for metal solubilisation (20, 21).Thiobacillus, the moderately thermophilic bacteria grow on pyrite, pentlandite and chalcopyrite at temperatures in the range of 50°C for easy metal recovery [22]. Brierley, Norris, Karavaiko and their co-workers have succeeded in isolating extremely thermophilic bacteria growing at temperatures above 60°C [23, 24]

I.IV. MINE WATER- A MENACE

Mine water refers to water that comes into contact with or is discharged from mining operations. It can originate from various sources, including rainwater seeping into underground mines, groundwater. encountering minerals and contaminants during mining activities, or runoff from mining waste piles, known as tailings. Treating mine water comes with several challenges. Contaminants such as heavy metals, sulphates, and acidity are often present in high concentrations, making treatment complex and expensive.

Additionally, the sheer volume of water generated by mining operations can overwhelm treatment facilities. Ensuring long-term effectiveness and sustainability of treatment methods is also a concern, especially in regions with limited resources or expertise [15]. Therefore, by the process of bioleaching we solve this problem too wherein we use mine water to extract valuable metals from e-waste obviously to turn trash into treasure

I.V. SCALING IDEAS

Scaling up the bioleaching process for organic waste recycling involves several steps:

I.V.I. Optimization of Microbial Consortia: Identify and optimize the microbial communities involved in bioleaching to enhance their efficiency in breaking down organic waste. Chemolithoautotrophic acidophilic bacteria are key players in metal solubilization, deriving their energy from inorganic sources like Fe^{+2} and reduced sulphur, while utilizing CO_2 for carbon. On the other hand, cyanogenic bacteria like Cyanobacterium violaceum, thriving in alkaline environments, which is helping in extracting gold (Au) [25].

I.V.II. Process engineering: Develop efficient bioreactors or fermentation tanks that can accommodate large volumes of organic waste while maintaining optimal conditions for microbial activity [26, 27].

I.V.III. Nutrient management: Ensure adequate supply of nitrogen and phosphorus, to support microbial growth and activity during the bioleaching process.

I.V.IV. pH control: Maintain optimal pH levels throughout the process to promote microbial activity and prevent inhibition. The pH of the medium plays an important role in the growth of bacteria and metal solubilization. As per the data,95% of metals are recovered at an acidic pH of 2-2.5 [28]. The proportion of Fe^{3+} ions, the number of microbes, and the pH of the solution are considered as major factors in the leaching of metals from solid phase to solution. The efficiency of copper extraction using A. ferrooxidans in a bioleaching process can be enhanced by the addition of sulphuric acid and reducing the pH to the range of 1.5-2.0 [36].

I.V.V. Temperature Control: Monitor and control temperature to ensure that it still is within the range suitable for the growth and activity of the microbial consortia. Temperature is a crucial factor that influences bacterial growth and consequently metal bioleaching. in a metal extraction process, maintaining an ideal temperature is a requisite for metal dissolution, which is very much linked to bacterial activity [12].

I.V.VI. Monitoring and control systems: Implement robust monitoring and control systems to track key parameters such as pH, temperature, nutrient levels, and microbial activity in real-time, allowing for prompt adjustments and optimization [18, 29].

I.V.VII. Scale-Up trials: Conduct scale-up trials to assess the performance of the bioleaching process at larger volumes and identify any challenges or limitations that need to be addressed.

I.V.VIII. Economic analysis: Evaluate the economic feasibility of scaling up the bioleaching process, considering factors such as capital investment, operating costs, and potential revenue from recycled products.

By addressing these aspects systematically, it is possible to effectively scale up the bioleaching process for recycling organic waste on a larger scale [30].

II. PROCESS

II.I. REVOLUTIONIZING RECYCLING: TURNING E-WASTE INTO COPPER MINES!

Emergent technologies for the recovery of metals from e-waste are an urgent need of the hour to improve the current scenario of waste disposal and waste treatment [31] . E-waste, a secondary ore in urban mining, contains higher concentrations of precious metals than that of a primary ore [32]. The process involves initial segregation of metals and plastics, making bulk collection of e-waste. Segregated materials are then subjected to a treatment process using reactors with solutions. Experimental data guides the periodic replacement of waste cartridges to maintain reactor efficiency. After several batches, copper extraction from the resulting sludge occurs through a chemical process. As per the literature E-waste materials are chopped up and segregated into metals and plastics to facilitate efficient recycling. Bulk e-waste is gathered for processing and maximizing the use of available resources. Segregated e-wastes are treated in reactors with appropriate solutions based on experimental data [33]. Waste cartridges within the reactors are periodically replaced according to experimental data to sustain optimal reactor performance [34]. After multiple treatment batches, copper extraction from the sludge is achieved through a chemical process.[35].

This recycling process effectively segregates e-waste materials, maximizes resource utilization and extracts copper efficiently from the sludge. Experimental data guides reactor maintenance and solution choice, contributing to the sustainability and effectiveness of the recycling process

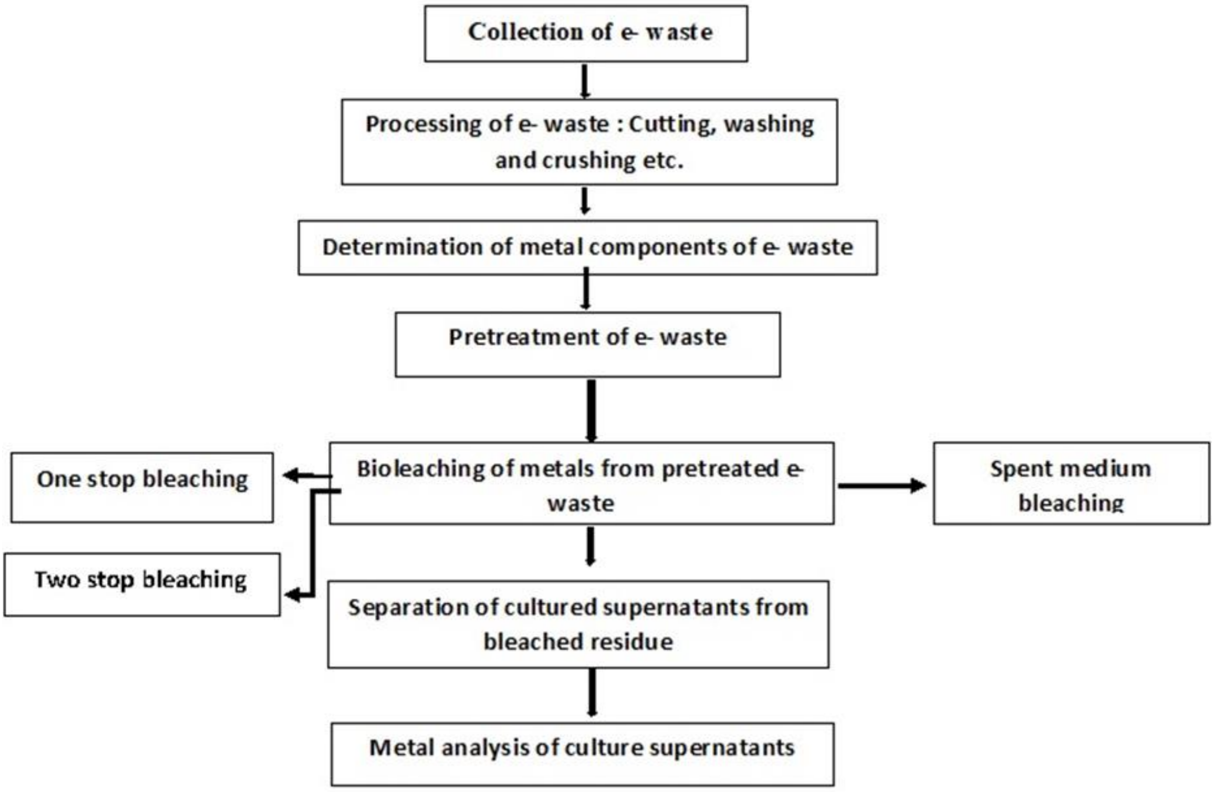


Fig.2 Flowchart for the different steps followed for Extraction of metal

II.II. COPPER HARVEST: A CHEMICAL SYMPHONY FROM E- WASTE SCRAPS!

The collected e-waste (bulk) after meticulous segregation and separation into metals and plastics, the metal scraps, particularly those containing copper, are crushed into smaller pieces for further processing. These crushed scraps are then introduced into a rotating, airtight machine where a gentle spinning motion is applied to the solution. Specific acidophilic bacteria such as Acidithiobacillus ferroxidans (found in mine water), are added to the shredded waste to extract the metal. It is important to ensure optimal environmental conditions for microbial activity [37]. Optimal conditions like acidic pH, regulated temperature and oxygen levels are the necessary parameters to maintain [38]. Acidophilic microorganisms catalyse the oxidation of metal sulphide minerals in electronic waste, which results in the production of metal ions [39, 40]. The spinning action facilitates the extraction of copper from the scraps, catalysing chemical reactions crucial for separation. However, to ensure optimal conditions for the reactions, it is essential to maintain precise levels of aeration. In instances where excessive aeration poses a challenge, nitrogen (N_2) is pressurized at atmospheric levels and introduced into the system. Controlled supply of oxygen, monitored using a dissolved oxygen (DO) meter, ensures that the chemical reactions continue smoothly without compromising efficiency [41]. A metal-containing solution (Leachate) further on electrolysis leads to the recovery of copper in solid form (rod).

III. CONCLUSION

Bioleaching is a fascinating process that uses microorganisms to extract metals from ores. Some recent developments in the field include Genetic Engineering: Researchers are genetically modifying microorganisms to enhance their ability to extract metals from ores. This involves identifying and incorporating genes that increase the efficiency of bioleaching. Optimization of Conditions. Scientists are continuously refining the environmental conditions under which bioleaching occurs to improve its efficiency. This includes factors such as temperature, pH levels, nutrient concentrations, and oxygen availability, Exploration of New Microorganisms. Efforts are being made to explore and identify new microorganisms that have the potential to efficiently leach metals from ores. This involves studying extreme environments where unique microbes thrive. Integration with Mining Processes- Bioleaching is being integrated into traditional mining processes to improve overall efficiency and reduce environmental impact. This includes developing strategies to combine bioleaching with other extraction methods of Valuable Metals. Research is focused on enhancing the recovery of valuable metals from bioleaching solutions through techniques such as solvent extraction, precipitation, and electro-winning. Environmental Considerations- There is a growing emphasis on ensuring that bioleaching processes are environmentally sustainable. This includes minimizing the use of toxic chemicals and reducing the generation of waste materials. These developments collectively aim to make bioleaching a more efficient, cost-effective and environment friendly method for extracting metals from ores.

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