**Microbial Interventions in Bioremediation of Heavy Metals**

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1. INTRODUCTION

Heavy metals are naturally occurring elements that have a high atomic number, high density and high atomic weights. They are toxic in nature and can harm both plants and animals, including humans, causing serious human diseases. They are extremely problematic since they can be persistent and are difficult to destroy. The toxicity of heavy metals is caused by a number of mechanisms, including the destruction of ion regulation and the disruption of enzyme processes. It may also have an impact on DNA synthesis. By being deposited in soil and water bodies as a result of various human activities, they can behave as pollutants.

Heavy metal pollution has escalated into a major threat to all living things inside an ecosystem. As a result, they pose a serious threat to both the superiority of the environment and the lives of organisms. Additionally, it may have an impact on biogeochemical cycles and ocean productivity. Through the food chain, heavy metals can move from one trophic level to another, causing malnutrition and physiological dysfunction in plants. It can also have a significant negative impact on human health. By building up in the cells of living organisms, these heavy metals may result in physiological and metabolic diseases. At very low doses, the majority of them are capable of being carcinogenic and mutagenic. Heavy metals may interfere with a variety of biological processes and functions. Due to their non-biodegradable and biaccumulative characteristics, heavy metals are a major environmental problem.

Due to these toxic heavy metals' detrimental impacts on organisms and the entire ecosystem, it is vital to eliminate the environmental pollution it causes. Bioremediation is a process of removing or reducing such pollutants from waste using biological mechanisms. Techniques used in bioremediation are non-invasive, cost effective and environmental friendly compared to physical and chemical methods of bioremediation. Using catabolic properties of bacteria and/or their products such as biosurfactants and enzymes will be a novel approach to increase the efficiency of bioremediation process. Also by inclusion of several external amendments such as compost, biosurfactant, inorganic nutrients and bulking agents we increase the effectiveness of the process. Though Several factors like PH, redox potential, moisture, temperature and chemical composition of heavy metals waste may limit or influence bioremediation process. Criterion such as cost, Pollutant nature, type of environment location and degree of pollution have to be taken into consideration while choosing appropriate bioremediation method.

This chapter therefore seeks to review various reports by previous investigators on toxic effects of heavy metals and pollution caused by them. It also discusses various bioremediation techniques involving different microorganisms for remediation of pollution caused by heavy metals.

**II. Factors responsible for accumulation of heavy metals in environment**

The weathering of parent materials amid pedogenetic forms causes the rise of overwhelming metals normally happening within the environment. Natural components incorporate normal, mechanical strong squander, agrarian, barometrical, inland gushing, and others are major sources of heavy metals. Wide ranges of the world have moreover been sullied by electroplating, metallurgical purifying operations, mining exercises, the utilize of phosphate fertilizer and agrarian pesticides, as well as natural excrements counting compost, metropolitan sewage slime, and animals excrements.

Due to human obstructions with nature's gradually happening geochemical cycle of metals, numerous overwhelming metals have amassed within the soil and water supplies. These tall sums of oheavy metals are awful for human wellbeing as well as for oceanic life, plants, creatures, and other biomes. These overwhelming metals are getting to be contaminants of soil and water bodies as a result of both man-made and common forms, the discharge of profoundly concentrated metal squander through businesses, the development from mines to other destinations where human presentation is higher and expanded bioavailability happens, and more.

**III. Environmental contamination by heavy metals**

Rapid urbanization and industry growth have a direct influence on the environment. Human life and the lives of all other living things around the world are under serious jeopardy from the contamination and degradation that has resulted. Through a variety of human activities that either directly or indirectly contributed to the pollution, several heavy metals have contaminated aquatic ecosystems and open water. A significant quantity of water contamination has occurred in various water bodies, including lakes, rivers, groundwater, and seas. Such a large volume of foreign substances can contaminate the water by altering its characteristics. Point sources and non-point sources are the two categories into which this water contamination can be divided.

Point sources of pollution are discrete, locally identifiable sources of water pollution. It may occur if poisonous and dangerous substances are released directly into water bodies. Examples include the 1989 Exxon Valdez oil spills, which resulted in the release of 11 million gallons of crude oil into the environment of Alaska after the ship came aground in the Prince William Sound.Water bodies that are being harmed by diffusion sources such contaminated runoff from agricultural areas pouring into rivers and ocean water bodies. Since there are several sources of pollution, it is challenging to identify a single solution.

**IV. Heavy metal-related illnesses**

Existing heavy metals in the environment and industrial effluent in developing countries are endangering human health and polluting ecosystems. Almost all ecosystems include varying quantities of various heavy metal components. Some of these substances, including Fe, Cu, Ni, and Zn, which exhibit a variety of characteristics, are necessary trace substances. If these heavy metals are taken in levels greater than the necessary concentration or if there is a significant level of accumulation, including in humans, they can cause substantial harm to living creatures. The quality of aquatic living organisms must be improved by lowering heavy metal content. Due to the direct or indirect release of waste containing heavy metals into the environment, there is a substantial environmental pollution problem that poses a serious threat to persons, soil, and sediment health. Heavy metals have extended half-lives and are resistant to the mechanisms that cause degradation.

Heavy metals can accumulate in various body parts and have long half-lives. They are also resistant to degrading processes. Because of reason, even in extremely low concentrations, they can pose a threat to all living things, including humans. They tend to bind to different biomolecules, such as nucleic acids and proteins, once entering the human body through absorption and disrupt their functions.

V. **Toxic effects of heavy metals**

1. Copper

One of the main substances that causes pollution from heavy metals is copper. It is located quite far underground. It can be found in nature both in the uncombined condition and in ores like chalcopyrite. It is a transition element and one of 25 elements with atomic weights of 63.55 and atomic numbers of 29 that are found in the earth's crust.Animal excrement may pollute the environment with copper. It is utilized in industrial settings, including paint and electronic manufacturing facilities. The primary causes of copper pollution include mine sites, landfills, waste water bodies, and places where fossil fuels are burned. It can be released into the environment by dust, dissolved substances in water, forest fires, as well as volcanic ash particles. When taken in high proportions, copper pollution can cause serious damage to the liver and kidneys and even death.

When copper builds up in various organs and zinc and sulfate ions are depleted, the body becomes more toxic, which is harmful to aquatic life. The accumulation of heavy metals inside a fish's body can have a negative impact on the internal organs. Despite being essential for the formation of hemoglobin, copper can be harmful to some living things.

Despite being essential for the formation of hemoglobin, copper can be harmful to some living things. In living things, copper functions as an antioxidant and takes part in the electron transport chain. It is a micronutrient that is largely stored in humans and is only needed in very small amounts.

1. Zinc

Another metal that can be detected in industrial effluent is zinc.Galvanization, electroplating, battery manufacturing, and metallurgical sectors are among the industries that emit it as waste. The development of plants can be significantly impacted by zinc. Development moderates down when the environment needs sufficient zinc. The zinc functional group can modify the plant membrane and molecular structure to promote plant stability. It can also act as a defense mechanism against plant diseases. Although zinc in its metallic form does not harm the environment, its reaction with other chemicals such as oxygen and acids can lead to the formation of potentially dangerous compounds that can harm biological systems.

1. Nickel

Along with zinc, nickel is another known environmental pollutant. It can be toxic, carcinogenic and clastogenic. Many nickel solubilities have different carcinogenic effects. NiO is a powerful white soluble and insoluble Ni3S2 that occurs as a moderate carcinogen. As an airborne impurity, nickelcarbonylnickel (CO)4 is produced as an intermediate product during nickel refining. It is highly toxic and when inhaled can cause pneumonia, respiratory failure and pulmonary edema, among other respiratory health problems.

**Cases of heavy metal pollution & its effects on microorganisms**

Numerous heavy metals, including Ni, Zn, Cu, Fe, Cd, Pb, and Mn, have been deposited, contaminating the land and the sea. Heavy metal metal concentrations are expanding in vegetables and cereals, and it is additionally harming the water supplies. In 1963, a number of heavy metal incidents occurred in Minamata Bay, Japan. Local residents living near Minamata Bay were eating a variety of shellfish containing very high levels of mercury.This was due to the uncontrolled release of their chemical constituents into the water. The seashells and other seafood were impacted by the leaked mercury, which caused the seashells to accumulate high mercury concentrations and become dangerous to the local population.

Heavy metal toxicity is the ability of a metal to exert a detrimental effect on microorganisms and depends on the bioavailability of the essential metal and the rate at which it is consumed. Heavy metal toxicity involves several mechanisms, including disruption of lethal enzymatic capacity, reaction as redox impulses in the formation of reactive oxygen species (ROS), direct effects on DNA and protein development, and interference with ion regulation. The physiological and biochemical properties of microorganisms can be altered by the presence of essential metals. Chromium (Cr) and cadmium (Cd) can cause oxidative damage and degeneration of microorganisms, affecting the bioremediation limits of organisms. Chromium Cr(III) can alter protein activity and structure by reacting with protein thiol and carboxyl groups (Cervantes et al., 2001). Intracellular cationic Cr(III) complexes can electrostatically react with negatively charged DNA phosphate groups, affecting replication and transcription and causing mutagenesis.

Heavy metals like copper (Cu (I) and Cu (II)) could catalyze the formation of ROS by means of Fenton and Haber-Weis reactions, which will serve as solvent electron carriers, dur to this DNA, cytoplasmic particles, lipids and different proteins can be severely damage. Superoxide radicals can be stabilized by Aluminium (Al), which is the cause for DNA damage. Heavy metals could stop essential functions enzymes by non-competitive or competitive interactions with substrates that will lead to formation of configurational changes in protein. Moreover, it can cause ion imbalance by attaching to the surface of the cell and entering through transmembrane carriers and ion channels.

Lead (Pb) and cadmium (Cd) adversely affect microorganisms and their cell membranes and can also destabilize DNA structures. This occurs through ligand interaction and displacement of the metal from its native binding site. Microbial metabolism, growth, and morphology are affected by oxidative phosphorylation, dysfunction, inhibition of enzymatic activity, cell membrane disruption, and alterations in nucleic acid structure.

**VI. Conventional heavy metal contamination cleanup techniques & other aspects**

Numerous remediation approaches using biological, physical and chemical methods have been proposed and implemented to remove heavy metals from contaminated or contaminated sites. The most common conventional techniques are reclamation and excavation. Other conventional techniques include chemical extraction, ion exchange, leaching, precipitation, polymer microencapsulation and hydrolysis. All of these chemical technologies pose significant risks to the environment and human health due to their toxicity. istorically, methods such as solidification, vapor extraction, stabilization, verification and membrane techniques have been used to remove metal ions from fouled areas. Most of these methods cannot completely remove heavy metals from contaminated areas, are expensive to install, and are not safe for continuous monitoring and control. The use of expensive technology completely changes the manufacturing process. The vast majority of business people do not use cleaning methods, nor do they replace outdated systems with safer, cleaner and greener equipment. The use of conventional chemicals has proven economically viable in combating heavy metal contamination at low ionic concentrations.

Standard processes are too expensive to treat large volumes of water and wastewater containing very low concentrations of heavy metals. Innovative treatment techniques are required to remove heavy metal ions from wastewater. Biological treatment or bioremediation methods can be used to remove heavy metal ions from contaminated soil and water. Various pollutants can be removed or transformed into harmless compounds through processes of bioremediation with the help of normal biological processes in ecosystems. It can also be described as a biological process that transforms organic or inorganic waste into harmless compounds. The process usually runs smoothly, but it can be improved by adding electron acceptors, vitamins, or other elements. Due to their low cost and relatively simple engineering processes, they can often be transported on site. It has been observed that certain plants, fungi, and bacteria can detoxify or break down harmful substances. By isolating them from an already contaminated region or somewhere else, microorganisms are applied to the polluted area. Living things can change contaminated materials through reactions that happen as part of their metabolic processes.

Bioremediation principles can be applied in a variety of ways, including bioventing, composting, biofilters, biosorption, bioaugmentation, land management, biostimulation, and bioreactors. Remove solid contaminants (sediment, soil, sludge), gases from industrial emissions and soil vents, liquid contaminants (industrial effluent, groundwater), and raw materials from industrial activities from contaminated areas. This can be done by living or non-living microorganisms with the help of enzymes. According to some researchers, some potential microbes can combat heavy metals by converting them into less toxic or completely harmless forms, using these forms for growth in metabolic processes, or completely removing heavy metals from the environment by adsorption. In order for bioremediation processes to be successful, microorganisms including bacteria, fungus, and algae must exhibit both tolerance and resistance.

**VII. Mechanisms of bioremediation in heavy metal-contaminated environment**

1. **Bioaccumulation**

When the rate of contamination absorption is greater than the rate of contaminant loss, bioaccumulation occurs. As a result, the contamination builds up within the organism and is kept there. The sensitivity of living things to toxins is affected by a number of toxicokinetic mechanisms. Organisms can typically withstand concentrations of some chemicals up to a certain point, after which the substances turn poisonous and may endanger the organism's life. The sensitivity of organisms to chemicals varies depending on the chemicals used and the type of organisms. The organisms that are chosen to bioaccumulate contaminants should be tolerant of several contaminants at high concentrations. These organisms may exhibit superior biotransformation abilities while still keeping the pollutant contained, transforming the toxic chemical into a non-toxic form that enables the organism to lower the toxicity of the contaminant. The bioaccumulation of metals may be advantageous and practical if they result in large metal concentrations. In contrast to biosorption, this process is based on the removal of metal from cells, and its return is linked to the requirement of cellular transformation.

As a result, there are several other cycles when biomass application is not possible. In the cells of many environmental bacteria,As a result, there are several other cycles when biomass application is not possible. In the cells of many environmental bacteria, large amounts of metals are accumulated. particularly in cell walls or areas that are surrounded by cytoplasm. These metals may be deposited by organisms up to 6% of the dry cell mass. When considering the water or soil environments, this process can result in a decrease in the amounts of heavy metal ions in the environment. Other organisms, including people, will benefit from this.

1. **Biosorption**

Biosorption is the process of removing heavy metals or other contaminants from liquids using biomass, either dead or alive. Different microorganisms participate in the surface adsorption of metals onto the cell surface of microorganisms, where they are then bonded together with extracellular polymers. Other methods include metal infiltration into the centre of the cell or intracellular metal buildup. The qualities of sorption is because bacteria have an exterior cell shield. Metals are connected by active chemical groups that exist in cell membrane layers. The majority of microorganisms from various groups that are susceptible to this reaction between active groups and metal ions have negative potential for their outer cell structures.The majority of microorganisms from various groups that exhibit this feature are engaged in metal linkage. The reversibility of this process, or desorption, is crucial for the practical application of biosorption. The desorption process makes it feasible to recover metals even in minuscule amounts. It is quite profitable because it recovers some expensive metals like gold, copper, and zinc. The biosorbents can include sorbents with an animal or plant origin (such as humus, sea plants, nut shells, moos peat, and tannin-rich crust).

1. **Biotransformation**

With the aid of oxidation, reduction, methylation, and demethylation processes, heavy metals are microbiologically changed during this process. These processes are carried out by the enzyme systems of microbes. Practically useful reactions can occur when very precious or poisonous metals are involved. For instance, a Gram-positive bacteria isolated from tannery sewage converted highly hazardous chromium (VI) to chromium (III). Any microscopic fungi and bacteria are capable of reducing metal ions to metallic form, especially those that are very valuable like silver and gold. From the perspective of this metal recovery, this reaction may occur on the cell surface, in vacuoles, and in the extracellular environment.

1. **Metal bioleaching**

To bring the metal contained in minerals to solution in connection to sulfide materials, bioleaching relies on the metabolic activities and byproducts of microorganisms like fungi and bacteria. According to Kisielowska et al. (2010), the fundamental idea underlying this method is the conversion of environmentally harmful heavy metals from moderately soluble molecules—often sulfides—to readily soluble compounds, from which they can be readily retrieved or removed. The ability of fungi to perform bioleaching, more specifically the mobilization of heavy metals from low-grade ores and industrial waste, is primarily related to two processes: the secretion of complexion agents and the production of various organic acids in the livingenvironment (gluconic acid, citric acid, and oxalic acid).

*Rhizopus sp., Aspergillus sp., Mucor sp., Penicillium sp., Cladosporium sp*., and *Alternaria sp.* are a few examples of such fungi. Due to their metabolic potential and relatively great resilience to unfavorable conditions, such temperature and pH, metals leach more readily. Only the aforementioned organisms are utilized for the remediation of contaminants when it is not possible to use any traditional chemical techniques or bacterial leaching. Leaching is done biologically in biohydrometallurgy. Microbiological techniques can be used to leach metals from oxide and sulfide minerals. It is feasible to recover metals including cobalt, antimony, zinc, arsenic, lead, vanadium, copper, gold, uranium, and molybdenum by using biohydrometallurgy techniques. As of right now, the recovery of metals like gold, uranium, and copper is the only limitation of these bioleaching procedures.

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1. **Bioprecipitation and biocrystallization**

Microbial action can cause the crystallization or precipitation of heavy metal compounds, which results in the transformation of heavy metal into form sparingly while simultaneously reducing their toxicity. In biological cycles like the deposition of manganese and iron, the mineralization of manganese and silver, and the production of microfossils, some biocrystallization and precipitations are involved. Metals precipitate on the cell surface or within the cell as a result of galactosis of secondary metabolites and enzyme activity.

1. **Extracellular Sequestration**

Extracellular sequestration refers to the deposition of metal ions by cellular components in the periplasm or the complexation of metal ions as insoluble compounds. Copper-resistant *Pseudomonas syringae* strains developed the copper-inducible proteins CopA, CopB (periplasmic proteins), and CopC (outer membrane protein), which bind microbial colonies and copper ions. Bacteria have the ability to expel metal ions from the cytoplasm and sequester the metal within the periplasm. Zinc ions can traverse the cytoplasm of *Synechocystis* PCC 6803 strain and concentrate in the periplasm.

Metal sequestration occurs extracellularly and is called precipitation. Iron reducing bacteria, like Desulfuromonas spp. and Geobacter spp., and sulfur reducing bacteria, like Desulfuromonas spp. and Geobacter spp., can reduce toxic metals to less toxic or nontoxic forms. Uranium (U) can be reduced from toxic U (VI) to less toxic U (IV) by a strict anaerobe known as *G. metallireducens*. *G. metallireducens* and *G. sulfurreducens* have the ability to reduce chromium (Cr) toxicity from the extremely poisonous Cr (VI) to Cr (III). Sulfate-reducing bacteria produce a significant amount of hydrogen sulfide, which leads to the precipitation of metal cations.

Thiosulfate is converted to hydrogen sulfide under anaerobic conditions, and the *Klebsiella planticola* strain precipitates cadmium ions as insoluble sulfides. Additionally, in aerobic circumstances, the P. aeruginosa strain precipitates cadmium. By using the *Vibrio harveyi* strain, soluble divalent lead is precipitated as complex lead phosphate salt.

1. **Intracellular sequestration**

Its is the term for the complexation of metal ions by various substances in the cytoplasm of the cell. Metal concentration and delayed transit into microbial cells are both possible outcomes of interaction with surface ligand. Numerous research, particularly those involving the treatment of wastewater, have investigated the ability of bacterial cells to accumulate metals intracellularly. With the help of cysteine-rich low weight proteins, the cadmium-tolerant P. putida strain has demonstrated the ability to sequester zinc, cadmium, and copper particles inside cells. Rhizobium leguminosarum cells also demonstrated glutathione-mediated intracellular cadmium ion sequestration.

Mineral ions, chitin proteins, lipids, polyphosphates, and polysaccharides containing nitrogen make form the stiff cell wall of fungi. Numerous fungi can undertake metal ion remediation by valence conversion, extracellular and intracellular precipitation, and energy uptake because they accumulate metals in their mycelium and spores. Inorganic metals that serve as a ligand for metal ion labeling are eliminated by fungi's surface cell walls. Components of the cell wall that are rich in metal-binding ligands include polysaccharide, lipid, and peptididoglycan (e.g., -SH, -HPO42, -OH, -COOH R2OSO3, -NH2, and SO42 -RCOO). Amines may be more effective in absorbing metals because they can interact electrostatically with anionic metal species through surface complexation and cationic metal species.

1. **Methylation of metal**

 Elevated lipophilicity and hence enhanced penetration across cell membranes cause an increase in metal toxicity, which is then caused by methylation. Metal cleanup greatly benefits from microbial methylation. Methylated substances are typically explosive; for instance, certain bacteria, including Pseudomonas spp., Escherichia spp., Clostridium spp., and Bacillus spp., can bio methylate Hg (II) to gaseous methyl mercury. In the polluted topsoil layer, bio methylation of lead (Pb) to dimethyl lead and arsenic (As) to gaseous arsines as well as selenium (Se) to volatile dimethyl selenide were found.

1. **Heavy metal reduction by microbial cell**

Microbial cells have the ability to change the oxidation state of metal ions, hence reducing their toxicity. Bacteria use metals and metallic metalloids as electron acceptors or donors for energy production. Metals in the oxidized state could serve as terminal acceptors of electrons during the anaerobic respiration of bacteria. Enzymatic activity can reduce metal ions to less harmful forms of chromium and mercury.

1. **Extracellular Barrier Prevents Metal Entry into Microbiological Cells**

Cell wall, capsule, or microbial plasma can act as a membrane barrier to stop metal ions from entering the cell. According to studies, bacteria can bind metal ions to ionizable groups of the cell wall's hydroxyl groups (hydroxyl groups, carboxyl, and amino phosphate). For nonviable cells of Bacillus sp., Brevibacterium sp., and Pseudomonas putida, there was a significant degree of passive biosorption of heavy metal ions. Pseudomonas aeruginosa biofilm cells demonstrated greater resilience to ions of lead, zinc, and copper than planktonic cells, despite cells at the biofilm's edge being killed. Ions of metal collected.

**VIII. Role of microorganisms in bioremediation of heavy metals**

The intake of heavy metals by microorganisms takes place via adsorption, which is a passive process and/or through bioaccumulation which is an active process. To clean up heavy-metal contaminated environments, several microorganisms such as algae, fungi and bacteria have been used. With the implementation metal-resistant strains in immobilized, consortium and single have yielded successful results. While to adsorb heavy metals efficiently, the immobilized form could have more chemisorption sites.

1. **Bacteria-** In microbes, microbial biomass has various biosorptive abilities which is very significant. However, the ability of biosorption of each microbial cell depends upon its experimental and pretreatment conditions. Biosorption by bacteria is an inexpensive and efficient technique to remove pollutants, including non-biodegradable elements, like heavy metals, from wastewater. To enhance biosorption, microbial cells must adapt to the alteration chemical, physical and bioreactor configuration. Due to their size, ubiquity and potential to grow under controlled conditions and their ability to withstand adverse environmental conditions, bacteria are crucial biosorptants. Bacterial species have adapted and developed mechanisms for metals ions resistance and remediation for their survival. Using bacteria such as *Bacillus, Pseudomonas, Enterobacter, Micrococcus* and Flavobacterium several heavy metals have been tested. Due to their potential active chemisorption (techoic acids) on the cell wall and high surface to volume ratios, they show great biosorption capability. Bacteria can survive better and are more stable when are used in mixed cultures. Therefore, consortia of cultures are more appropriate in this field since they are metabolically superior for the biosorption of the metals. Bacterial biomass accomplishes the rapid removal of metals such as Cu, Zn, Pb, Cd, and Cr. The bacterial cell wall is the primary physical contact linking metal ions and the bacterial biomass. The overall negative charge due to anionic functional groups (like amine, hydroxyl, carboxyl, sulphate, phosphate) present in Gram-positive bacteria (in peptidoglycan, teichoic acids, and teichuronic acids) and in Gram-negative bacteria (in peptidoglycan, lipopolysaccharides, and phospholipids) imparts metal-binding capacity on or within the cell wall. It was reported that using a bacterial consortium of Arthrobacter sp. and Acinetobacter sp. there was 78% reduction of chromium (Cr) at 16mg/L concentration. To remove a large quantity of Pb in synthetic medium, Micrococcus luteus was used. The elimination ability was 1965 mg/g under ideal environments. Abioye and his co-workers (Abioye et al., 2018) used *Aspergillus niger, Bacillus subtilis, Penicillium sp.* and *B. megaterium* in biosorption of Cr, Cd and Pb. *B. megatarium* showed highest lead reduction (2.13-0.03 mg/L), followed by *bacillus subtilis* (2.13-0.04 mg/L). Highest ability to reduce the concentrations of Cr (1.38-0.08 mg/L) was shown by *Aspergillus niger* followed by *penicillium sp.* (1.38-0.13 mg/L). While highest ability to reduce the concentrations of Cd (0.04-0.03 mg/L) was shown by *Bacillus subtilis* followed by Bacillus megaterium (0.04-0.06 mg/L) after a period of 20 days. Kim and his co-workers created a batch system using zeolite-immobilized *Desulfovibriodesufuricans* for the removal of Ni, Cu and Cr6+ with efficiencies of 90.1%, 98.2% and 99.8% reapectively. Removal of cadmium, chromium, cobalt, copper and zinc at 75%-85% by bacterial consortia in less than two hours of exposure has been reported.
2. **Algae -** Algal growth produces gigantic biomass compared to other microbial biosorbents since they are autotrophic in nature. This biosorbents have a tall sorption capacity and are utilized for evacuation of heavy metals. Biomass of algae is utilized for bioremediation of heavy metal contaminated profluent through integration into cells or by adsorption. The use of various cyanobacteria and algae to recover heavy metals by either breaking down toxic substances or directly removing them is called phycoremediation. Between the three groups of algae; i.e. Phaeophyta, Rhodophyta and Chlorophyta (i.e. brown, green and red respectively), brown algae has been reported to have better biosorption capacity. The surface of algae has various moieties such as phosphate, amide, hydroxyl and carboxyl that act as metal binding sites. Calcium, magnesium, and sodium ions present in the cell wall get replaced by heavy metal ions via ion exchange. The results shows that the biomass of chlorella vulgaris is highly efficient biosorbent for release of Cu2+, Pb2+ and Cd2+ at 97%, 99.4% and 95.5% respectively from a mixed solution of 50 mg/dm-3 of each metal ion.
3. **Fungi -** With excellent capabilities for metal take-up and recuperation, fungi are broadly utilized as bisorbants for the remediation of heavy metals from the affected areas. Most of the studies showcased that dead and alive cells of fungi play a exceptional part within the grip of inorganic chemicals and is known as mycoremediation. It poses a complete solution because of the full mineralization of the pollutants in nature. It was also reported the potential of *Aspergillus sp*. in remediation of chromium in tannery wastewater. Compared to 65% removal of chromium from the tannery effluent, 85% was removed in a bioreactor system at pH 6 from the synthetic medium. This could be due to deterrent caused to growth of organisms due to the presence of organic pollutants. Since *Coprinopsis atramentaria* can bioaccumulate 94.67% Pb+2 and 76% Cd+2 , it can be considered an effective bioaccumulator of lead up to 800 mg/l. Park and coworkers (2005) found that toxic Cr(VI) can be converted to less toxic or non-toxic Cr(III) using biomass of dead fungi *Rhizopus oryzae*, *Penicillium chrysogenum*, *A. niger* and *Saccharomyces cerevisiae*. *Candida sphaerica* has been reported to produce biosurfactants with heavy metal removal efficiencies of 90%, 79%, and 95% for Zn, Pb, and Fe, respectively. Biosurfactants have attracted great interest in recent years due to their biodegradability, diversity and low toxicity. Mulligan et al., (2001) assessed the reasonability of utilizing rhamnolipid, sophorolipid and surfactin for remediation of heavy metals (Zn and Cu). 18% of Zn and 65% of Cu was removed with a single wash of 0.5% rhamnolipid, whereas 60% of Zn and 25% of Cu was removed by sophorolipid. Several yeast strains such as *Yarrowialipolytica*, *S. cerevisiae, Rhidotorulapilimanae, Hansenula polymorpha, Rhodotorula lima* and *Pichia guilliermondii* have been used for the bioconversion of Cr(IV) to Cr(III).
4. **Heavy metal remediation using biofilm-** The use of biofilms for heavy metal remediation has been described in several papers. Biofilm can be used both as a biological stabilizer and as a means of expert bioremediation. Even at lethal concentrations of inorganic elements, biofilms show a high resistance to them. In the study of *Rhodoturula mucilaginosa*, it was found that biofilm metal removal efficiency was 91.71-95.39% for biofilm cells and 4.79-10.25% for planktonic cells. The mechanisms shown by biofilms in the bioremediation of heavy metals may be due to the presence of exopolymers and biosorbents containing molecules with emulsifying or surfactant properties.

**IX. Future Prospects**

Different analysts have recognized certain variables repressing the far reaching application of this innovation which incorporate getting solid comes about and among others are negative impacts of coexisting metal particles on biosorptive capacity. Earlier to the application biosorbent characteristics and substrate nature ought to be surveyed altogether. The future prospect of bioremediation innovation looks promising with improvement of expanded specificity utilizing biofilms which may well be achieved by immobilization strategies and optimization prepare. Moreover, there's a extraordinary improvement in microbial hereditary innovation. Thus there's a colossal scope for more investigate in hereditarily adjusted organisms, microbial fuel cell (MFC) and biofilms interceded bioremediation.

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