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Recovery and Recycling of Valuable Metals from Low-Grade Ores Using Microorganisms: A Brief Review

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ABSTRACT

The demand for metals is ever increasing with the advancement of the industrialized world. But the global reserve high levels of ores are adjacent to decline. However, there exists there is a vast reserve of metals inferior ore, and other subsidiary sources. Low category ores as well as metal recovery conventional strategies such as pyrometallurgy, hydrometallurgy, etc., require strong and asset inputs that are often environmentally friendly pollution. Accordingly, there is required for the utilization of more coherent technologies to the recuperation of metals. The utilization of microbes to recovery metal ions is considered a unique key optimistic and revolutionary field of environmental biotechnology. The components of this method are disintegrated in an aqueous solution, which provides them more effective in addition, treatment, and convalescence. Recycling giant metals is also very important to prevent pollution and to prevent wastage of sources. Biological means are also used to easily recycle metals from their secondary sources. In this research, various approaches using microbes to recover giant metals from primary (low-grade ore) and secondary (electronic wastes) sources are discussed. Future prospects of utilizing microbes are also granted here.

Keywords: Microorganisms, Metal ore, Recycling, Bioleaching, Biosorption, Recovery, and Electronic waste.

1. INTRODUCTION:

A valuable metal is a sparse, naturally occurring metallic chemical component of giant economic value. Primary source for giant metals is metallic ores while mines, foundries, electronic waste are considered as secondary sources. The increasing ordered of different essential metals as a consequence of the enlargement of new technologies; require the enlargement of innovative technologies that enable an economic and environmentally friendly metal retrieval from different sources (Rahman *et al.*, 2019). Industrial effluents containing heavy metals may consider a major source

of contamination causing serious environmental problems. A number of approaches have been developed for removal of metal such as precipitation, electroplating, evaporation, etc. These methods are seemed to be expensive due to use of unrenewable materials, high cost and generation of toxic sludge. To overcome this problem various biological methods using microbes are considered beneficial over this conventional technique. Again there are serious concerns that the demand for some critical components may exceed current supply in a few years and so it is more important to improve the exploitation and processing

of ores Strategic metal recycling must be applied. The use of biological methods is natural characteristics of organisms, bio-compounds and organic compounds for bonding to minerals, Materials, metals or metallic ions Biomining or bio-trickling, biosorption, etc. are some methods that use microbes for the reclamation as well as recycling of giant metals (Pollman *et al.*, 2018).

Biomining is a technique of extracting metals from ores and other solid materials typically using prokaryotes or fungi. These organisms secrete different organic compounds that chelate metals from environment. Giant metals are commonly bound up in solid minerals. Some microbes can oxidize those metals, allowing them to dissolve in water. This is the main procedure behind key biomining, which is utilized for metals which can be more comfortably repossess when dissolved from hard rock. A different one Biotechnology uses germs for metals that are not disintegrated by germs to break down the neighboring minerals; the metal of attentiveness is made easier to recover straightly from the remaining rock. Maximum current biomining operations target giant metals such as copper, uranium, nickel and gold that are frequently found in sulfur-bearing minerals. Microbes are principally good at oxidizing sulfur containing minerals that can be easily converted to a dissolving form. When the metal of attentiveness is directly dissolved the process of biomining is called "bio-trickling" and when the metal of interest is further made Ingredients that are accessible or left behind are enriched, this is called "biooxidation". At present biomining approaches is also used to recycle giant metals from wastewater and electronic waste. Biomining is an environmentally friendly (green) approach, including much lower temperatures and smaller carbon footprints. The next claim is justified Autotrophs are the major microorganisms involved in the mineral oxidation approaches (i.e. they fix carbon dioxide, much in the same way as green plants), which contrasts with smelting operations that emit large amounts of CO₂. Bio-processing also operates at atmospheric pressure and at relatively low temperatures (20-80)°C. Usually external heat source is not required as the oxidation of sulfide minerals is an exothermal approach. Indeed, excess heat is generated where rates of oxidation are

intense (as in stirred tank operations) and systems require to be cooled to maintain suitable temperatures (generally 40-45°C) for the mineral-degrading microorganisms (Rawlings *et al.*, 2003; Olson *et al.*, 2003).

Biotrickling Metal is the approaches by which metals are dissolved from ore bearing rocks using microorganism. The commonly used microorganisms in bio-trickling are *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans*. Biosorption is a specific type of inactive, dead, Microbial biomass to bind and condense heavy metals from even very thin aqueous the solution. Biomass exhibits this property, acting as an ion just as a chemical Exchange of biological source (Das, 2010). Biosorbents are pursued from variety microorganisms, fungi, algae, yeasts, and some biovast Materials on organic synthesis of precious metals (Akcil and Deveci, 2010). Waste electric and electronic equipment (WEEE), or electronic waste (e-waste), has been taken into consideration not only by the government but also by the public due to their hazardous material contents (Cui *et al.*, 2003).

Recycling of electronic waste is an important issue Not only in terms of waste treatment but also in terms of valuable recovery materials The U.S. EPA has point out seven major ones When it comes to scrap iron and steel, there are advantages like saving energy and reducing pollution Used instead of virgin substances. Using recycled materials in place of virgin materials results in significant energy savings. From the material composition point, electronic waste can be stipulate as a mixture of different metals, especially copper, aluminum and steel, combined, covered or mixed with different types of plastics and ceramics. Precious metal manufacturing has a wide application Contact material due to their high chemical stability and their good handling properties. Platinum grade metals are utilized among other things in switching contacts (relays, switches) or as sensors (Rawlings, 2004). This study focuses on the utilization of microbes for the retrieval and recycling of giant metals from different sources. Methods using microbes are discussed as it provides eco-friendly approaches. Different biological approaches using microbes for recovering valuable metal of great economic value are discussed in this research.

2. Retrieval of valuable metal from low grade ore

Global Ore Imports are declining rapidly due to rapid industrialization and demand. However, this difficulty can be overcome by using huge stocks of low and thin grade ores (Akcil and Deveci, 2010). Bio-trickling is a specialized biohydro-metallurgical approach. In the approaches involved in either metabolic activity or products of microorganisms. This process is dependent on the capability of microorganisms (bacteria and fungi) to convert solid compounds into soluble and extractable components, which can be recovered (Bayraktar, 2005). The Bio-trickling allows recycling of metals from low level ores, such as national waste Electronic scraps, and the approaches of duplicating used catalysts and near site cleanup the natural biochemical cycle (Xu and Ting, 2009).

In general, metal resources can be divided into two main groups: (i) Naturally occurring resources, for most of the metals for industry, (ii) Second hand resources e.g. industrial waste and materials used. An ore contains metals in the form of minerals or an aggregate of minerals, as well as gangue minerals. Gangue is undesired minerals which are associated with ore and are mostly non-metallic in nature. Ores are divided into: (a) high grade ores, i.e. which is in metal the density is relatively high and (b) low grade ores, with low density Metals, such as shells and schists, etc (Mulligan *et al.*, 2004).

2.1. Biotrickling

Microbial trickling is the mining of metals from their ores using microbes. Microbial technology High-grade minerals at one time, offered an economic alternative for the mining industry resources are running out (Ndlovu, 2008). In general, bio-trickling is a

approach “Specifically described as dissolving metals from naturally occurring mineral sources So that germs can “live” or use microorganisms to transform elements the material can be drained from the material when it is filtered from the water (Olson *et al.*, 2003; Akcil and Deveci, 2010). There are two types of microbial trickling on the basis of microbes which are known: autotrophic trickling and hetero-trophic trickling (Anjum *et al.*, 2009a).

2.1.1. Autotrophic trickling

Most autotrophic trickling is conducted by Autotrophic, acidophilic bacteria that fix carbon dioxide and gain energy from oxidation of ferrous iron or depleted sulfur compounds. These metabolic processes yield Fe(III) or H₂SO₄ as the respective end products. The microorganisms involved in autotrophic trickling include sulfur-oxidizing bacteria, e.g. *T. thiooxidans*, iron and sulfur-oxidizing bacteria. As a result of sulfur and iron-oxidation by these bacteria, Metallic sulfides dissolve and the pH of the environment immediately decreases, which increases the solubility of other metallic compounds. Its autotrophic trickling Metal sulfides are very well established by the species *Theobacillus* and other acidophilic bacteria. The industrial scale of fossil fuels is used in biomining approaches which include ores, shells, and skis, etc.

2.1.2. Heterotrophic (chemoorganotrophic) dribbling

Heterotrophic trickling is a different form of microbial dribbling so that organisms need living organic carbon sources for germs to survive the metabolites extracted by the approaches are the result of the metabolism of organic carbon Source, which does not take any part of the ore.

Table 1: Some autotrophic bacteria with biohydro-metallurgy potential

Organism	Ore minerals	References
<i>T. ferrooxidans</i>	Chalcopyrite concentrate	(Fowler <i>et al.</i> , 2001)
	Pyrite concentrate	(Curutchet and Donati, 2000)
	Covellite concentrate (CuS)	(Giaveno and Donati, 2001)
	Heazlewoodite (Ni ₃ S ₂)	(Veglio <i>et al.</i> , 1998)
<i>T. thiooxidans</i>	Pyrrhotite	(Dopson and Lindstrom, 1999)
<i>T. caldus</i>	Arsenopyrite	(Boon and Heijnen, 1998)
<i>L. ferrooxidans</i>	Pyrite concentrate	(Konishi <i>et al.</i> , 1999)

Table 2: Some heterotrophic microbes with biohydro-metallurgy potential

Organism	Ore minerals	References
<i>Aspergillus sp.</i> + <i>Penicillium sp.</i>	Low-grade nickel–cobalt oxide ores	(Valix <i>et al.</i> , 2001)
	Low-grade Laterite ores	(Valix <i>et al.</i> , 2001)
	Aluminosilicate (95% spodumene)	(Castro <i>et al.</i> , 2000)
<i>Rhodotorula rubra</i>	Aluminosilicate (95% spodumene)	(Valix <i>et al.</i> , 2001)

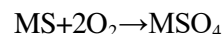
Metabolisms are composed of organic acids which can leak certain ores, i.e. a completely indirect mechanism with no interaction between organisms and ore. This type of dribbling is worthy for minerals that are low in sulfur and sulfides, and consequently does not provide adequate sulfur sources for the production of sulfuric acid in autotrophic acidophiles. Can produce heterotrophic organic acids which are very mild acids that may be suitable for dissolving metals of economical value in the pH range between 4 and 6, and for the continuation of ferric iron and therefore may result in a leak solution essentially free of iron. They can produce non-acidic metabolic agents from protein metabolism which can be the suitable use in alkaline dribbling systems such as ammonia dribbling (Anjum *et al.*, 2009a).

Most of the various microorganisms with dribbling activity are mostly filamentous fungi and Bacteria metal leaks are usually involved in indirect as well as direct approaches these are microbial products of organic acids, amino acids and other metabolites. Metallic ions dissolve metabolic metals by transferring them from the ore matrix by the formation of hydrogen ions or soluble metallic complexes and plates. Mostly Fungi are important species are *Aspergillus sp.* and *Penicillium sp.* because of their ability to excrete abundant concentration of organic acids for bio-dribbling of metals from ores (Castro *et al.*, 2000). Generally, fungi can work well between pH range of 2–8, and in a temperature range of 20–40 °C. The fungus has a relatively high tolerance compared to heavy metals, Therefore these were used in the past for carbonaceous low grade dribbling Ore and mining waste. Deterioration of uninterrupted carbon sources, such as charcoal and the black shell is accelerated by fungal activity which results in the release of inorganic Minerals and metals (Wengel *et al.*, 2006; Akcil and Deveci, 2010).

2.2 Mechanism of bio-dribbling

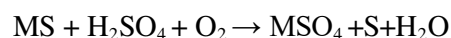
2.2.1 Bacterial dribbling

A generalized reaction can be used to describe the biological oxidation of a mineral sulfide involved in trickling:



Where, M is the bivalent metal that gets solubilized from the system by the action of microbial metabolites. Until now, the bio-trickling of ores includes the following two types of mechanism in microbial metal solubilization of sulfide minerals (Anjum *et al.*, 2009a).

Contact microbial dribbling - There is direct contact with a specific part of the microorganism Mineral tone-mouth, but not towards the entire mineral surface. Thus, the metal is due to dissolve Electronic chemical interaction. Absorbs the absorption of cells into suspended mineral particles put in a few minutes or hours (Brocht *et al.*, 2004). In this way, microorganism development and the heavy metal dribbling takes place together. This technique is easy to perform, but the microbial metabolism and growth can be negatively affected by dissolved metal ions which then limit the biotrickling procedure efficiency. In direct contact mechanism, microorganisms will directly oxidize minerals and solubilize metals; the reactions can be simplified as (Li *et al.*, 2015):



Non-contact microbial trickling - This mechanism involves the generation of organic and inorganic salts by fungal and bacterial species. Biotrickling is carried out in two stages. In the first one, The Microbes are allowed to grow in an adequate medium under appropriate culture Active metabolism production conditions for the absorption procedure. Later, spend Culture medium under aggressive leaking conditions (low pH, high temperature, etc) used as a trickling agent in

the second stage for the mineral in the absence of growing microorganisms. Therefore, it increases the metal's removal. In many cases direct the mechanism favors the indirect procedure due to direct physical contact Bacteria with mineral surface (Ndlovu, 2008).

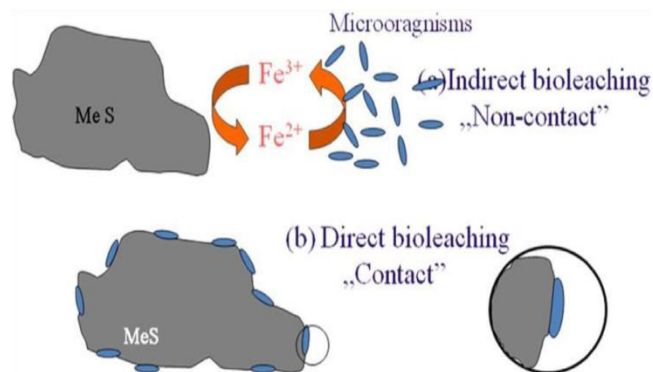


Fig 1: “Contact” and “non-contact” mechanisms.

2.2.2 Fungal trickling

Trickling of metallic fungi from minerals is basically based on:

- i. Acidolysis: Protonation of oxygen atoms around the metal surface Compound. The protons and oxygen involved in the water expel the metal from the metal space Surface (Ndlovu, 2008)
- ii. Complexolysis: Alts re-formation of metal complex Dissolution of metallic ions such as oxalic acid and iron complex. Plus, it is the procedure often reduces heavy metal toxicity toward fungi.
- iii. Redoxolysis: Reduction of metal ions in an acidic environment, such as reduction of ferric iron and manganese under the influence of oxalic acid. A series of organic acids is formed by fungal metabolism resulting in organic acidolysis, complex and cholate formation (Ndlovu, 2008).

In general, fungi need a lot of energy for their microbial activities. Fungus trickling is a bit slower than bacterial trickling. Ingredients like black shell contain a lot of organic matter, but fungus trickling is better (Deepatana *et al.*, 2006). Trickling of fungi results in the build of soluble complexes metal ions in neutral environments or less toxic, which is another benefit of it presence of fungus leaking agents. Parallel to the metabolic procedures of the fungus High vegetation without carbohydrate synthesis. Organic acids are produced from glucose in the glycolytic pathway by fungi

(Murad *et al.*, 2003). The most active trickling the fungus comes from the genus *Penicillium* and *Aspergillus* (Deepatana *et al.*, 2006). *A. niger* has good potential for the production of organic acids such as oxalic and citric, malic and tartaric acids which are effective for metallic solutions (Pina *et al.*, 2005).

2.3. Biotrickling of metals by autotrophs

Some recent research demonstrated the microbial retrieval of metal ions like Al, Mo, V, U and radio nuclides by chemolithotrophic bacteria in acidic environments (*A. ferrooxidans*, *A. thiooxidans*, and *S. acidocaldarius*). These bacteria use sulfide minerals as a source of energy Shell and schist as impure. These exercises are now used for isolation Number of metallic ions from their sulfide minerals such as sulfidic copper and refractory gold Ore (Abdelouas *et al.*, 2000), as well as manganese and iron ores. *A. thiooxidans* there were in early 1922, Waxman and Joffe broke up to rapidly oxidize primary sulfur. When *T. ferrooxidance* during the layering procedure was added to the mixture of sulfide minerals. The cells prioritize the pyrite and suppress its bottom. So, using Germs, pirates can be separated from raw ore. Thus, different metals like Zn, Pb and microbial was recovered from the Cu mine (Willscher and Bosecker, 2003). Microbial retrieval of metals due to leakage of bacterial strains is more efficient than chemical launching its maximum amount of metal. Scanning for electron microscopic analysis of energy after trickling the components show a considerable amount of biological decay control chemical is more elastic than observed in experimental tests (Orquidea *et al.*, 2008).

Cuban serpentines are undertaken to be one of the richest inserts of Ni and Co in the world. *A. thiooxidans* were utilized to make inorganic acids as metabolites utilizing elemental sulfur as energy source to trick these ores. Maximum percentage of metal solubilization, Co (100%) and Ni (80%) approximately, was gained just after 15 days of incubation. Indirect bio-trickling tests using sulfuric acid metabolism, Significant Ni (9%) and Co (55%) were also recovered (Uryga *et al.*, 2004). Flotation Mining by-products also contain significant levels of metals such as Co, Cu and As. These metals were extracted from the water by germs isolated. Bio-trickling is a bit

slow procedures than chemical leaches, but there are more advanced ways to consume wastes, Bacteria as layers during the oxidation process. At this point the energy is released the process is produced by germs and by the metabolism of organic and inorganic acids as which can be used as ingredients in commercial food ingredients (Pradhan *et al.*, 2006).

A report found that effective retrieval of alumina from ore after only 6 days by *Bacillus* notification of *in situ* bio-trickling and bacteria leaching in aluminum more efficient retrieval than fungus bio-trickling (Vijay-araghavan and Yun, 2008; Ekhlal *et al.*, 2014; Uddin *et al.*, 2017). Retrieval of giant metals in the form of sulfides has also been made from bio-trickling solution by sulfate reducing bacteria (Junya *et al.*, 2009). These bacteria can isolate Fe from pyrite and Cu from chalcopyrite up to 95% within 30 days of inoculation; P and Fe were extracted from high phosphorus iron ores (Zhang *et al.*, 2010; Wang *et al.*, 2009).

Significant recoveries of Cu, Cr, Ni, Zn and Pb was also reported, using *A. thiooxidans*, in an analogous way to the retrieval of these metals by *A. ferrooxidans* after 24 days of cultivation (Liang *et al.*, 2010). The mixed culture of the two acidophils gives better the single has resulted in more than one. Important metals are not just taken from microbials Mines and other deposits of lower grade ores, but also from the ash below the waste burner.

2.4. Bio-trickling of metals by heterotrophs: a literature survey

Different species of fungi can use for bio-trickling procedure. Plenty of literature has been published about the capability of fungi to isolate metals from various sources. Metals were extracted from carbonaceous low level ores using fungal species, whereas Ti was extracted from rock after fungal activity. Zinc extraction was reported through the yield of tartaric and citric acid by *A. niger*. Bio-trickling from ores and use of gold dust *Penicillium* spp; some organic acids such as citric, tartaric, Lactic and malic acid, it can be used for bio-trickling of various ores. The use of microorganisms in ore trickling to extract metals has long been a commercial business. Preliminary investi-

gations have shown that bacteria and fungi can be used effectively extracts Fe and C from clay, sand and low grade ores (Cameselle *et al.*, 2003).

Improved retrieval of Fe from kaolin with oxalic acid produced by *A. niger* was investigated (Bosecker K2001). Ni and Co were leached from non-sulfidic nickel ores using *Aspergillus* and *Penicillium* spp. They confirmed the presence of citric, oxalic and other organic acids in the leach liquors, indicating their role in the bio-trickling procedure. Cu, U and Au were extracted from organic acid production and consequently low grade ore and as a result complex low-pound fungi spread to the environment by microbial activity bacteria. The retrieval of Cr, Ni, Zn, Cu, Cd and Pb from ore were reported through fungal bio-trickling (Venkateshwara *et al.*, 2002). Bio-trickling of important elements like Al, Fe, Co, Cu, Zn, Sn, Pb and Ni from their ores using *Penicillium* as well as *Aspergillus* spp. have also been examined earlier. A set of experiments also showed that the strains of these two fungi Was able to combine metals by producing some organic acids such as citric, Tartaric, lactic and malic acids (Ndlovu, 2008). 20 isolates of fungal strains of genera *Aspergillus*, *Penicillium* and *Rhizopus* were examined for Cu extraction from low grade chalcopyrite (Acharya *et al.*, 2004). *Penicillium* and *Aspergillus* spp. the most efficient microorganisms not only in organic acids production, but also in trickling of Ni, Co and Fe from late rite in a direct trickling procedure that was comparable with chemical trickling retrieval of these metals. Bio-trickling is also a more feasible technique for the extraction of Mn up to 64.6% from ore after 30 days of incubation (Wu and Ting, 2006).

Heterotrophic fungi are capable of producing complex agents of metabolism (citrate, Malate and lactate) which can play an important role in metal extraction. Al from the bottom Grade ore is exactly 15 days after *in situ* trickling by *A. niger*. Metals like Al, Mn, Zn, and the like Pd has been extracted from MSW Incinerator Fly Ash by *A. niger*. There was gluconic acid Identified as the main alloy in metal bio-trickling (Wang *et al.*, 2009). *A. niger* is known to be able of bio-trickling heavy metal ions from urban solid waste incineration fly ash. Citric acid production correlated

with and was responsible for the trickling of Al, Fe and Zn. Bio-trickling of useful metals from solid waste incinerator fly ash is an environment friendly procedure with an extraction efficiency of K, Na, Ca and Cr (Yang et al., 2011). It is reported that retrieval of Ni, Cu and Co from low grade Ni, Cu and Co Sulfide ore is being transported to the shaken flask after only 60 days of bio-trickling, where retrieval Among these metals the column was acquired 120 days after the leak.

3. Retrieval/recycling of giant metals from electronic waste

The waste electrical and electronic equipment's (WEEE) are diverse, including printed circuit boards (PCBs), television sets, refrigerators, computers, cell phones, and batteries, etc. Although WEEE accounts for only 3-5% in solid waste, the varieties and contents of giant metals in it are far more than other forms of municipal waste. We have high amounts of base metals in printed circuit boards, TV scraps and electronic devices viz personal computer and mobile phone scraps (Cui and Zhang, 2008). So, WEEE is Worthy of the name "Urban Mine". According to the survey by Environmental Protection Agency (EPA), United States, and Recycling Metal Sources Compared to Primary Metal Products WEEE has significant benefits such as less subsidiary waste and less energy cost (Wang and Xu, 2015). However, WEEE does not only contain all types of metals, However other chemical low-parts which are quite complex, such as plastics and Bright flame retardants (BFR). If WEEE is not disposed or recovered properly, it will cause severe environmental pollution and even jeopardize human health (Morin et al., 2006). Most of applications for recovering WEEE with the help of microbes are still in a laboratory scale. There are two main field of that use microbe for retrieval of metals, namely bio-trickling and biosorption.

3.1 Biotrickling of metals from electronic waste

The disinfectant has been successfully applied in the retrieval of metals from metallic sulfides using a bactericidal reaction, which is the main bearing mineral for many bases and precious metals. The isolation of metals viz Co, Mo, Ni, Pb, and Zn from

sulfidic ores by bio-trickling is technically feasible (Debaraj and Young-Ha, 2010). The procedure of bio-trickling and therefore the metal will be leaked from the electronic waste Discussed here. Bio-trickling using bacterial-assisted reactions is technically possible to extract valuable metals viz Q, Ni, Zn, Cr and precious metals from WEE Laboratory scale current results. For bio-trickling, acidophilic group of bacteria plays an significant role in bio-trickling of heavy metals viz *A. ferrooxidans*, *A. thiooxidans*, *L. ferrooxidans*, and *Sulfolobus* sp. Bio-trickling procedures is used to mobilize metals from waste PCBs. Preliminary investigation is on the feasibility of retrieval of gold from printed circuit boards by bio-trickling approach. Gold containing (5mm ×10mm) were obtained by manually cutting printed circuit boards followed by manual sorting. Each piece subdued approximately 10mg of gold. Using *C. violaceum*, it is focused that gold can be microbially dissolved from printed circuit boards.

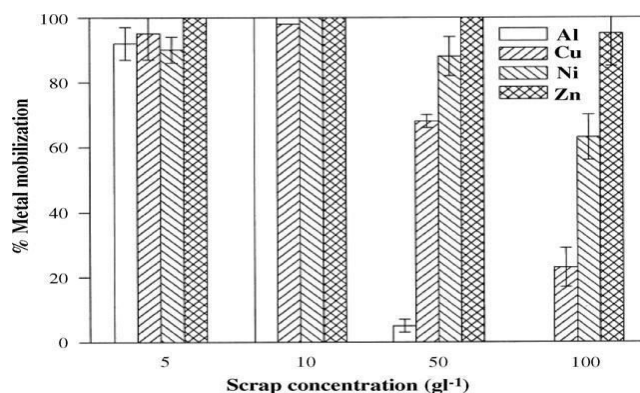
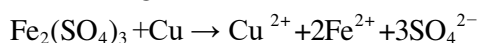


Fig 2: Mobilization of Al, Cu, Ni, and Zn from different concentrations of electronic scrap at 30°C in a two-step approach: A heterogeneous culture of *T. ferrooxidans*, & *T. thiooxidans* was previously grown for 7 days in the absence of electronic scrap. Scrap was added and the culture was grown for an additional period of 10 days. Bars represent mean values ± standard errors of duplicate experiments.

Dust collected from shredding approaches of electronic scrap was used in the investigation. The trickling experiments by using a heterogeneous culture of *T. ferrooxidans* and *T. thiooxidans* on electronic scrap represented that the addition of raised amounts of scrap led to an increase of the initial pH due to the alkalinity of electronic scrap. Orderly reduce toxic

effects on the microorganisms, a two-step approach was introduced. In the empirical stage, biomass was produced in the absence of electronic scrap. Afterwards, electronic scrap was added in various concentrations and the cultures were inoculated for an additional time schedule. The trickling results showed (Fig 2) that at scrap concentrations of 5 and 10 g/L, approximately, *Thiobacilli* were capable to leach more than 90% of the available Al, Cu, Ni, and Zn. At larger concentration, metal mobilization was diminished, mainly for Al and Cu. Ni and Zn represented much better findings with mobilization of 60% and 95%, distributively. The feasibility for using fungi (*A. niger*, and *P. simplicissimum*) to leach metals from electronic scrap by a two-step approach was also investigated. In a two-step trickling, however, concentrations of up to 100g/L electronic scrap could be easily treated resulting in almost complete solubilization of the available Cu, Pb, Sn, and Zn. The bio-trickling mechanism of copper from printed circuit boards' shreds by *A. ferrooxidans* has been suggested to be similar to that of metal sulfide. In the trickling approach, $Fe_2(SO_4)_3$ formed by *A. ferrooxidans* oxidizes the elemental copper contained in PCBs to cupric ion following the reaction.



The possibility of bio-trickling Zn, Cu, Pb, Ni, Cd and Cr from waste PCBs by using a culture of sulphur oxidising bacteria and a mixed culture of bio-surfactant-producing bacteria and sulphuroxidising bacteria has been evaluated. The results focused that 48% Zn and 93% Cd were dissolved in both media. There were even better effects for Ne and Cu. Obtained in

acidic medium with removal rate of 47.5% and 53% respectively. Pb was moved with very low efficiency (below 0.5%).

3.2. Biosorption for retrieval of metals from electronic waste

Biosorption is defined as the property of biomass or certain biomolecules to bind and concentrate selected ions or other molecules from aqueous solutions. It is a passive approach and independent from metabolic activities. Therefore, nutrients are not required and processes can perform in environments with high toxicity. Biosorption has been mainly applied for the disposal of toxic metals from polluted waters, such as arsenic, chromate, cadmium, or uranium (Hol et al., 2010). The approach of biosorption is a substance-chemical and meta-metabolism-independent approaches resulting in removal Substances from solution by organic matter (Mata et al., 2009). Its features some inactive or dead microbial biomass materials allow them to bind and condensate metallic ions from industrial and aqueous solutions. Are biosorbents prepared from a variety of microorganisms, including bacteria, fungi, algae, actinomycetes, Yeasts and some biovast materials in precious metals biosorption? Au (third) was successful Brown algae recovered using dead biomass as metallic gold nanoparticles. The results of vasculosis indicate that the brown loose. Vasculosis can restore and reduce Au (III) to Au (0) (Das N 2010). Most gold uptakes were obtained at initial pH values between 4 and 9, the best with pH 7. The marine alga *S. natans* and the fungal cells of *A. niger*, *M. rouxii* and *R. arrihus* were also found to take up precious metals like gold.

Table 3: Adsorbents used for precious metal biosorption

Adsorbents	Metal	pH	Q _{max} ^a (mmol/g)
Bacteria			
<i>Streptomyces erythraeus</i>	Au ³⁺	4.0	0.03
<i>Spirulina platensis</i>	Au ³⁺	4.0	0.026
<i>Desulfovibriode sulfuricans</i>	Pd ²⁺	2.0	1.2
<i>Desulfovibrio fructosivorans</i>	Pd ²⁺	2.0	1.2
<i>Desulfovibrio vulgaris</i>	Pd ²⁺	2.0	1.0
<i>Desulfovibriode sulfuricans</i>	Pt ⁴⁺	2.0	0.32
<i>Desulfovibrio fructosivorans</i>	Pt ⁴⁺	2.0	0.17
<i>Desulfovibrio vulgaris</i>	Pt ⁴⁺	2.0	0.17
<i>Penicilium chrysogenum</i>	Au(CN) ²⁻	2.0	0.0072
<i>Bacillus subtilis</i>	Au(CN) ²⁻	2.0	0.008

Fungi			
<i>Saccharomyces cerevisiae</i>	Au ³⁺	5.0	0.026
<i>Cladosporium cladosporioides</i>	Au ³⁺	4.0	0.5
<i>Cladosporium cladosporioides</i>	Au, waste water	4.0	0.18
<i>Cladosporium cladosporioides</i> Strain 1	Au ³⁺	4.0	0.4
<i>Cladosporium cladosporioides</i> Strain 2	Au ³⁺	4.0	0.5
<i>Cladosporium cladosporioides</i> Strain 1	Ag ⁺	4.0	0.4
<i>Cladosporium cladosporioides</i> Strain 2	Ag ⁺	4.0	0.12
<i>Aspergillus niger</i>	Au ³⁺	2.5	1.0
<i>Rhizopus arrhizus</i>	Au ³⁺	2.5	0.8
PVA-immobilized biomass (<i>Fomitopsis carnea</i>)	Au ³⁺	1–13	0.48
<i>Aspergillus niger</i>	Ag ⁺	5–7	0.9
<i>Neurospora crassa</i>	Ag ⁺	5–7	0.6
<i>Fusarium oxysporium</i>	Ag ⁺	5–7	0.5
Algae			
<i>Chlorella vulgaris</i>	Ag ⁺	6.7	0.5
<i>Chlorella vulgaris</i>	Au ³⁺	2	0.5
<i>Sargassum natans</i>	Au ³⁺	2.5	2.1
<i>Ascophyllum nodosum</i>	Au ³⁺	2.5	0.15
<i>Sargassum fluitans</i>	Au(CN) ²⁻	2.0	0.0032
Alginate cross-linked with CaCl ₂	Au ³⁺	2.0	1.47
Alginate cross-linked with Ca(OH) ₂	Au ³⁺	2.0	0.34

3.2.1. Biomass used for retrieval of precious metals

Biosorbents are naturally prepared in large quantities and/or from waste Biomass of algae, fungi or bacteria. The type of biomass used for valuable biosorption Metal ions are varied. **Table 3** gives a list of advertisers used for precious metal ions the following retrieval decisions can be summarized from the table:

For the organic synthesis of precious metals from acid state solution, especially for the synthesis of bacteria and derivatives of chitosan.

- 1) The adsorption capacities (Q_{max}) of precious metals on different types of biomass vary from 0.003 to 40mmol/g (dry biomass). This indicates that much more work should be done to select a perfect biomass from the billions of microorganisms and their derivatives.
- 2) Researches on biosorption of precious metals mainly focused on gold. More attentions should be taken into biosorption of silver from solutions.
- 3) The biomass may be used in its “natural state” or modified, e.g. by cross-linking to improve biosorption efficiency.

- 4) Biosorption by chitosan derivatives provides an alternative for retrieval of precious metals from solution due to the fact that relatively higher adsorption capacities have been obtained for Au³⁺, Pt⁴⁺, and Pd²⁺.

3.2.2. Mechanism of biosorption

Biosorption mechanisms strongly depend on the metabolism of microbial cells and the location of metal removal (Abbas *et al.*, 2014). Biosorption can be (i) metabolism depending on or (ii) non-metabolism depending on according to the activity of biomass. Based on the zone of the metal removal, biosorption can occur via extra-cellular accumulation/precipitation; Cell surface sorption/precipitation; Intra-cellular accumulation (Abbas *et al.*, 2014). **Fig 2** and **Fig 3** report a flow structure and a schematic illustration, respectively, of the biosorption techniques depending on the presence/absence of metabolism and the zone of the metals sorbed. Whereas, ion exchange, physical adsorption and complexation also take place in the absence of cellular metabolism.

Notwithstanding the various classifications, all biosorption techniques are strictly related to each other

and can take place with both metabolic and non-metabolic microbial activities.

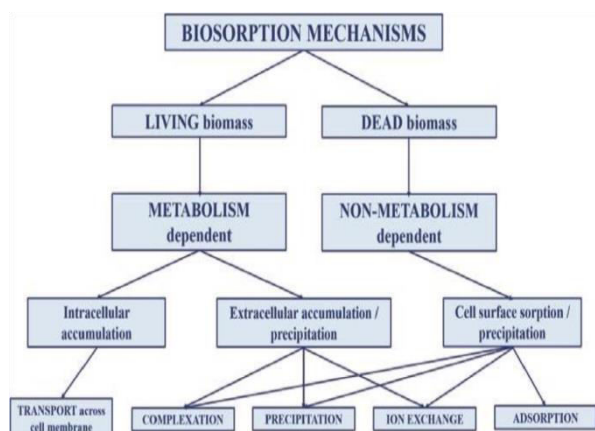


Fig 3: Biosorption techniques correlation according to metabolism and metal removal zone. Note the complexity of the approach and the maximum of the concomitant approaches contributing to the range of biosorption.

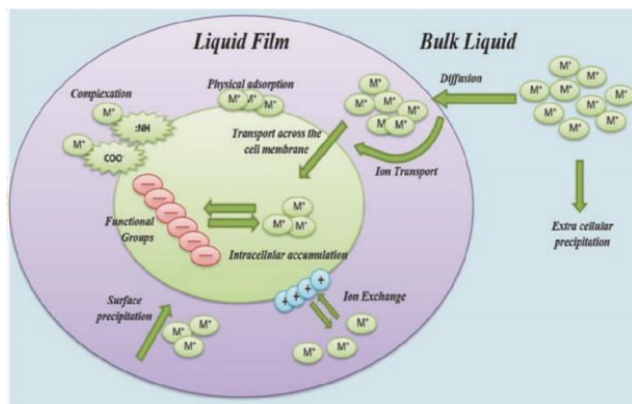


Fig 4: Schematic illustration of the main techniques related in biosorption. Metabolism depending on approaches includes the transport across the cell membrane and intra-cellular accumulation by reacting with mobile functional groups.

Non-metabolism dependent techniques are mainly rapid and reversible physical-chemical interactions between metals and the functional groups on the cell surface. Conversely, intracellular uptake phenomena (bioaccumulation) is ruled by cellular metabolism and occurs at lower rates. Metallic precipitation may take place and affected by microbial metabolism, when performed with the compounds produced Microbials or not when a common chemical inter-action between metal and cell surface takes up space.

In the next section, metals and their interactions with the microorganisms will be deepened. In particular, the focus will be on Differences between metallic complexation on cell walls and EPS. Since biosorption primarily occurs on the microbial surface, it is of major importance to know whether microbes are present as single cells or complex agglomerates, e.g. flocs, granules or biofilms, held together by EPS.

3.2.2.1. Metal: Cell Wall Interaction

Bacterial cell wall is fundamental for cell integrity and is characterized by the presence of *N* acetylmuramic acid (peptidoglycan) and poly-*N*-acetylglucosamine right out of the cytoplasmic membrane (Vijayaraghavan and Yun, 2008). 10 to 20% and 90% of the cell wall of Gram-negative and Gram-positive bacteria, respectively, is made by peptidoglycan. The remaining part of the outer membrane consists of phospholipids and lipopolysaccharides. The membranes are created of anionic functional groups which the key elements are determining the capability of cell walls to bind metals. Dense metals preferentially bind with oxygen-containing ligands, whereas, mushy metals bind with nitrogen or sulfur containing ligands. To give an example, carboxylic groups perceived on the *S. pilosus* cell walls clearly affect Cu and Pb removal. In parallel, Cd reduction and Pb uptake can be efficiently performed by dried *Sargassum* species featured by a maximum of carboxylic groups. Furthermore, COOH groups, the presence of Cu on the bacterial cell surface is due to the interaction with phosphoryl groups (Kang et al., 2007).

Amine groups also come up with to metal biosorption, especially the binding of Cr ions by using *P. aeruginosa*. The chemical changes of lipids, carboxylic and amino functional groups affect Pb, Cu and Cd biosorption. After the etherification of carboxyl and methylation of amine groups, a tiny metal biosorption is focused (Boyanov et al., 2003). Pb and Hg biosorption increases the concentration of increasing metals although its saturation binding sites happen more quickly. However, Ni and Zn are complementary at the same time *E. Meliloti* greatly affects the absorption of Pb and Hg over the EPS of MS-125. Its EPS *R. atlee*, isolated from a human knowledge-rich environment, shows a priority encour-

agement. For instance, *B. subtilis* and *B. licheniformis* cell walls bind relatively 30 times more Cu^{2+} than *E. coli*. Regarding the different metals used, *S. aureus* cell walls have a higher affinity with Ce^{3+} than Cu^{2+} . Lastly, the key role of the cell wall functional groups, the specific microbial strains and the metallic contaminant used are fundamental for metal binding. A careful sorting of the most relevant biosorbent is thus required for achieving proper ways efficiency.

3.2.2.2. Metal Interaction with Living and Dead Biomass

The amount of metal removal varies considerably when biosorption is performed living or dead biomass. Metallic stimulation in dead cells is mainly carried through its interaction between cell wall and contaminants. Can occur through biosorption Interactions with active amine and sulfadryl functional groups, divided into dead biomass, Through various transport events on the cell wall and/or for intracellular frozen. Furthermore, bio-sort performance can be positive or negative Affected by metabolic activity (e.g. respiration, nutrient uptake and metabolism) which clearly corrects the environment around the house. Living cells perform chew uptake basically better than dead cells through intracellular freezing. Densely frozen Algae are observed in cytoplasmic fractions and yeasts (Srinath *et al.*, 2002). The use of living cells, however, results in lower metal sorption efficiencies in non-buffered systems under acidic conditions. For instance, a higher Cr^{6+} bio-sorption by dead cells of two *B. sphaericus* strains has been reported at a stable pH of 4.0 (Velásquez and Dussan, 2009), mainly owing to the good interaction between metal and biomass under acidic conditions. Cr^{6+} uptake is indeed driven by acid adsorption for the higher concentration of H^+ involved in the anion exchange. Besides Cr^{6+} , the enhancement of metal uptake when using dead cells of *M. xanthus* and *S. cerevisiae* has been reported for other metals such as La^{3+} , Co^{2+} , Mn^{2+} , Pb^{2+} , Co^{2+} , Ag^+ , Zn^{2+} , Cd^{2+} , Cr^{3+} and Ba^{2+} .

3.2.2.3. Interaction between metals and extracellular polymeric substances

The presence of EPS increases biosorption yields, especially in involved systems Bacterial colonies form

biofilms. EPS is a biopolymer produced by cell activity dissemination of active bacteria, cell surface and cell lysis materials. Moreover, EPS can derive from biological absorption from the environment (Sponza, 2002). Composition EPS is made up of organic matter with high amounts of sugars and Protein and a small fraction of humic, uronic and nucleic acids. There is an abundance of EPS Negatively charged activity groups that create powerful biosorbents for their use for metallic abbreviations (Leidin, 2000). EPS can be divided into two main groups: bound and soluble bound EPS consists mainly of organic matter and organic matter produced by bacteria Connected to microbial aggregates. Soluble EPS is composed of hydrolyzed products from the combined organic matter, the organic molecules are expressed by cell lysis and solubility Polymers produced by germs. Besides different characteristics, the two groups have different metal bio-sorption efficiency: Cu^{2+} , Pb^{2+} , Ni^{2+} and Cd^{2+} removal is higher with soluble EPS than bound EPS (Rasulov *et al.*, 2013).

An increase of Pb and Hg uptake can be achieved at acidic pH by EPS of *A. chroococcum* XUI. Feed metal concentration and the coexistence of other metals also affect biosorption onto EPS (Lakzian *et al.*, 2008). Pb and Hg biosorption increases the concentration of increasing metals although its saturation Binding sites happen more quickly. However, Nee and ZN are complementary at the same time *E. Meliloti* greatly affects the absorption of Pb and Hg over the EPS of MS-125. Its EPS *R. atlee*, isolated from a human-knowledge-rich environment, shows a priority encouragement of Mn^{2+} compared to Zn^{2+} , Pb^{2+} , Co^{2+} , Ni^{2+} and Cu^{2+} (Malik, 2004). By metal biosorption EPS cannot be considered a reverse approach because metals can form stable complexes EPS results in less efficient metal bio-retrieval. However, on the other hand, heavy metal biosorption immutability can usually lead to a lower metal release environment.

4. Future prospects

In recent years, research focus has been emphasized on anaerobic bio-reduction (Laguna *et al.*, 2011; Hol *et al.*, 2011b), combined biooxidation& bio-reduction and electro-biochemical approaches for the metal leaching purposes, which can also be extended for the

pre-treatment of refractory Au ores. In the bio-reduction approach, sulfate reducing bacteria or archaea, which are able to use hydrogen as electron donor and sulfur species as electron acceptors, were employed at the first stage of refractory Au mineral ores treatment? Advanced molecular techniques were also employed to unravel the bio-trickling mechanisms. The comprehensive 50 mer-based oligonucleotide micro-array method is developed and evaluated to monitor the microbial populations in acidic and bio-trickling environments. Meta-genomic studies for bio-trickling microbials the community is also currently conducting research to understand the metabolic activity and interaction of individual germs in the mining environment (Hu *et al.*, 2013; Valdes *et al.*, 2010).

More recent bio-trickling methods focus on non-sulfidics looks for materials and different possibilities with different waste materials Natural microorganisms can extract metals in a wide range of conditions. Whereas numerous studies investigated the release of elements such as Cu, Au, only few studies concentrate on rarer elements. Bio-reduction has been mainly applied for the removal of Pd(II) from industrial waste streams (Creamer *et al.*, 2006). However, the methods can be principally also applied for other precious metals such as Pt or Au. After a decade of trying, Reusable technologies for metals from WEEE have made clear improvements. There Three things to look for and ensure for future reuse Technology-Science Innovation:

- a) Must be prepared to face technologies in the future Cases for small and medium enterprises in commercialization and investment or equipment; Further research should focus on the development of pilot scale testing Creating operational and cost data with the ultimate goal of commercialization;
- b) Alone technology cannot solve all problems because WEEE is a low-pleasing system. So, reusable technologies will be more diverse and technologies should be integrated According to the physical and chemical properties of all kinds of WEEE;
- c) Future technologies should have higher segregation efficiency, retrieval rate and greater durability.

5. CONCLUSION:

Advanced and modified technologies can successfully recover base, metals such as Cu, Pb, Zn, Cd and pre-quadruple metals such as Au, Ag. Advanced reusable methods and technologies have also been compared and improved including the traditional method of protecting the environment. Here are three Rations should be considered and confirmed for future reusable technologies Innovation: (i) Well-designed pre-treatments like removal of plastics, papers, irons etc. Necessary, for example, is a mechanical-physical technology as a means of pretreatment A mechanism is required to separate metallic and nonmetal to avoid generation Residues from toxic gases like PCDD / F and similar and non-metallic metals in WEEE; (ii) Enterprise or government should advocate the use of “green” reagent in recycling approaches/ technologies to reduce pollution of waste water; (iii) Comprehensive resource utilization as far as possible for both metals and nonmetals in WEEE should be the target in recycling approaches/technologies. Biological methods can contribute to increased metal retrieval from technical waste products, approaching waste, Industrial waste water and others secondary source. Microorganisms developed many approaches that influence biogeochemical cycles of elements, e.g. bio-weathering, microbial reduction, biomineralization and precipitation, or bioaccumulation. Provides these processes nature can be used as a retrieval tool for a variety of different cleaning industrial approaches metals, novel biobased materials, bioremediation, but also “green recycling” approaches. As using microbes for retrieval and recycling of giant metals is gaining popularity over chemical approach in recent year, it should be given more and more attention. So it’s time to crucial, combined technologies can be developed and tested for their efficiency.

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7. CONFLICTS OF INTEREST:

The author’s declared there are no potential conflicts of the interest.

8. REFERENCENCES:

1. Abbas SH, Ismail IM, Mostafa TM, Sulaymon AH. (2014). Biosorption of heavy metals: A review. *J Chem Sci Technol*, **3**, 74–102.
2. Abdelouas A, Lutze W, Gong W, and Travis BJ. (2000). Biological reduction of uranium in groundwater and subsurface soil. *Sci. Total. Environ.* **1–3**(250), 21–35.
<https://pubmed.ncbi.nlm.nih.gov/10811248/>
3. Acharya C, Kar RN, Sukla LB and Vibhuti N. (2004). Fungal leaching of manganese ore. *Trans. Indian Inst. Metall.* **5**(57), 501–508.
4. Akcil A and Deveci H. (2010). Mineral biotechnology of sulphides (eds) Jain S, Khan A and Rai MK Geomicrobiology. *Science Publishers*, Enfield, New Hampshire, USA, pp. 101–137.
5. Anjum F, Bhatti HN and Ambreen A. (2009a). Bioleaching of black shale by *Acidithiobacillus Ferrooxidans*. *Asian J. Chem.* **7**(21), 5251–5266.
6. Bayraktar, O. (2005). Bioleaching of nickel from equilibrium fluid catalytic cracking catalysts. *World J. Microbiol. Biotechnol.* **21**, 661–665.
<https://link.springer.com/article/10.1007/s11274-004-3573-6>
7. Boon M, and Heijnen JJ. (1998). Chemical oxidation kinetics of pyrite in bioleaching processes. *Hydrometallurgy*, **48**, 27–41.
8. Bosecker, K. (2001). Microbial leaching in environmental clean-up programmes. *Hydrometallurgy*, **59**, 245–248.
[https://doi.org/10.1016/S0304-386X\(00\)00163-8](https://doi.org/10.1016/S0304-386X(00)00163-8)
9. Boyanov MI, Kelly SD, and Kemner KM *et al.* (2003). Adsorption of cadmium to *B. subtilis* bacterial cell walls: a pH-dependent X-ray absorption fine structure spectroscopy study. *Geochim Cosmochim Acta.* **67**, 3299–3311.
[https://doi.org/10.1016/S0016-7037\(02\)01343-1](https://doi.org/10.1016/S0016-7037(02)01343-1)
10. Brocht S, Durance MV, D'Hugues P and Mugabi M. (2004). Modelling of the bioleaching of sulphide ores: application for the simulation of the bioleaching/gravity section of the Kasese Cobalt Company Ltd process plant. *Miner. Eng.* **17**, 253–260.
11. Cameselle C, Ricart MT, Nunez MJ and Lema JM. (2003). Iron removal from kaolin. Comparison between *in situ* and two stage bioleaching processes. *Hydrometallurgy*, **68** 97–105.
12. Castro IM, Fietto JLR, Vieira RX, and Brand RL. (2000). Bioleaching of zinc and nickel from silicates using *Aspergillus niger* cultures. *Hydrometallurgy*, **57**, 39–49.
[https://doi.org/10.1016/S0304-386X\(00\)00088-8](https://doi.org/10.1016/S0304-386X(00)00088-8)
13. Creamer NJ, Baxter-Plant VS, Potter M, and Macaskie LE. (2006). Palladium and gold removal and recovery from precious metal solutions and electronic scrap leachates by *Desulfovibrio sulfuricans*. *Biotechnol. Lett.* **28**(18), 1475-1484.
14. Cui J, and Forssberg E. (2003). Mechanical recycling of waste electric and electronic equipment-A review. *J. Hazard. Mater.*, **99**(3), 243–263.
<https://pubmed.ncbi.nlm.nih.gov/12758010/>
15. Cui J, and Zhang L. (2008). Metallurgical recovery of metals from electronic waste: A review. *Journal of Hazardous Materials*, **158**, 228-256.
16. Curutchet G, and Donati E. (2000). Iron-oxidizing and leaching activities of sulphur grown *Thiobacillus ferrooxidans* cells on other substrates: effect of culture pH. *J. Biosci. Bioeng.* **90**, 57–60.
<https://pubmed.ncbi.nlm.nih.gov/16232818/>
17. Das N. (2010). Recovery of precious metals through biosorption-A review, *Hydrometallurgy*, **103**, 180-189.
18. Debaraj M, and Young-Ha Rhee, (2010). Current research trends of microbiological leaching for metal recovery from industrial wastes. *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology*, **4**, 1289-1296.
19. Deepatana A, Tang JA, and Valix M. (2006). Comparative study of chelating ion exchange resins for metal recovery from bioleaching of nickel laterite ores. *Miner. Eng.* **19**, 1280-1289.
<https://doi.org/10.1016/j.mineng.2006.04.015>

20. Dopson M, and Lindstrom EB. (1999). Potential role of *Thiobacillus caldus* in arsenopyrite bioleaching. *Appl. Environ. Microbiol.* **65**, 36–40.
21. Ekhlas Uddin Md., Pulak Maitra, Firoz Alam Md., (2014). Isolation and characterization of proteases enzyme from locally isolated *Bacillus* sp., *American J. of Life Sciences*, **2**(6), 338-344.
<https://doi.org/10.11648/j.ajls.20140206.12>
22. Fowler TA, Holmes PR, and Crundwell FK. (2001). On the kinetics and mechanism of the dissolution of pyrite in the presence of *Thiobacillus ferrooxidans*. *Hydrometallurgy* **59**, 257–270.
[https://doi.org/10.1016/S0304-386X\(00\)00172-9](https://doi.org/10.1016/S0304-386X(00)00172-9)
23. Giaveno A, and Donati E. (2001). Bioleaching of heazel woodite by *Thiobacllus* sp. *Process. Biochem.* **36**, 955–962.
24. Hol A, Weert GV, Kondos P, and Buisman CJN. (2010). Bioreduction of pyrite investigated in a gas lift loop reactor. *International Journal of Mineral Processing*, **94**, 140-146.
25. Hol A, Weert GV, Kondos P, and Buisman CJN, (2011b). The effect of anaerobic processes on the leachability of an arsenopyrite refractory ore. *Miner. Engin.*, **24**, 535-540.
26. Hu Q, Liang Y, Hao X, Liu X, and Qiu G. (2013). Metagenomic insights into the microbial community diversity between leaching heap and acid mine drainage. *Advanced Materials Research*, **825**, 141-144.
27. Junya C, Zhang G, Mao Z, Fang Z and Yang C. (2009). Precipitation of valuable metals from bioleaching solution by biogenic sulphides. *Miner. Eng.* **22**, 289–295.
<https://www.x-mol.com/paper/1308102676947636224?adv>
28. Kang SY, Lee JU, and Kim KW, (2007). Biosorption of Cr(III) and Cr(VI) onto the cell surface of *Pseudomonas aeruginosa*. *J. Biochem Eng.* **36**, 54–58.
29. Konishi Y, Asai S, and Tokushige M, (1999). Kinetics of the bioleaching of chalcopyrite concentrates by acidophilic thermophile *Acidianus brierleyi*. *Biotechnol.* **15**, 681–688.
<https://doi.org/10.1021/bp9900662>
30. Laguna C, Gonzalez F, and Muñoz JA. (2011). Bioreduction of iron compounds as a possible clean environmental alternative for metal recovery. *Minerals Engineering*, **24**, 10–18.
31. Lakzian A, Berenji AR, Karimi E and Razavi S. (2008). Adsorption capability of lead, nickel and zinc by exopolysaccharide and dried cell of *Ensifer meliloti*. *Asian J Chem.* **20**, 6075–6080.
<https://profdoc.um.ac.ir/articles/a/1006738.pdf>
32. Ledin, M. (2000). Accumulation of metals by microorganisms – processes and importance for soil systems. *Earth-Sci Rev*, **51**, 1–31.
33. Li J, Zeng X, Chen M, and Stevels A. (2015). "Control-Alt-Delete": Rebooting Solutions for the E-Waste Problem. *Environmental Sci. & Technol.* **49**, 7095-7108.
<https://doi.org/10.1021/acs.est.5b00449>
34. Liang G, Mo Y, and Zhou Q. (2010). Novel strategies of bioleaching metals from printed circuit boards (PCBs) in mixed cultivation of two acidophiles. *Enzyme Microb. Technol.* **7**(47), 322–326.
35. Malik, A. (2004). Metal bioremediation through growing cells. *Environ Int.* **30**, 261–278.
36. Mata YN, Torres E, and Muñoz JA. (2009). Gold(III) biosorption and bioreduction with the brown alga *Fucus vesiculosus*. *J. of Hazardous Materials*, **166**, 612-618.
<https://pubmed.ncbi.nlm.nih.gov/19124199/>
37. Morin D, Lips A, and Pinches T, et al. (2006). BioMinE – Integrated project for the development of biotechnology for metal-bearing materials in Europe. *Hydrometallurgy*, **83**(1–4), 69–76.
<https://doi.org/10.1016/j.hydromet.2006.03.047>
38. Mulligan CN, Bernard F, and Gibbs F. (2004). Bioleaching of heavy metals from a low grade mining ore using *Aspergillus niger*. *J. Hazard. Mater.* **110**, 77–84.
39. Murad A, El-Holi K, and Al-Delaimy S. (2003). Citric acid production from whey with sugars and additives by *Aspergillus niger*. *Afr. J. Biotechnol.* **2**(10), 356–359.
<https://www.ajol.info/index.php/ajb/article/view/14852>

40. Ndlovu, S. (2008). Biohydrometallurgy for sustainable development in the African minerals industry. *Hydrometallurgy*, **91**, 20–27.
41. Olson GJ, Brierley JA, and Brierley CL. (2003). Bioleaching review. Part B. Progress in bioleaching: applications of microbial processes by the minerals industry. *Appl. Microbiol Biotechnol.* **63**, 249-257. <https://pubmed.ncbi.nlm.nih.gov/14566430/>
42. Orquidea C, Galizia F, Marrero J, and Donati E. (2008). Cobalt and nickel recoveries from laterite tailings by organic and inorganic bioacids. *Hydrometallurgy*, **94**, 18–22.
43. Pina PS, Leao VA, Silva CA, Daman D, and Frenay J. (2005). The effect of ferrous and ferric iron on sphalerite bioleaching with *Acidithiobacillus sp.* *Miner. Eng.* **18**, 549-551.
44. Pollmann K, Kutschke S, and Lederer FL. (2018). Bio-recycling of metals: Recycling of technical products using biological applications. *Biotechnol. Advan.*, **36**(4), 1048-1062. <https://pubmed.ncbi.nlm.nih.gov/29555455/>
45. Pradhan N, Das B, Gahan CS, Kar RN, and Sukla LB. (2006). Beneficiation of iron ore slime using *Aspergillus niger*, and *Bacillus circulans*. *Bioresour. Technol.* **97**, 1876–1879.
46. Rahman MA, Uddin ME, and Ahmed R. (2019). Isolation, identification and antibiotic sensitivity pattern of *Salmonella* spp. from locally isolated samples, *Am. J. Pure Appl. Sci.*, **1**(1), 1-11. <https://doi.org/10.34104/ajpab.019.019111>
47. Rasulov BA, Yili A, and Aisa HA. (2013). Biosorption of metal ions by exopolysaccharide produced by *Azotobacter chroococcum* XU1. *J Environ Prot.* **4**, 989–993.
48. Rawlings, DE. (2004). Microbially assisted dissolution of minerals and its use in the mining Industry. *Pure Appl. Chem.* **76**, 847–859.
49. Rawlings DE, Dew D, and du Plessis C. (2003). Biomineralization of metal containing ores and concentrates. *Tren. Biotech.* **21**, 38-44. <https://pubmed.ncbi.nlm.nih.gov/12480349/>
50. Rezza I, Salinas E, Elorza M, Donato E. (2001). Mechanisms involved in bioleaching of an aluminosilicate by heterotrophic microorganisms. *Process Biochem.* **36**, 495–500.
51. Sponza, DT. (2002). Extracellular polymer substances and physicochemical properties of flocs in steady and unsteady-state activated sludge systems. *Proc. Biochem.* **37**, 983-998. [https://doi.org/10.1016/S0032-9592\(01\)00306-5](https://doi.org/10.1016/S0032-9592(01)00306-5)
52. Srinath T, Verma T, and Garg SK. (2002). Chromium (VI) biosorption and bioaccumulation by chromate resistant bacteria. *Chemosphere*, **48**, 427–435.
53. Uddin M. E., Ahmad T., and Ahammed T. (2017). Thermotolerant extracellular proteases produced by *B. subtilis* isolated from local soil that representing industrial applications. *J. of Pure and Applied Microbiol.* **11**(2), 733-741. <https://doi.org/10.22207/JPAM.11.2.12>
54. Uryga A, Sadowski Z, and Grotowski A. (2004). Bioleaching of cobalt from mineral products. *Physicochem. Probl. Miner. Process*, **38**, 291 –299.
55. Valdes J, Cardenas JP, Quatrini R, and Holmes DS. (2010). Comparative genomics begins to unravel the ecophysiology of bioleaching. *Hydrometallurgy*, **104**, 471-476. <https://doi.org/10.1016/j.hydromet.2010.03.028>
56. Valix MF, Usai and Malik R. (2001). Fungal bioleaching of low grade laterite ore, *Miner. Eng.* **14**(2), 197–203.
57. Veglio F, Beolchini F and Ubaldini S. (1998). Empirical models for oxygen mass transfer: a comparison between shake flask and lab-scale fermentor and application to manganiferous ore bioleaching *Process. Bioch.* **33**(4), 367-376.
58. Velásquez L, and Dussan J. (2009). Biosorption and bioaccumulation of heavy metals on dead and living biomass of *Bacillus sphaericus*. *J Hazard Mater.* **167**, 713–716. <https://pubmed.ncbi.nlm.nih.gov/19201532/>
59. Venkateshwara R, Shivammavar TC, and Gaddad SM. (2002). Bioleaching of Copper from chalcopyrite ore by fungi. *Indian J. Exp. Biol.* **40**(3), 319–324.
60. Vijayaraghavan K, and Yun YS. (2008). Bacterial biosorbents and biosorption. *Biotechnol Adv.* **26**, 266–291. <https://pubmed.ncbi.nlm.nih.gov/18353595/>
61. Wang J and Xu Z 2015 Disposing and Recycling Waste Printed Circuit Boards:

- Disconnecting, Resource Recovery, and Pollution Control. *Environmental Science & Technology*, **49**, 721-733.
62. Wang KS, Lin KL, and Lee HC. (2009). Melting of municipal solid waste incinerator fly ash by waste-derived thermite reaction. *J. Hazard. Mater.*, **162**, 338–343.
63. Wengel M, Kothe E, Heide K, and Gleixner G. (2006). Degradation of organic matter from black shales and charcoal by the wood-rotting fungus *Schizophyllum commune* and release of DOC and heavy metals in the aqueous phase. *Sci. Total. Environ.* **367**, 383–393.
<https://pubmed.ncbi.nlm.nih.gov/16483638/>
64. Willscher RS, and Bosecker K. (2003). Studies on the leaching behavior of heterotrophic microorganisms isolated from an alkaline slag dump. *Hydrometallurgy*, **71**, 257–264.
65. Wu HY, and Ting YP. (2006). Metal extraction from municipal solid waste (MSW) incinerator fly ash chemical leach in fungal bioleaching. *Enzyme Microbiol. Technol.* **38**(6), 839–847.
<https://doi.org/10.1016/j.enzmictec.2005.08.012>
66. Xu TJ, and Ting YP. (2009). Fungal bioleaching of incineration fly ash: metal extraction and modeling growth kinetics. *Enzyme Microbiol. Technol.* **44**(5), 323–328.
67. Yang C, Qin W, Lai S, and Chang Z, (2011). Bioleaching of a low grade nickel-copper-cobalt sulfide ore. *Hydrometallurgy*, **1–2** (106), 32–37.
68. Zhang RY, Xia JI, Nie ZY, and Gua, (2010). A new strain *L. ferriphilum* YTW315 for bioleaching of metal sulfides ores. *Trans. Nonferrous Metall. Soc. China*, **20**, 135–141.
<http://www.paper.edu.cn/scholar/showpdf/OUT2gN3IMTj0QxeQh>

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