

# A Review on Removal of Heavy Metals by Biosorption: A Green Technology

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## ABSTRACT

Heavy metals have been introduced into the environment because of industrialization. It is well known that heavy metals linger in the environment and endanger organisms. Industrial effluents include microorganisms. To counteract the negative impacts of these metals, they have implemented a variety of measures. These tactics can depend on or be independent of metabolism. One such tactic is biosorption, which involves the interaction of metal ions with cell wall-based metal binding proteins. Algae, fungi, yeasts, and bacteria all engage in biosorption. In addition to live things, leftovers of dead microorganisms also possess biosorbent qualities, such as agricultural wastes like husks, seeds, peels, and stalks from various plants. Temperature, pH, the nature of the biosorbents, the surface area to volume ratio, the quantity of biomass, the initial metal ion concentration, and the metal affinity to the biosorbent are some of the variables that influence the rate of biosorption. Biosorption can be explained using several models, including the Freundlich model and the Langmuir model. Utilizing substances such as thiosulfate, mineral acids, and organic acids, biosorbed metals can be recovered. To avoid changing a biosorbent's physical qualities, the desorption agent should be carefully chosen. It concludes that, biosorption is an effective green technology to remove heavy metals from various types of effluents.

**Keywords:** Heavy metals, biosorption, bacteria, algae, fungi, yeasts.

## 1. INTRODUCTION

The biosphere, lithosphere, hydrosphere, and atmosphere are the four spheres that nature has endowed our planet with. These

spheres work together to promote a healthy ecology [1]. It's amazing how far the industrial revolution has come in the last fifty years. All spheres have become polluted as a result of human activity, population growth, industry, and urbanization [2]. Heavy metals are introduced into the environment primarily through two sources: (1) natural sources, such as volcanic emissions, forest fires, deep-sea vents, and geysers [3]; and (2) anthropogenic sources, such as mining and smelting operations, metal-manufacturing facilities, painting and coating industries, and tanneries. Direct environmental discharge of these heavy metals occurs. Metal concentrations that are higher than permitted limits cause health problems [4]. Given that heavy metals are known to accumulate within biological systems, there is a potential for bioaccumulation and associated chronic toxicity even when the concentration of metals does not exceed these limits [5]. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc are some of these metals [6]. Heavy metals are known to be present in industrial effluents and come from a variety of sources, including metal plating, mining, smelting, battery production, tanneries, petroleum refining, paint production, pesticide production, pigment production, and the printing and photographic industries [7].

## 2. Heavy Metals

Metals with a density more than  $5 \text{ g/cm}^3$  are typically referred to as heavy metals. Metals

are divided into essential and non-essential categories. Metals such as zinc, nickel, copper, and others are important metals because they are required for optimal cellular growth. While these metals are necessary at low quantities (nM), all heavy metals are toxic to living things at higher doses (M to mM) [8]. Metals are referred to as non-essential metals if they are known to have no biological use, such as lead, cadmium, and mercury. Such metals are poisonous in any amount. The list of heavy metals that are both necessary and optional is provided (Table 1). The periodic table has 90 naturally occurring elements, of which 21 are non-metals, 16 are light metals, and the remaining 53 are heavy metals (including As) [9]. Transition elements are primarily heavy metals in the periodic table. Heavy-metal cations can create complex compounds with partially filled 'd' orbitals that may or may not be redox-active. Cobalt, copper, nickel, and zinc are examples of heavy metals that operate as "trace elements" in complex biological reactions and serve as crucial cofactors for enzymes and metalloproteins. Heavy metal ions become harmful when their concentration in cells rises, which causes them to form complex compounds [10]. By lateral gene transfer, microorganisms develop tolerance to certain hazardous metals. The way that microorganisms interact with metal ions relies on a number of variables, including the metal's oxidation state, chemical and physical makeup, and the microorganism's stage of development.

Category of heavy metal	Example of heavy metals
Essential	Copper (Cu)
	Nickel (Ni)
	Iron (Fe)
	Zinc (Zn)
	Magnesium (Mg)
Non-essential	Lead (Pb)
	Mercury (Hg)
	Cadmium (Cd)
	Tin (Sn)
	Arsenic (As)

Table 1. Lists both necessary and optional heavy metals.

### 3. Heavy metal removal techniques

Various physical and chemical techniques have been used to remove metals from the environment throughout the past few decades. Below is a list of items: Chemical processes include electrochemical processing, oxidation/reduction, and chemical precipitation. Ion exchange, membrane technology, reverse osmosis, evaporation recovery, and filtering are examples of physical approaches. Microorganisms such as bacteria, fungi, or algae are examples of biological agents. However, due to their high cost, poor effectiveness, labor-intensive nature, or lack of selectivity in the treatment process, these solutions were not the first option [11]. According to decades of study on bioremediation or biosorption-based remediation strategies, bioremediation is both a cost-effective and natural process.

### 4. Biosorption

The ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated (by the use of ATP) or spontaneous physicochemical pathways of uptake (not at the cost of ATP) is referred to as biosorption. It is also a characteristic of some types of inactive, non-living microbial biomass that binds and concentrates heavy metals from even very dilute aqueous solutions. A number of variables, including cell physiology, physicochemical factors including pH, temperature, contact time, ionic strength, and metal concentration, as well as the makeup of microorganisms' cell walls, all play a role in this complex process. Various groups have investigated the biosorption of various heavy metals, such as cadmium, silver, lead, nickel, etc. employing microorganisms like fungi, algae, or bacteria [12].

#### 4.1. Importance

Numerous benefits of bioremediation include its cheap operating costs, minimal volume of discarded sludge, great efficacy in detoxifying very diluted effluents, and

even the ability to do remediation in place. Heavy metals are detoxified by bacteria in a number of ways. Although other types of heavy metal stress tolerance mechanisms have been discovered in bacteria, Cd detoxification has only been limited to efflux pumps. The best described plasmid encoded cad systems are found in *Staphylococcus aureus* and *Alcaligenes eutrophus*. By actively keeping Cd ions outside of the intracellular environment, these systems prevent its harmful effects. Numerous studies have consistently found that susceptible strains of bacteria can accumulate 3–15 times more Cd than resistant ones [13]. The covalent bonding of Cd ions to sulfhydryl groups is their most significant characteristic. Although this is a contributing factor to its high toxicity, many species employ this property to make the metal innocuous to the cell by sequestering it with metal-detoxifying ligands, which reduces the metal's bioavailability.

#### 4.2. Benefits of biosorption

The benefits of biosorption over traditional metal removal techniques are listed in [14]. Cheaper biomass production (bacteria or fungi), utilizing biomass to remove heavy metals, simultaneous absorption of several heavy metals, sewage treatment for huge amounts, Chemical additives are not necessary since the extremely selective uptake and disposal of metals, Functional in many different circumstances, such as temperature, pH, the presence of other metal ions, etc. Metals linked to biomass may be easily and cheaply removed, decreased creation of trash or hazardous materials.

#### 4.3. Biosorption's negative aspects

The following list of biosorption's drawbacks is taken from, Saturation of metal-binding ligands' active sites, Metals can reversibly bind to biomass.

### 5. Biosorption systems

Heavy metal ion binding to the peptidoglycan component of bacterial cell

walls can be dependent or independent on metabolism.

#### 5.1. Biosorption that is metabolism dependent.

Biosorption that depends on metabolism is displayed by living biological material. Physical adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. Chelation is a specific way in which ions and molecules bind to metal ions and it involves the formation or presence of two or more separate coordinate bonds between a polydentate ligand and a single central atom. A film of the adsorbate is formed on the adsorbent's surface as a result of this action. A surface phenomenon, Adsorption is typically categorized as either physisorption, which is characterized by weak van der Waals forces, or chemisorption, which is characterized by covalent bonding. Precipitation, which is the formation of a solid in a solution or inside another solid during a chemical reaction or by diffusion in a solid, may also result from electrostatic attraction. When this reaction takes place in a liquid solution, the solid that results is referred to as the "precipitate," and the chemical that initiates the solid's formation is referred to as the "precipitant." This reaction is also referred to as complexation, which is made up of a central atom or ion—typically metallic—known as the coordination center and an array of bound molecules or ions—known as ligands or complexing agents—that surround it. Coordination complexes are common in compounds containing metals, particularly those of transition metals. One of these processes may be present, or there may be a combination of these processes. If the metal attachment to the cell wall depends on metabolism, then ATP provides the necessary energy. The phosphoryl, carboxyl, carbonyl, sulfhydryl, and hydroxyl groups found on biological material's cell walls act as ligands to immobilize the metal ion before uptake takes place [15]. The nature of heavy metal

ions, the conditions of the medium, the makeup of the cell wall, etc. are additional parameters that affect the uptake of metals by live biomass. Adsorption to cell walls and entry into the cytoplasm are two steps in the absorption process by live biomass.

## 5.2. Biosorption independent of metabolism

The biomass made up primarily of dead cells is where the metabolism independent process predominates. The primary driving force behind such a physicochemical biosorption mechanism is the adsorption process. Ionic interactions or physiochemical adsorption are two possible adsorption processes. Metal biosorption is also significantly influenced by the presence of anionic ligands on bacterial cell walls, such as carboxyl, amine, hydroxyl, phosphate, and sulfhydryl groups. Because live cells have the capacity for continual metal uptake and self-replenishment, they are favored to dead mass. Adsorption is a quick process, whereas accumulation takes time and requires energy, according to previous reports. Depending on the type of bacterium, the fate of the metal inside the cell may be accumulation, detoxification, or efflux. Numerous organizations have been working on heavy metal resistant bacteria that can be utilized for bioremediation during the past few decades. Numerous researchers claimed that *Pseudomonas* and *Alcaligenes* bacteria cells might be employed for bioremediation [16].

## 5.3. Metal build-up

Heavy metals must enter the cell in order to have the physiological effect on the proliferation of cells. The two types of metal absorption systems seen in bacteria are rapid and unspecific, constitutively expressed, and ATP-free. Typically, they are only influenced by the chemiosmotic gradient across bacterial cytoplasmic membranes. In addition to being dependent on the chemiosmotic gradient, the second type of absorption mechanism is also very selective, sluggish, inducible, and ATP-dependent.

Only times of need, famine, or unique metabolic circumstances can induce them [17].

A complex is formed when a metal ion contacts a cell surface; this complex is necessary for an organism to absorb metals. The metal is transferred into the periplasmic space of Gram-negative cells after surface sorption occurs, and it is then moved further into the cytoplasm [60]. When a cell comes into contact with a high concentration of a heavy metal, the heavy metal ion is carried into the cytoplasm and accumulates there thanks to one kind of metal absorption that is quick, non-specific, constitutively expressed, and doesn't need ATP [18]. The function of the corresponding physiological cations is inhibited by interactions between the cations of heavy metals and physiological ions, such as  $\text{Cd}^{2+}$  with  $\text{Zn}^{2+}$  or  $\text{Ca}^{2+}$ ,  $\text{Ni}^{2+}$  and  $\text{Co}^{2+}$  with  $\text{Fe}^{2+}$ , and  $\text{Zn}^{2+}$  with  $\text{Mg}^{2+}$ . The cell experiences oxidative stress as a result.

## 6. Various biosorbent types

Organic compounds that are alive or non-living might be categorized as biosorbents. They are covered in more detail below.

### 6.1. Microbes

In terms of microorganisms, bacteria are the most prevalent, adaptable, and diversified species on Earth. They are primarily categorized as rods, cocci, or spirillums based on their morphology. The cell wall, cell membrane, capsule, slime layer, and internal organelles such as the mitochondria, Golgi apparatus, ribosomes, and endoplasmic reticulum make up the relatively straightforward morphology of bacteria. For the chelation of metals, slime layer comprises functional groups like carboxyl, amino, phosphate, or sulfate. According to various binding mechanisms, the cell wall generally controls the surface binding sites and binding strength for various metal ions. Because of their tiny size and capacity to thrive in various environmental circumstances, numerous bacterial species, including *Bacillus*,

*Pseudomonas*, and *Escherichia* [19], exhibit biosorption property. Bacteria are divided into Gram positive and Gram negative broad categories by the Gram classification system. Despite the fact that pathogens are also recorded in Gram positive, Gram negative pathogens predominate. Gram-positive bacteria are known to possess polyalcohols and teichoic acids and are made up of thick peptidoglycan layers joined by amino acid bridges. 90% of the peptidoglycan in gram-positive bacteria's cell walls is overall. Some teichoic acids create lipoteichoic acids when they bind to the lipids in a lipid bilayer. These lipids of the cytoplasmic membrane are connected to these lipoteichoic acids. They serve as the peptidoglycan's connection to the cytoplasmic membrane. Peptidoglycans get cross-linked as a result, generating a grid-like pattern. Due to the existence of phosphodiester linkages between the teichoic acid monomers, these teichoic acids are in charge of the negative charge on the cell wall. Gram-negative bacteria's cell walls, on the other hand, have an extra outer membrane made of phospholipids and lipopolysaccharides. Peptidoglycan makes

up 10–20% of the wall of gram-negative cells. Lipopolysaccharides, teichoic acids, and teichuronic acids are the causes of the Gram negative bacteria's negative charge. Additionally, extracellular polysaccharides have the ability to bind to metals. Not all Gram negative bacteria contain them. Additionally, those species that do contain them can simply get rid of them through mechanical or chemical disruption [20].

### 6.1.1. Bacterial biosorption

The initial part of biosorption is when a metal ion comes into contact with a bacterial cell wall. The functional groups (amine, carboxyl, hydroxyl, phosphate, sulfate, and carboxyl) found on the cell wall are where the metal ions attach. The general process of internalizing metal ions in bacteria involves attaching metal ions to reactive groups on the bacterial cell wall first. Because glycoproteins are present, Gram-positive bacteria can absorb more metal. Due to phospholipids and LPS, Gram negative bacteria are seen to take up metals less readily [21]. Table 2 lists the several microorganisms that can biosorb different metals.

Sr. No.	Metals	Bacteria	Temperature (°C)	pH	Agitation	Time	Wt (g/L)	q(mg/g) or % removal
1.	Arsenic	<i>Bacillus</i> sp. KM02	—	—	—	—	—	—
		<i>Kocuria</i> sp.	—	—	—	—	—	—
		<i>Bacillus</i> sp.	—	—	—	—	—	—
2.	Cadmium	<i>Pseudomonas putida</i> mt2	—	—	—	—	—	—
		<i>Cupriavidus metallidurans</i> CH34	—	—	—	—	—	—
		<i>Enterobacter cloacae</i>	25	5	240	2	0.1	58.9%
		<i>Stenotrophomonas maltophilia</i>	28	5	140	2	20	0.12
		<i>Actinomycetes</i> sp.	30	6	150	24	5	32.63
3.	Chromium	<i>Micrococcus</i> sp.	35	5	120	24	—	92%
		<i>Bacillus licheniformis</i>	28	3.5	120	48	—	95%
		<i>Staphylococcus saprophyticus</i>	27	2	150	3	0.2	24.1
		<i>Enterobacter cloacae</i>	25	4	240	2	0.1	55.8
		<i>Pseudomonas aeruginosa</i>	25	—	—	—	—	1.07
		<i>Micrococcus</i> sp.	35	5	120	24	—	92%
4.	Cobalt	<i>Rhodopseudomonas palustris</i>	—	—	—	—	—	—
5.	Copper	<i>Stenotrophomonas maltophilia</i>	25	5	140	2	20	0.57
		<i>Bacillus licheniformis</i>	28	2.5	120	48	—	32%
		<i>Geobacillus thermodenitrificans</i>	25	5	100	12	—	51
		<i>Bacillus cereus</i>	25	5.5	—	24	1.0	50.32
		<i>Pseudomonas aeruginosa</i>	25	—	—	—	—	0.67
		<i>Thiobacillus thiooxidans</i>	30	5	786	2	0.25	39.84
		<i>Enterobacter cloacae</i>	25	5	240	2	0.1	78.9
		<i>Staphylococcus saprophyticus</i>	27	3.5	150	2	0.2	14.5
6.	Gold	<i>Cupriavidus</i>	—	—	—	—	—	—

		<i>metallidurans</i> CH34						
7.	Lead	<i>Enterobacter cloacae</i>	25	5	240	2	0.1	67.9
		<i>Bacillus</i> sp.	30	5–9	100	24	—	69.34
		<i>Pseudomonas</i> sp.	30	5–9	100	24	—	90.41
		<i>Micrococcus</i> sp.	30	5–9	100	24	—	84.27%
		<i>Bacillus cereus</i>	25	5.5	—	24	1.0	36.71
		<i>Geobacillus thermodenitrificans</i>	25	4	100	12	—	53
		<i>Stenotrophomonas maltophilia</i>	25	5.0	140	2	20	0.41
8.	Mercury	<i>Enterobacter cloacae</i>	25	4	240	2	0.1	43.23
9.	Nickel	<i>Actinomyces</i> sp.	30	5	150	24	5	36.55
		<i>Micrococcus</i> sp.	35	5	120	24	—	90%
10.	Selenium	<i>Cupriavidus metallidurans</i> CH34	—	—	—	—	—	—
11.	Silver	<i>Cupriavidus metallidurans</i> CH34	—	—	—	—	—	—
12.	Zinc	<i>Pseudomonas aeruginosa</i>	25	—	—	—	—	1.33
		<i>Geobacillus thermodenitrificans</i>	25	5	100	12	—	18

Table 2. Bacteria and their metal biosorption characteristics [18].

Wt is the weight of the utilized adsorbent. Q is for pollutant uptake removal (mg/g); Agitation is shaker speed (rpm); T - experiment's temperature in degrees Celsius.

## 6.2. Algae

Aquatic plants called algae lack genuine roots and stalks. Microalgae and macroalgae are both possible. They grow on their own. They can produce a significant amount of biomass even with little food. They are regarded as good biosorbent materials because of their large size, high sorption capacity, and lack of harmful chemical formation. They are typically divided into three categories: microalgae (fresh water or green algae), macroalgae (marine or brown algae), and red algae. The brown alga is said to have the highest metal absorption capability among these three types. The ionic charge of the metal, the species of algae, and the chemical make-up of the metal ion solution are what cause heavy metal ions to bind to algal surfaces. Sulfhydryl, hydroxyl, phosphate, sulfate, imidazole, amine, and carboxyl groups are among the metal ion binding sites on algal surfaces [22]. The process through which

metal ions bind to the surface of algae before being internalized is comparable to that of bacteria. Abbas et al. claim that one of two mechanisms—ion exchange, in which metal ions replace the calcium, magnesium, sodium, and potassium ions that are already present on the surface of the algae, or complexation between functional groups and metal ions—is at work during algal biosorption.

### 6.2.1. Algal biosorption

Alginic acid, chitin, xylan, and mannan are polysaccharides that give functional groups (sulfate, hydroxyl, phosphate, imidazole, amino, and amine) known to operate as metal binding sites, according to Abbas et al. Ionic charge and covalent bonding are proposed as the mechanisms governing metal binding. Covalent bonds between a metal ion and a functional group are formed by amino and carboxyl groups, while ionic bonds are formed by carboxyl and sulfate groups. Phytochelatins are created within the algal body in reaction to metal ions [23]. Table 3 lists the several microorganisms that can biosorb different metals.

Sr. No.	Metals	Algae	Temperature (°C)	pH	Agitation	Time	Wt (g/L)	q(mg/g) or % removal
1.	Arsenic	<i>Spirogyra hyalina</i>	25	—	180	2	1	9.8
2.	Cadmium	<i>Bifurcaria bifurcata</i>	-	4.5	175	3	2.5	95
		Oocystis	28	7.5	72	60–80	28–51	-
		<i>Pithophora</i>	25	-	-	9 days	0.17–14	-
		spp. (filamentous)	30	5	150	-	-	22.2
		<i>Sargassum</i> sp. (brown algae)	25	6	150	24	4	0.4 mmol/g
		<i>Sargassum tenerrimum</i>	25	6	-	2	0.25	1.12 mmol/g
		<i>Fucus vesiculosus</i> (brown algae)	25	6	-	2	0.5–1	114.9
		<i>Ascophyllum nodosum</i>						
3.	Chromium	<i>Pithophora</i>	25	-	-	9 days	-	-
		spp. (filamentous)	30	4	-	6	2–5	68.9
		<i>Sargassum</i> sp.	30	4	180	3	1–3	265
		<i>Spirogyra</i> sp. (green algae)	30	3	150	-	-	20.2
		<i>Sargassum</i> sp. (brown algae)						
4.	Cobalt	<i>Spirogyra hyalina</i>	25	—	180	2	2.5	7.856
5.	Copper	<i>Calotropis procera</i>	25	4	150	6	2	14.5
		Oocystis	28	5.5	60–80	72	4.4–6.0	-
		<i>Sargassum filipendula</i>	25	4.5	175	6	5	-
		Microalgae	30	-	150	-	5	0.66
		<i>Sargassum</i> sp. (brown algae)	30	4	150	-	-	18.6
		<i>Fucus vesiculosus</i> (brown algae)	25	5	-	2	0.25	0.97
		<i>Ascophyllum nodosum</i>	25	4	-	2	0.5–1	70.9
7.	Lead	<i>Calotropis procera</i>	25	4	150	6	2	22.8
		Oocystis	28	5.5	60–80	72	16–80	-
		<i>Pithophora</i>	25	-	-	9 days	0.12–	-
		spp. (filamentous)	25	5	-	2	0.13	1.04
		<i>Fucus vesiculosus</i> (brown algae)					0.25	
8.	Mercury	<i>Sargassum</i> sp. (brown algae)	30	4	100	-	-	14.8
		<i>Cladophora fascicularis</i>	25	-	180	2	1	20
		<i>Spirogyra hyaline</i>	25	-	180	2	2.5	39.2
9.	Nickel	<i>Sargassum</i> sp. (brown algae)	30	5	150	-	-	26.1
		<i>Fucus vesiculosus</i> (brown algae)	25	5	-	2	0.25	0.80
		<i>Ascophyllum nodosum</i>	25	6	-	2	0.5–1	50
12.	Zinc	Microalgae	30	-	150	-	5	0.72 mmol/g
		<i>Sargassum</i> sp. (brown algae)	30	3	150	-	-	15.4
		<i>Ascophyllum nodosum</i>	25	6	-	2	0.5–1	53.2
13.	Iron	<i>Sargassum</i> sp. (brown algae)	30	3	150	—	—	14.6

Table 3 shows the characteristics of algae's biosorption of various metals [19].

### 6.3. Fungi

Yeasts, mushrooms, molds, and other eukaryotic living organisms are all considered to be fungi. Fungi's cell wall structure has high metal-binding capabilities. Fungi can be employed as a biosorbent material in both their living and dead forms. Two processes are used by fungi to absorb metals: I active uptake, also known as bioaccumulation or intracellular uptake, which depends on the metabolism of the cell, and (ii) passive uptake, also known as biosorption, which involves binding metal ions to the surface of the cell wall and is independent of the metabolism of the cell. The metabolic inhibitors, temperature, and other factors can all have an impact on the

energy-free metal absorption mechanism. Both active and passive metal absorption by fungi have been documented. Only live cells experienced active absorption. In this situation, ion-exchange, complexation, or simple physical adsorption may be involved in the interaction of metal ions with cell surface functional groups.

#### 6.3.1. Fungi's biosorption

The components of a fungal cell wall, according to Das et al., display superior metal binding characteristics. In addition to lipids, polysaccharides, and colors like melanin, the cell wall of fungi is mostly made up of chitins, mannans, and glucans. 90% polysaccharides are said to make up

the fungal cell wall. Functional groups such as carboxyl, phosphate, uranic acids, proteins, nitrogen-containing ligands, chitin, or chitosan are involved in metal binding. Both physical and chemical treatments, such as autoclaving, heating, dimethyl sulfoxide, laundry detergent, orthophosphoric acid, formaldehyde, glutaraldehyde, and NaOH, can affect the biosorption capacity of fungi

[23]. Macrofungi, often known as mushrooms, naturally develop in a variety of settings, including forests, contaminated soils, and aquatic bodies. They absorb the metals in their mycelia, sporocarps, and fruiting bodies. Tables 4 and 5 show the numerous metals that certain fungi and mushrooms can biosorb.

Sr. No.	Metals	Bacteria	Temperature (°C)	pH	Agitation	Time	Wt (g/L)	q(mg/g) or % removal
1.	Arsenic	<i>Penicillium chrysogenum</i>	25	3-4	190	—	1	24.5
2.	Cadmium	<i>Aspergillus cristatus</i>	25	6	120	2	0.4	23.2
		<i>Aspergillus niger</i>	25	4.75	125	6	0.7	13
		<i>Hydrilla verticillata</i>	25	5	150	0.33	3-9	15
3.	Chromium	<i>Aspergillus niger</i>	28	4.5	150	1	10	16.39
		<i>Pleurotus ostreatus</i>	25	4.5	150	3	2	1.97
		<i>Trichoderma viride</i>	-	6	150	0.75	3.75	4.66
		<i>Mucor</i>	35	5.5	-	-	-	-
		<i>Penicillium canescens</i>	20	6	100	4	2	34.8
4.	Copper	<i>Pleurotus ostreatus</i>	25	4.5	150	3	2	4.0
		<i>Fomes fasciatus</i>	25	5.5	200	1	1	32.2
		<i>Aspergillus lentulus</i>	35	6	180	0.41	4	-
5.	Lead	<i>Rhizopus nigricans</i>	25	5.5	225	-	25	80.8
		<i>Trichoderma longibrachiatum</i>	25	7	-	0.33	-	71
		<i>Pleurotus ostreatus</i>	25	5.5	-	3	2	4.84
6.	Mercury	<i>Aspergillus flavus</i>	30	5.5	100	8	10	95.3%
		<i>Aspergillus fumigatus</i>	30	5.5	100	8	10	95.3%
7.	Nickel	<i>Aspergillus niger</i>	25	4.5	150	3	1	7.69

Table 4 shows the characteristics of fungi's biosorption of various metals [20].

Sr. No.	Mushrooms	Metals
1.	<i>Volvariella volvacea</i> (edible Mushroom) – mycelia, sporocarps	Cadmium, lead, Copper, Chromium
2.	<i>Ganoderma lucidum</i>	Chromium
3.	<i>Corioliopsis strumosa</i>	Copper
4.	<i>Daedalea tenuis</i>	Copper
5.	<i>Lentinus strigosus</i>	Copper
6.	<i>Lenzites malaccensis</i>	Copper
7.	<i>Phellinus xeranticus</i>	Copper
8.	<i>Rigidoporus lineatus</i>	Copper
9.	<i>Rigidoporus microporus</i>	Copper
10.	<i>Trametes lactinea</i>	Copper
11.	<i>Ganoderma lucidum</i>	Copper
12.	<i>Agaricus macrospores</i>	Cadmium, mercury, copper

Table 5 shows how various metals are absorbed by mushrooms [21].

#### 6.4. Yeasts

Yeast is a well-known organism for biosorption research. The well-known yeast *Saccharomyces cerevisiae* is used as a model system to research biosorption. They yield a substantial amount of biomass using a straightforward growing media, are non-pathogenic, and are simple to culture [80]. Its genetic engineering is simple due to the availability of entire genome information [21]. In experiments involving molecular biology, they are also regarded as the perfect experimental organisms. The ability of *S. cerevisiae* cells to biosorb is influenced

by a number of variables, including cell age, culture conditions (growth medium composition, carbon source), and biosorption conditions (initial concentration of metals and biomass, availability of metal ions, temperature, pH, and other ions in growth medium). Additionally, yeast are excellent candidates for metal bioremediation due to their huge size. The yeast strain *Saccharomyces cerevisiae* has been extensively investigated. Its many forms, such as immobilized vs free cells, living versus dead cells, engineered versus non-engineered cells, cultured versus trash



cells, etc. are already being explored for their biosorption capabilities.

#### 6.4.1. Yeast biosorption

Yeast cells in their free state are not thought to make ideal candidates for biosorption. The issue of solid-liquid phase separation affects free cells. In flocculating cells, this issue appears to be less prevalent [90]. An increase in the surface to volume ratio for metal binding with the metal binding sites can come through pretreatment of yeast

cells. The biosorption of metals by yeast cells is said to be optimized at pH levels higher than 5. In yeasts, a larger concentration of heavy metals can be deposited by the bioaccumulation process than through the biosorption process, according to Abbas et al. However, the main mode of heavy metal uptake for many filamentous fungus is generic biosorption. Table 6 lists the several yeasts that can biosorb various metals.

Sr. No.	Metals	Yeasts	Temperature (°C)	pH	Agitation	Time	Wt (g/L)	q(mg/g) or % removal
1.	Cadmium	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	12.3
2.	Chromium	<i>Saccharomyces cerevisiae</i>	25	5.2	150	1	80	55.3%
		<i>Candida utilis</i>	25	5.5	160	1	1.0	28
3.	Cobalt	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	8.2
4.	Copper	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	29.9
		<i>Candida pelliculosa</i>	30	6	120	120	13.3	95.04%
		<i>Schizosaccharomyces pombe</i>	25	4	-	96	-	74.85
5.	Lead	<i>Mucor rouxii</i>	25	5.0	125	15	—	17.13
6.	Mercury	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	76.2
7.	Nickel	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	14.1
8.	Zinc	<i>Saccharomyces cerevisiae</i>	25	7	100	2	2	11.8

Table 6 lists the characteristics of yeasts' biosorption of various metals [22].

### 6.5. Nonliving Organic Materials

#### 6.5.1. Agricultural and food industry waste

Corn cobs, soy bean hulls, cotton seed hulls, fruit peels, and other agricultural byproducts are included in the category of wastes from agriculture or the food industry. Their cell walls include cellulosic material, which is known to contain functional groups like carboxylic or phenolic ones. The interaction of a metal ion with a functional group causes biosorption, which removes the metal ion from the medium on the basis of cation exchange between functional groups and metal ions.

### 7. Elements that impact biosorption

The following variables have an impact on the biosorption process [24].

**7.1. Temperature:** The ideal temperature had to be researched in order to effectively remove metal ions from the environment. It is commonly accepted that biosorption occurs between 20 and 35 degrees Celsius. High temperatures exceeding 45°C may

cause protein degradation, which in turn inhibits the process of absorbing metals.

**7.2. pH:** This is a crucial metric. It has an impact on the biomass binding sites and the solubility of metal ions. The biosorption of metals is impacted at lower pH levels. The normal pH range for absorbing metals is 2.5 to 6. Above this point, the biosorbent's capacity to absorb metals is weakened.

**7.3. Nature of biosorbents:** Metal uptake has been observed in a variety of forms, including biofilms, microbial cells that are suspended freely, and microbial cells that have been immobilized. Physical or chemical treatments can change it. Physical therapies include drying, boiling, sonication, and autoclaving. As the name suggests, chemical therapy uses chemicals like acid or alkali to increase biosorption capability. Wang and Chen claim that deacetylation of the fungal cells changes the structure of chitin and leads to the development of chitosan-glycan complexes with high metal affinity. Age and the components of the growth media have an impact on

biosorption, which may affect cell wall composition, cell size, and the generation of EPS, according to Abbas et al 's research.

**7.4. Surface area to volume ratio:** This characteristic is crucial for the effective removal of heavy metal from a medium. In the case of biofilms, the surface area attribute is crucial. It has previously been documented that metal ions can bind to microbial cell walls. Microorganisms prefer intracellular metal adsorption over wall adsorption even though it is an energy-intensive process.

**7.5. Concentration of biomass:** According to several studies, the amount of biomass is inversely correlated with the intake of metals. According to reports, electrostatic contact between the cells is crucial for metal uptake. At a given equilibrium, low cell densities allow the biomass to adsorb more metal ions than high densities [100]. The absorption of metal depends on the binding sites. More metal ions or higher biomass concentrations prevent metal ions from accessing binding sites.

**7.6. Initial concentration of metal ions:** According to research by [102], the initial concentration acts as a significant driving power to overcome any mass transfer resistance of metal between the aqueous and solid phases. The initial concentration of metals will enhance the amount of metal adsorbed by the biomass. Low initial metal concentrations provide for the best metal removal %. As a result, the metal absorption rises with increasing starting concentration at a given biomass content.

**7.7. Metal affinity to biosorbent:** Physical and chemical preparation of the biomass alters its permeability and surface charges and renders metal binding groups available for binding. The amount of metal uptake may be increased by pretreating the biomass with alkalis, acids, detergents, and heat.

## 8. Biosorption kinetics

Before delving into the specifics of investigating the kinetics of biosorption, it is important to comprehend the characteristics of a biosorbent. Two aspects should be taken into account when evaluating a biosorbent's performance: (i) the amount of metal ions that the biosorbent attracts, and (ii) the degree to which metal ions are immobilized on the biosorbent. By comparing the initial amounts of metal ions in the medium to those that are still present in the medium after biosorption occurs, it is possible to quantify the amount of metal that the biosorbent has taken up. The following Eq. 1 [25] examines this:

$$q = V(C_i - C_e) / M \quad \text{----- E1}$$

V = Volume of metal solution (L); C<sub>i</sub> = Initial concentration of metal (mg/L); and q = Amount of metal biosorbed by biomass (mg/g); C<sub>e</sub> = Equilibrium metal concentration (mg/L); M = Adsorbent mass.

When engineering process - mass balance calculations need to be taken into consideration, units are milligrams of solute sorbed per gram of dry biosorbent material or mmol/g (when the mechanism or stoichiometry are to be considered).

According to Abdi and Kazemi, sorption performance of a biosorbent must be taken into account in order to observe the biosorption kinetics of any heavy metal. A biosorption isotherm should be investigated for it. The graph of metal uptake (q) vs equilibrium solute concentration in the solution is a biosorption isotherm (C<sub>f</sub>). Temperature, pH, and ionic strength are all kept constant while metal concentration is changed when analyzing isotherm plots. According to the literature, people are confused about pH because it is widely held that a medium's pH fluctuates throughout the entire biosorption process. The Freundlich and Langmuir models are usually used to describe biosorption isotherms. These models, which have only two parameters, are frequently employed to represent the equilibrium state for experiments involving the adsorption of metal ions.

**8.1. Freundlich model:** The first mathematical equation to describe the isotherm was published by Freundlich and Kuster in 1907. A non-linear sorption model is used. It is characterized by ongoing interactions between adsorbed molecules and involves the monolayer sorption of metal with active sites. Eq. 2 gives it away:  
$$q_e = K C_e^{1/n}$$
-----E2  
K is expressed as mg/g or l/mg, where  $1/n$  or  $n$  is the Freundlich constant related to adsorption intensity.

A model for representing gas or liquid adsorbed on solid material was presented by Langmuir in 1918. It speaks of the monolayer sorption of metal with active sites and excludes interactions between molecules that have been adsorbed. Eq. 3 gives it away:

$$q_e = q_{max} b C_e / (1 + b C_e)$$
-----E3

$q_e$  stands for the amount of metal ion eliminated (mg/g),  $C_e$  for equilibrium concentration (mg/L),  $b$  for the affinity-related Langmuir constant, and  $q_{max}$  for the maximal metal uptake (mg/g) under the conditions specified.

Freundlich and Langmuir constants,  $k$ , and  $n$  (where  $n$  is greater than 1.0 and indicates that sorption is a favorable physical process).

## 9. Metal desorption and recovery

Following biosorption of heavy metal from the environment, its recovery—which entails desorption of metal from the biosorbent—is a vital next step. Various agents were employed for this purpose, including complexing agents (thiosulfate, EDTA), mineral acids ( $HNO_3$ ,  $H_2SO_4$ , HCl), organic acids, and more, according to earlier literature. (Acetic acid, citric acid). Before selecting a recovery agent, it is important to keep in mind that this agent should cause the least amount of damage to a biosorbent's physical qualities in order to preserve the biosorbent's ability to bind metals in its natural state.

## 10. CONCLUSION

Metals may be easily and affordably removed from the environment through biosorption. Numerous details concerning various biosorbent forms and their mechanisms of metal uptake were revealed by earlier studies carried out over the previous 50 years. To investigate new environmental biosorbents, more study is required. In order to retrieve metal in a condition that can be used, a thorough understanding of not only the procedure of metal removal but also its effective recovery is necessary.

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