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Bio-Sorption of Heavy Metals: A Review

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Abstract: *Discharge of heavy metals from metal processing industries is known to have adverse effects on the environment. Conventional treatment technologies for removal of heavy metals from aqueous solution are not economical and generate huge quantity of toxic chemical sludge. Biosorption of heavy metals by metabolically inactive non-living biomass of microbial or plant origin is an innovative and alternative technology for removal of these pollutants from aqueous solution. Biosorption is regarded as a potential cost-effective biotechnology for the treatment of high volume low-concentration complex wastewaters containing heavy metals. Some factors such as solution pH may affect biosorption process. The equilibrium of biosorption process can be described by isotherm models such as Langmuir and Freundlich. A vast array of biological materials, especially bacteria, algae, yeasts and fungi have received increasing attention for heavy metal removal and recovery due to their good performance, low cost and large available quantities, have been reviewed in this paper. Tree bark is among the widely available and low-cost sorbents for metal adsorption in aqueous environments. Peat is also a type of commonly used biosorbent.*

Keywords: *Biosorption, Heavy Metals, Bioaccumulation, Biosorbents, Bacteria, Fungi, Bark, Algae.*

1. INTRODUCTION

Pollution generally refers to a change that is harmful to the environment. Water pollution occurs when harmful substances—often chemicals or microorganisms—contaminate a stream, river, lake, ocean, aquifer, or other body of water, degrading water quality and rendering it toxic to humans or the environment. The introduction of many new products for the home and office - computers, drugs, textiles, paints and dyes, plastics (hazardous waste), including toxic chemicals ,other heavy metals into the environment, leads to water contamination.[1]

Heavy metals are characterized as metals/metalloids that have at least 5 times higher density than water. It is characterized as any dense metal or metalloid that has the capacity to pollute the environment. They are found naturally in Earth’s crust; however their concentration increases due to various industrial, domestic, agricultural, medical and technological applications. Some heavy metals have bio-importance as trace elements but, the bio toxic effects of many of them in human biochemistry are of great concern. The over accumulation can lead to toxicity, which depends on various factors like, dose, route of exposure, and chemical species. [2]Industrialization in India gained a momentum with initiation of five year developmental plan in the early 50's. The pollutants of concern include lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, gold, silver, copper and nickel. These toxic materials may be derived from mining operations, refining ores, sludge disposal, fly ash from incinerators, the processing of radioactive materials, metal plating, or the manufacture of electrical equipment, paints, alloys, batteries, pesticides or preservatives. Heavy metals such as zinc, lead and chromium have a number of applications in basic engineering works, paper and pulp industries, leather tanning, organic chemicals, petrochemicals fertilisers, etc. [4] Major lead pollution is through automobiles and battery manufacturers. For zinc and chromium the major application is in fertiliser and leather tanning respectively. Hence, it is essential to remove these heavy metals from the water bodies and other surfaces in order to prevent harmful adverse effects.

Table1. *Sources and harmful effects of various heavy metals*

Heavy metal	Major Sources	Toxic Effect	References
Copper	Plating, copper polishing paint, printing, operations	Neurotoxicity, and acute toxicity, dizziness, diarrhoea	[28]
Zinc	Mining, refineries, brass manufacturing, plumping	Causes short term metal-fume fever, gastrointestinal distress	[29]
Mercury	Batteries, paper industry, paint industries, mining	Damage to nervous system, proto plasm poisoning, corrosive to skin, eyes, muscles, dermatitis, kidney damage	[30]
Nickel	Porcelain enamelling, non-ferrous metal, paint formulation, electroplating	Chronic bronchitis, reduced lung function, lung cancer	[31]
Arsenic	Smelting, mining, rock sedimentation, pesticides,	Bronchitis, dermatitis, bone marrow depression, haemolysis, hepatomegaly	[32]
Chromium	Textile, dyeing, paints and pigments, steel fabrication	Carcinogenic, mutagenic, teratogenicity, epigastria pain nausea, vomiting, severe diarrhoea, producing lung tumors	[33]
Lead	Mining, paint, pigments, electroplating, manufacturing of batteries, burning of coal	Anaemia, brain damage, anorexia, malaise, loss of appetite, Liver, kidney, gastrointestinal damage, mental retardation in children	[34, 35]

There are various methods for treating these heavy metal accumulated water bodies. Methods for treating wastewater containing heavy metals often involve technologies for reduction of toxicity. Removal processes such as; ion exchange, Coagulation and Flocculation, membrane filtration, electro dialysis, reverse osmosis, ultra filtration and photo catalysis are the common methods. [5]

- **Ion Exchange:** Ion Exchange is an exchange of ions between two electrolyte solutions. The main limitations of the method is it is economically expensive .The separation process is inexpensive if operated with low concentration of ions, increase of concentration result in a cost increase. It is also not beneficial because of partial separation of ions.[7]

- **Reverse Osmosis:** It is technology that uses a semi permeable membrane to remove ions, molecules and larger particles from drinking water. It operates at a pressure which is higher than the osmotic pressure. This technology consumes more energy than regular methods and is also time consuming. It sometimes also removes the essential elements of water like Iron, Magnesium and many more. [7]

- **Electro Dialysis:** It is the process in which ions are transported through semi permeable membrane under the influence of electrical potential. Under the influence of electric potential cations and anions separate and accumulate at respective electrodes. In this method however, prior treatment of feed is essential to prevent clogging and fouling of the system. Organic matters and colloids cannot be removed by this process; only ions can be removed by feed stream.[7]

- **Ultrafiltration:** In this technology, filtration is carried out using a medium fine porous membraneto retain colloidal particles, viruses or large molecules. It removes suspended particles and bacteria but is sensitive to oxidative chemicals such that nitric acid, sulphuric acid and peroxides. Sludge formation prevents the further process to occur. [7]

- **Phytoremediation:** Phytoremediation is a technology that uses plants to remove hazardous contaminants from soil, air or water. It refers to the natural ability of certain plants to bio accumulate, degrade, or supply contaminants in soils, water, or air. Toxic heavy metals and organic pollutants are the major targets for phytoremediation. However, survival of plants is affected by the toxicity of the contaminated land and the general condition of the soil. It is limited to the surface area.[7]

Due to the following disadvantages of various technologies, certain eco-friendly methods have been studied in order to obtain a cost efficient method. Various methods have been studied for the development of cheap and effective technologies, in order to decrease the amount of wastewater produced as well as to improve the quality of the treated effluent. Adsorption is one of the alternatives.[7]Adsorption is a mass transfer process in which substance from the liquid phase is transferred to the surface of a solid, where it gets bounded by physical or chemical interactions. The adsorbents may be of mineral, organic or biological origin, zeolites, industrial by-products, agricultural wastes, biomass, and polymeric materials . Recently, a great deal of interest in the research for the removal of heavy metals from industrial effluent has been focused on the use of agricultural by-products as adsorbents.[8] The use of agricultural by-products in bioremediation of heavy metal ions is known as bio-sorption. Considering their cost and efficiency, biomass-based adsorbents or bio sorbents are the most attractive alternatives to ion exchange resins and activated carbons. Hence, Bio sorption is an efficient method. [7-9]

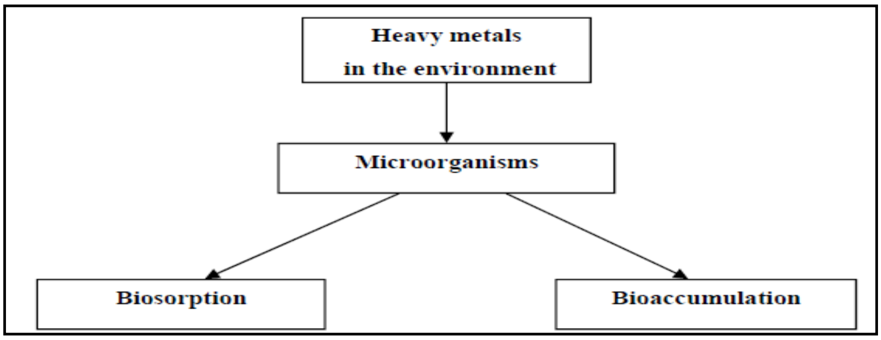

Fig1. *Biological methods for removal of heavy metals [4]*

2. Bio Sorption and Bio Accumulation

Bio sorption is a property of certain types of inactive, dead, microbial biomass to bind and concentrate heavy metals from even very dilute aqueous solutions. It describes the removal of heavy metals by binding to biomass in an aqueous solution by passive adsorption. Biomass exhibits this property just as a chemical substance for ion exchange. It is the ability of biological materials to accumulate heavy metals from wastewater by various physio-chemical pathways of uptake. [10] It is possible by both living and non-living biomass. It is an environment friendly process as compared to other techniques. It has wide industrial applications. The contaminants are mostly bounded just on the microbial surface. Materials which exhibit bio-sorptive behaviour include certain algae, fungi and bacteria.

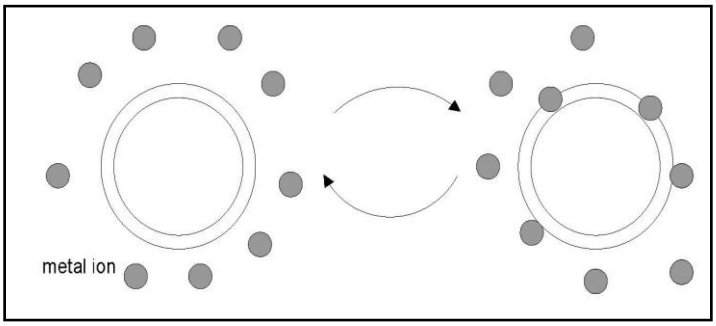

Fig2. *Bio sorption of metal ions [11]*

However, bioaccumulation is an active process of metal removal by living cells. The contaminants are bounded inside the microbial cells. It occurs only when microbial cells are alive because removal of metals requires metabolic activity. It is an irreversible phenomenon, because of which recovery of metals becomes difficult. [4]

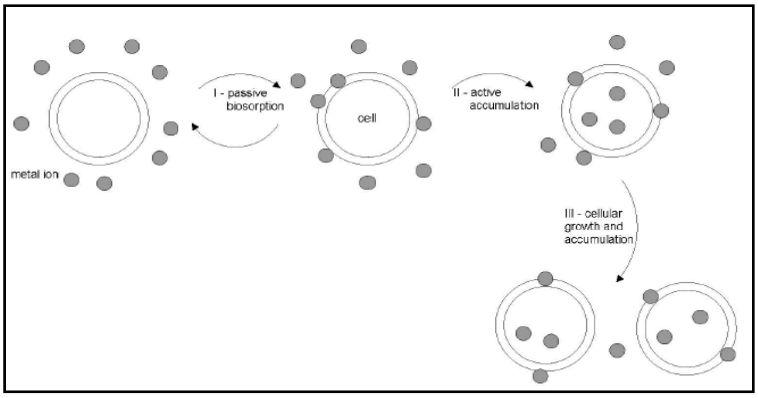

Fig3. *The stages of bioaccumulation of metal ions [11]*

There are many differences between bio accumulation and bio sorption as given in the table below. (TABLE 2)

Table2. *Difference between bio sorption and bioaccumulation*

Feature	Bio sorption process	Bioaccumulation process
Definition	The passive sorption of the dead micro bial cell walls is called as bio sorption	The active process of metal removal by living cells is referred to as bioaccumulation
Metal affinity	Higher under favourable conditions	Toxicity affects metal uptake by living cells, but in some instances, there is high metal accumulation
Rate of metal uptake	Generally rapid, a few seconds for outer cell wall accumulation	Normally slower than biosorption
Selectivity	Variety of ligands involved, hence poor	Better than biosorption, but less than some chemical technologies
Temperature	Within a modest range	Inhibited by low temperature
Versatility	Metal uptake may be affected by anions or other molecules.Extent of metal uptake usually pH dependent	Require an energy source Dependent on plasma membrane ATPase activity

2.1. Advantages of Bio sorption

- Low cost
- High efficiency in terms of removal and recovery of specific heavy metals
- Minimization of chemical and or Biological sludge
- No additional nutrient requirement, regeneration of bio sorbent
- Possibility of metal recovery [12]
- Use of naturally available and renewable biomaterials that can be cheaply produced
- Allows to handle multiple heavy metals and mixed wastes
- Greatly reduces the volume of hazardous waste produced
- Operates over a wide range of conditions including temperature, pH, and presence of other ions (including Ca (II) and Mg (II))
- High affinity for metals hereby, reducing metal concentrations to below 1 ppb
- Small requirement for additional expensive reagents which typically cause disposal and space problems[11]
- Bio sorbents can be reused, after the metal is recycled
- Bio sorption is capable of performance comparable to the most similar technique, ion exchange treatment

2.2. Mechanism of Bio Sorption

Bio sorption involves mechanism like ion exchange, chelation, complexation and surface precipitation. The difference in composition of various micro organisms affects the amount of metal ions binding to them.

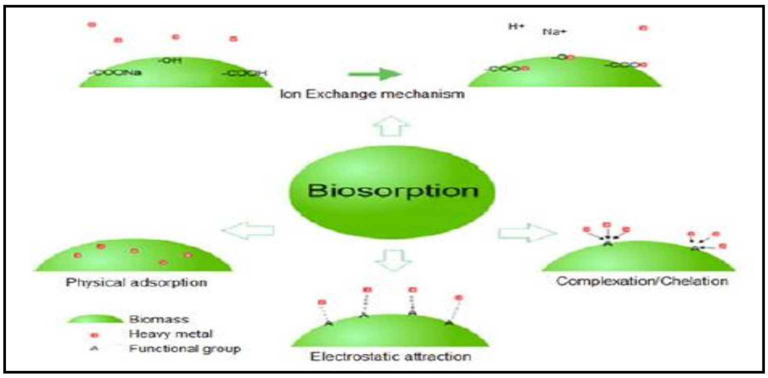

Fig4. *A schematic representation of the mechanisms involved in the bio sorption of potentially toxic elements [13]*

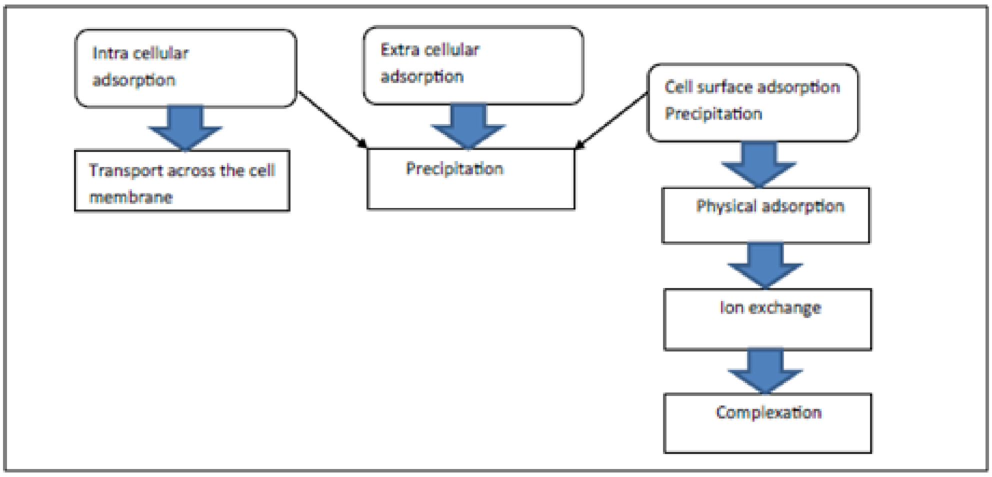

Fig5. *Mechanisms of bio sorption based on location of where metal removed are found [15]*

Passive bio sorption is a reversible adsorption- desorption process which has dynamic equilibrium. It takes place rapidly either by single or as a combined effect of the following methods: [14]

- **Transport across Cell Membrane:** Heavy metals get transported through microbial cells in a way similar to transport of essential metals like **magnesium, calcium and potassium**. The membranes get confused with the heavy metals of same charge. Bio sorption is carried out in 2 steps: Firstly, the metals get bounded to the cell wall and: Secondly, the metal ions are transported inside the cell membrane by intracellular uptake.[5]
- **Physical Adsorption:** It takes place as a result of van der Waals' forces. Metals ions like **cadmium, copper, cobalt, zinc** and **uranium,** get adsorbed on the surfaces of various dead algae, fungi, and yeasts takes place as a consequence of electrostatic force. This force occurs between metal ions and microbial cell walls. [5]
- **Ion Exchange:** Many microbial organisms have their cell walls made up of various polysaccharides. The ions of polysaccharides get exchanged by the heavy metal ions. This exchange can take place only in case of bivalent ions. [5]
    - ➢ $B^- + M^+ \longleftrightarrow BM$
    - ➢ Where B= Free Binding Site, M= adsorbate metal, BM= Adsorbed metal on microbial surface[17]
- **Complexation:** Heavy metals can also be removed by formation of a complex result of interaction between metals and active groups present on the cell surface. This mechanism occurs only at the cell surface. It is the only mechanism by means of which various metals ions like **calcium, magnesium, cadmium, zinc, mercury** and **copper** get adsorbed on the surface of bacteria. Some microorganisms also release organic acids, which helps to chelate the toxic metals forming metal based organic molecules. The organic acids formed help to make the metals soluble and leach them from surface of microbial organisms. Metals may wither be adsorbed on the surface or be complexed by carboxyl groups that are found in polysaccharides and then leached out. [5]
- **Precipitation:** This mechanism can be carried out in 2 ways:
    - ➢ **Precipitation depending on the metabolic activity of microbial cell wall:**In this case, the active self defense system of the cell reacts in the presence of heavy metals leading to formation of various compounds supporting precipitation.
    - ➢ **Precipitation independent of metabolic activity of microbial cell wall:** In this case, precipitation occurs as a result of reaction between metal and cell wall surface. [5]

In Second Part due to Active Bio sorption, metal ions penetrate the cell membrane entering inside the cells.

2.3. Factors Affecting Bio Sorption

Although, there are many variables which can influence metal bio sorption, parameters such as the biomass type, pH, ionic strength and competition between metal ions can have a significant effect on metal binding. Some of the most important factors affecting metal binding are discussed below: [16]

- **PH:** Solution pH is the most important factor affecting bio sorption. The adsorption of positive ions increases, while that of negative ions decreases by increasing the pH of solution. Only some negative ligands or complexes do not show any effect or decreases with increasing pH. There are 3 ways in which pH affects bio sorption:
  - When there are acidic binding groups present on cell surface, the availability of adsorption depends on pH of solution. In such conditions the available places becomes protonated, and a competition occurs between metals ions and protonated sites. At low pH, the metal ions get desorbed easily.
  - At extremely high pH, the structure and capacity of adsorbents get affected.
  - The formation of metals in solution is pH dependent. [17-18]
- **Ionic strength (presence of other cations):** Other positive ions present in solution reduce the adsorptive property of the heavy metals. The rate of inhibition depends on the binding strength of other metal ions. **Alkali metals** like **Potassium** and **Sodium** inhibit the binding of heavy metalions to microbial biomass, whereas heavy metals like **Zinc, Copper**, and **Iron** inhibit the binding properties of **uranium** or **radium**.[17-18]
- **Temperature:** Temperature enhances biosorptive removal of adsorptive heavy metals, but damages the physical structure of the bio sorbent. Simple adsorption processes are generally exothermic. Haug and Smidsrod derived the following equation.

$$K = \exp\left(\frac{-\Delta G^o}{RT}\right) = \exp\left(\frac{-\Delta H^o + T\Delta S^o}{RT}\right) = \exp\left(\frac{-\Delta H^o}{RT}\right)\ \exp\left(\frac{\Delta S^o}{R}\right)$$ [17]

- **Type and Availability of Bio sorbent:** There are various types of bio sorbents like algae, fungi, bacteria, molasses, peat, bark etc. Not only the type of biomass but also the type of environment in which they grow affects the rate of bio sorption. The nature of bio sorbents and their availability, treatment methods, dosage and size affect bio sorption. [17-18]
- **Agitation Speed:** As the speed of agitation increases, the rate of bio sorption of heavy metal increases, as the mass transfer resistance decreases. But as the agitation increases, the adsorbents get harmed physically. [18]
- **Presence of Anions (Ligands):** Various ligands can cause the following:
  - Formation of chelating or complexing compounds that increase the adsorption properties of the heavy metals, thereby increasing the rate of bio sorption, or vice versa.
  - It sometimes reacts with the microbial organisms thus reducing the number of active adsorption sites.[17]

2.4. Equilibrium Studies in Bio sorption

By fitting experimental data with various isotherm models, Equilibrium of Bio sorption process can be predicted.

Langmuir and Freundlich are the two well-known equilibrium adsorption isotherm models.

- **Langmuir Isotherm:** The model was proposed by Langmuir and is based on a homogenous surface. Formation of a monomolecular sorption layer and active sites on the sorbent surface are energetically identical, is been assumed on the surface of the adsorbent. It considers adsorption as a chemical phenomenon. $q = \frac{q_{max} b C_{eq}}{1 + b C_{eq}}$ [19]

It is the basic formula for Langmuir Isotherm, and the linear form of Langmuir formula is defined as follows:

$$\frac{C_{eq}}{q} = \frac{1}{q_{max}b} + \frac{1}{q_{max}} C_{eq}$$ [19]

Where q -amount of accumulated metal (mg/g);

C_{eq}- ion concentration in solution at equilibrium (mg/L);

q_{max}-maximum metal sorption (mg/g);

b-Ratio of adsorption and desorption rates (mL/mg).

This model cannot be described for heterogeneous adsorption systems. [19]

- **Freundlich Isotherm:** The model is an empirical model for monolayer adsorption which is derived by using various empirical methods to calculate the relative change of surface tension (Jirgensons and traumanis, 1954) and is usually based on a heterogenous surface. It does not assume monolayer capacity.[19]

$$q = K_F C_{eq}^{1/n}$$ [19]

It is the basic formula for Freundlich Isotherm, and the linear form of Freundlich formula is defined as follows:

$$\log q = \log K_F + \frac{1}{n}(log C_{eq})$$ [19]

Where K_F (mg/g) and n are Freundlich constants.

K_F- adsorption capacity

n - Adsorption intensity (sorbent heterogeneity).

q – Amount of metals accumulated

It provides good accuracy over a wide range of heterogeneous systems of adsorption. [19]

Other Adsorption Isotherms for Bio sorption of metals is modelled according to non-linear functions that are described by Brunauer-Emmet-Teller (BET) isotherms.

Table3. *Examples of Physiochemical Models of Adsorption [20, 36]*

Adsorption Model	Equation	Advantages	Disadvantages
Langmuir	$q=(Q_{max}bC_{EQ})/(1+bC_{EQ})$	Interpretable parameters	Not structured; Monolayer Adsorption
Freundlich	$q = K_F C_{EQ}^{1/n}$	Simple expression	Not structured; No levelling off
Combination Langmuir-Freundlich	$q=(Q_{MAX}bC_{EQ}^{1/n})/(1+bC_{EQ})$	Interpretable parameters, Simple expression	Unnecessarily complicated
Radke- Prausnitz	$1/q= 1/(aC_{EQ})+1/(bC_{EQ}^{\beta})$	Simple expression	Empirical, uses 3 parameters
Brunaer- Emmet- Teller	$q=(BCQ^0)/\{[Cs-C][1+(B-1)C/C_S]\}$	Multilayer adsorption; Inflection point	No total capacity equivalent

3. Kinetic Models for Bio sorption

Kinetics of metal sorption is governed by the rate equation that determines the residence time and is one of the important characteristics that defines the efficiency of an adsorbent. Several factors or independent processes like external mass transfer (film diffusion), bulk diffusion, intra particle diffusion and chemical reactions control Bio sorption kinetics.

Where: External Mass Transfer – Diffusion of heavy metals through boundary around bio Sorbent

Bulk Diffusion – Transport of metal ions in the solution

Chemical Reactions (Chemisorptions) – Reaction between active sites of bio sorbent

And metal ion

Intra Particle diffusion - Diffusion of metals from bio sorbent surface to internal Sites [21]

Various kinetic models used are discussed below:

Table4. *Various Kinetic Models*

Model	Equation	Parameters	Reference
Pseudo-first-order	$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t$	q_t (mg/g) = amount of adsorbate adsorbed at time t, k_1(min^{-1})= pseudo-first-order rate constant k_2 (g mg^{-1} min^{-1}) = pseudo-second-order rate constant	
Pseudo-second order	$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}t$		
Elovich			

4. Bio Sorbents

Potentials of a good bio sorbent are:

- Available in large amount
- Cheap
- Must have high uptake capacity
- Should be easy to operate
- Must have good regeneration ability[22]

Depending on the biomaterial origin, potent metal bio sorbents can be categorized as plant products or microbes. [23]

4.1. Plant Products

Bio sorbents from plant products are mainly agricultural by-products such as maize cob and husk, sunflower stalk, Medicagosativa, cassava waste, wild cocoyam, sphagnumpeat moss, chitosan, sago waste, shea butter seed husks, banana pith, coconut fibre, sugar beet pulp, wheat bran, sugar cane bagasse, wool, rice, exhausted coffee, waste tea, walnut skin, cork biomass, seeds of Ocimum basilicum, defatted rice bran, rice hulls, soybean hulls and cotton seed hulls, hardwood, pea pod, cotton and mustard seed[23]

4.2. Microbes

There are different types of microbes which find use in metal bio sorption due to their binding properties. They are more efficient due to their cell structure and stability as compared to plant products. [23]

Table5. *Types of microbial bio sorbents [25]*

Category	Examples
Bacteria	Gram-positive bacteria (Bacilus sp., Corynebacterium sp., etc), gram-negative bacteria (Es.cherichia sp., Pseudomonas sp., etc) cyanobacteria (Anabaena sp., Synechocysis sp., etc)
Fungi	Molds (Aspergilus ap., Rhizopus sp., etc), mushrooms (Agaricus sp., Trichaptum sp., etc), and yeast (Saccharomyces sp., Candida sp., etc)
Algae	Micro-algae (clorella sp, Chlamydomonas sp., etc), macro-algae (green seaweed (Enteromorpha sp., Codium sp, etc) brown seaweed (Sargassum sp., Eckria sp., etc) and red seaweed Geidum sp., Porphyra sp., etc)

4.2.1. Bacteria

Bacteria is the most abundant and versatile form of microorganisms which constitute a significant fraction of the entire living terrestrial biomass. Earlier in 1980, some microorganisms were found to accumulate metallic elements with high capacity. Some marine microorganisms enriched Pb and Cd relative to the aqueous solute concentration of these elements in ocean water. Bacteria were used as bio sorbent because of its small size, ubiquity, and ability to grow under controlled conditions, and its resilience to a wide range of environmental situations. Bacteria species such as Bacillus, Pseudomonas, Streptomycin, Escherichia, Micrococcus, etc, have been tested for uptake metals or organics. Bacteria may either possess the capacity for bio sorption of many elements or, alternatively, depends on the species, it may be element specific. [24]

4.2.2. Fungi

Fungi though being a large diversity, only 3 of them are of importance:

- Yeasts
- Molds
- Mushrooms

However, out of the above mentioned 3 only Yeast and molds are used mostly for Bio sorption. Molds are filamentous, while Yeast is unicellular. [24]

Fungi and yeasts

- Are easy to grow,
- produce high yields of biomass
- Can be manipulated genetically and morphologically.[24]

Table6. *Bio sorption by Fungal Biomass*

Species of Fungi	Metal ions	References
Aspergillusniger, Mucorrouxii, Rhizopusarrhizus	Au	[37]
Penicillium spp. (living cells)	Ag,Cu,Cd,Pb	[37]
Penicillium, Aspergillus, Trichoderma, Rhizopus, Mucor, Saccharomyces, Fusarium (living cells)	Pb, Cu, Cd, Zn	[37]
Aspergillus, Penicillium, Rhizopus, Saccharomyces, Trichoderma, Mucor, Rhizopus (living cells)	Th ,U, Sr, Cs, La	[37]
Phanerochaetechryosporium (living cells)	Cd, Pb, Cu	[38]

The yeast biomass has been successfully used as biosorbent for removal of Ag, Au, Cd, Co, Cr, Cu, Ni, Pb, U, Th and Zn metals from aqueous solution. Most of yeasts can adsorb a wide range of metal ions or be strictly specific in respect of only one metal ion.

Penicillium (a type of Filamentous Fungi) can remove a variety of heavy metal ions from aqueous solutions, such as Cu, Au, Zn, Cd, Mn, U and Th. [24]

4.2.3. Algae

Algae are of special interest for the development of new biosorbent material due to its high sorption capacity and ready availability in practically unlimited quantities in the seas and oceans. Higher binding capacity for metal ions is been found for brown algae in comparison of red and green algae. Algae adsorb one or more heavy metal ions, including K, Mg, Ca, Fe, Sr, Co, Cu, Mn, Ni, V, Zn, As, Cd, Mo, Pb, Se, Al, with good metal uptake capacity.[24]

Table7. *Comparison of adsorption capabilities of algae*

Metal ions	Brown Algae	Red Algae	Green Algae	Average Value	Reference
Cd	0.930	0.260	0.598	0.812	
Ni	0.865	0.272	0.515	0.734	
Zn	0.676		0.370	0.213	
Cu	1.017		0.504	0.909	
Pb	1.239	0.651	0.813	1.127	

4.3. Peat as Bio Sorbent

Peat is an accumulation of partially decayed vegetation or organic matter. The various characteristics of peat are:

- Large Specific Surface Area
- It has High water holding capacity and porosity
- It can be easily processed and blended
- It is widely available in many areas of world and is comparatively cheap [26]

4.4. Bark as Bio Sorbent

Out of the various tree components tree bark has the highest capacity to be used as a biosorbent. Though heavy metal adsorption studies have been conducted in the early 1920s, new bio sorbents like bark were tested after 1970. Bark has high adsorption capacity for Cadmium (Cd^{2+}) ions, studied by various scientists. Barks of Pinus ponderosa, C. japonica and Quercusvelutina showed the highest potential in the removal of copper, chromium and mercury, respectively. [27]

5. CONCLUSION

Conventional methods of removal of heavy metal ions are expensive; hence the search of using low cost, friendly ecosystem material must be needed. Bio sorption has great potential to compete with conventional technologies for the treatment of metal-contaminated waters originating from point and non-point sources of pollution. It is being an alternative to conventional methods for the removal of toxic heavy metals from industrial effluents. It offers several advantages including cost effectiveness, high efficiency, minimization of chemical/biological sludge, and regeneration of biosorbent with possibility of metal recovery. The process of bio sorption has many attractive features including removal of metals over quit broad range of pH and temperature, its rapid kinetics of adsorption and desorption and low capital and operation cost. Biological biomass can be regenerated relatively easily and used again. Bark shows a high adsorption capacity of metals, often comparable to that of activated. Carbon.

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