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MICROBIAL BIOREMEDIATION OF HEAVY METALS IN INDUSTRIAL WASTEWATER

Venkanna Jeedi
Research Scholar, Jayoti Vidyapeeth Women's University, Jaipur, Rajasthan

Dr. Nidhi Goyal
Research Supervisor, Jayoti Vidyapeeth Women's University, Jaipur, Rajasthan

ABSTRACT

Microbial bioremediation is an environmentally friendly and cost-effective approach for removing heavy metals from industrial wastewater. Heavy metals such as lead, cadmium, chromium, mercury, nickel, copper, and zinc are persistent pollutants that can accumulate in ecosystems and pose serious risks to human health and aquatic organisms. Conventional treatment methods may be expensive and can generate secondary pollutants, whereas microorganisms provide a sustainable alternative through biosorption, bioaccumulation, biotransformation, precipitation, and enzymatic reduction mechanisms. Bacteria, fungi, algae, and other microbial species possess functional groups and metabolic pathways capable of binding, transforming, or immobilizing toxic metals. Factors such as pH, temperature, metal concentration, microbial biomass, and contact time influence remediation efficiency. The application of free or immobilized microbial biomass can improve metal removal and facilitate treatment-process management. This study focuses on the mechanisms, applications, advantages, limitations, and future prospects of microbial bioremediation for the effective treatment of heavy-metal-contaminated industrial wastewater.

***Keywords:* -** Microbial bioremediation, Heavy metals, Industrial wastewater, Biosorption, Bioaccumulation, Biotransformation, Microorganisms.

INTRODUCTION

Wastewater contaminated with hazardous heavy metals including lead, cadmium, chromium, mercury, nickel, copper, and zinc has being produced at an alarming rate due to industrialisation. Severe environmental and health issues may be caused by the accumulation of these metals in soil, water, plants, animals, and people. What's more, they are persistent and non-biodegradable. Heavy metal removal using conventional physicochemical techniques may be costly to operate and generate waste. One viable and eco-friendly option for cleaning polluted industrial effluent is microbial bioremediation. The process employs microbial processes such biosorption, bioaccumulation, biotransformation, precipitation, and enzymatic reduction to eliminate, modify, immobilise, or detoxify heavy metals. Many different functional groups in microbial cells are capable of binding metal ions, and some microbes even have mechanisms that allow them to withstand metal stress. Reducing heavy-metal pollution and increasing the quality of industrial wastewater may be achieved by an effective, inexpensive, and sustainable method known as microbial bioremediation.

REVIEW OF LITRETURE

Kuzmanović, Ana et al., (2021) Because metal ions are persistent, bioavailable, and poisonous, heavy metal contamination is a major environmental hazard. Environmental cleanup has long made use of a wide variety of tried-and-true physical and chemical methods. The employment of live organisms, also known as bioremediation, is on the rise as an alternative to traditional approaches, which have a number of disadvantages. Numerous microbial strains have been shown to be effective in eliminating heavy metals, and the biotechnological use of microbes is both established and constantly evolving. This study outlines the interactions between microorganisms and heavy metals and gives an overview of their major properties. The article outlines the primary concepts and kinds of heavy metal bioremediation technologies, including specifics on pilot size bioreactor experiments that were effective, and it goes on to define important processes by which microorganisms resist these metals. Because they have evolved to survive in contaminated settings and have developed resistance mechanisms, native bacteria should get extra care when they are extracted from such sites. Using bacterial biofilms or consortia might be beneficial since they have more tolerance and can use many metabolic routes, which means they can potentially remove multiple heavy metals at once. Nanotechnology, genetic engineering, metagenomics, and other cutting-edge technologies are being used to enhance bioremediation processes, as discussed in this article. In conclusion, bioremediation offers a promising strategy for environmental cleanup.

Kelany, Mahmoud et al., (2023) When it comes to industrial effluent, heavy metals are by far the most prevalent contaminants. For the elements zinc, iron, lead, copper, manganese, nickel, and cadmium, only three of thirty bacterial isolates showed the strongest metal resistance activity. Isolates OM144907 SCUF0000311, OM180597 SCUF0000312, and OM181067 SCUF0000313 of Enterobacter kobei, Enterobacter cloacae, and Enterobacter hormaechei, respectively, were identified and deposited in WDCM based on biochemical and DNA homology similarities of 99.79%, 99.86%, and 99.58%, respectively. For E. kobei and E. cloacae, the MIC of heavy metal concentrations was 25, 15, and 15 mmol/l for Ni^{+2}, Fe^{+2}, and Mn^{+2}, respectively; for E. hormaechei, it is 15 mmol/l for Ni^{+2}, Fe^{+2}, and Mn^{+2}, and 10 mmol/l for Zn^{+2}, Pb^{+2}, Co^{+2}, and Cd^{+2}. The study demonstrated that three different bacterial strains were able to remove over 90% of the heavy metals zinc, iron, lead, manganese, nickel, and cadmium from a non-concentrated polluted sample at 100%, 200%, and 300% concentrations in industrial wastewater. While the contaminated sample concentration was doubled (200%), E. cloacae had the greatest removal efficiencies for Zn^{+2}, Pb^{+2}, Mn^{+2}, Ni^{+2}, and Cd^{+2} at 70.75%, 66%, 65.5%, and 57%, respectively. After the contaminated sample concentration was increased to 300%, E. cloacae was able to remove more than 45% of all heavy metals tested, with the exception of Pb^{+2}. At greater concentrations, E. cloacae demonstrated the greatest efficacy in heavy metal removal, according to the guidelines. Added Information You may find further resources for this article online at 10.1007/s10661-023-11951-x.

Abo-Alkasem, Mohamed et al., (2023) As a consequence of the industrial revolution, there is a growing need to develop new technologies that can prioritise the elimination of heavy metals entirely. Researchers discovered that bioremediation significantly reduced the amount of both organic and inorganic contaminants in the environment. Bioremediation, in its main body, is an interdisciplinary field that has shown to be a cost-effective, efficient, and safe technique. The in-situ treatment, which decreases the likelihood of spreading the toxins to another location, is another key element of bioremediation technique. Among the most exciting new developments in bioremediation is the use of genetic engineering to create transgenic plants or microorganisms with the capacity to remove several heavy metals simultaneously. To sum up, ecologists still face a significant difficulty when it comes to removing heavy metal pollution. This study aimed to shed light on bioremediation technology, including its significance, mode of action, and potential.

Tayang, Amanso&Songachan, L S (2021) Heavy metals are poisonous to all kinds of life and tend to stick around for a long time. Water and soil are being polluted with heavy metals due to the ever-increasing levels of industrialisation, urbanisation, and dangerous agricultural methods. There are a number of plans in the works to lessen the environmental damage that heavy metals do. But each of them has its own set of restrictions. One eco-friendly, efficient, and cost-effective way to detoxify metals is via bioremediation, which involves microorganisms. Microbes have the ability to convert metal pollutants into less harmful forms by using them as an energy source. Microorganisms interact with metals for extended periods of time, allowing them to build a tolerance and resistance mechanism. Biosorption, bioleaching, biomineralisation, bioaccu-mulation, and biotransformation are some of the ways in which microbes and metals may interact. Metal resistance mechanisms, such as barriers, efflux systems, sequestration, and reduction, may be better understood by research into these interactions. The resistance genes found on plasmids and chromosomes are responsible for encoding these processes. Strategies for bioremediation of metals need an understanding of how microorganisms resist metals.

Taha, Ayat et al., (2023) Natural and man-made sources of heavy metals in the environment pollute wastewater. Due of soil's inherent remedial basic and micronutrient richness, wastewater's application in agriculture has grown in recent years. Heavy metal removal from wastewater has therefore become more important. A number of issues have plagued previous cleanup approaches, including exorbitant costs and the generation of massive amounts of hazardous waste, which in turn contribute to secondary pollution sources. Therefore, in order to remediate heavy metals from wastewater before it is used in agriculture, it is essential to employ green technology that is both economically and ecologically benign. Regarding this matter, recent developments in microbial biotechnology have shown that fungi play a significant role. Fungi are an important class of microbes with various environmental traits, one of which is the capacity to bioaccumulate and biosorb these metals from wastewater. This method's benefits include eco-friendliness, widespread support from the general public, and the fact that it has little to no impact on the economy or nature.

MICROBIAL MECHANISMS AND PROCESSES INVOLVED IN HEAVY METAL BIOREMEDIATION

Heavy metal microbial bioremediation is the process of removing, immobilising, transforming, or detoxifying harmful metal ions from industrial effluent by use of the metabolic activities of microbes. Heavy metals, in contrast to organic contaminants, are not biodegradable; hence, microbes mitigate their toxicity and mobility by means of several biochemical and physicochemical processes. Among the several mechanisms by which metal ions attach to functional groups on extracellular polymers and microbial cell walls, biosorption stands out. Metals including lead, cadmium, chromium, copper, and nickel may be immobilised via interactions with carboxyl, hydroxyl, amino, phosphate, and sulfhydryl groups. Living microbial cells actively transfer metal ions into their internal systems via bioaccumulation, which is another significant method. Metals may be stored or complexed with cellular molecules inside these systems. Microbes are capable of biotransformation as well, which involves changing the oxidation state of metals to modify their mobility, solubility, and toxicity. As an example, certain microorganisms have the ability to convert the very poisonous hexavalent chromium (Cr(VI)) to the much safer trivalent chromium (Cr(III)). Bioprecipitation is the process by which insoluble chemicals may be removed from wastewater by reacting with dissolved metals. Extracellular polymeric compounds produced by microbes may also entrap and immobilise metal ions close to cell surfaces. Metal detoxification is aided by the internal synthesis of metal-binding proteins, metallothioneins, and other substances by some resistant microbes. In addition to providing protection against high metal concentrations, efflux systems may flush out metal ions that have built up in microbial cells. Certain variables, including microbial species, temperature, pH, metal concentration, biomass concentration, nutrition availability, and contact duration, determine how effective these systems are. Heavy metals may be effectively removed via a process that involves biosorption, bioaccumulation, biotransformation, and precipitation. For the purpose of developing biological treatment systems for industrial wastewater that are effective, cost-effective, and ecologically sustainable, it is crucial to have a thorough understanding of these microbial processes.

ROLE OF BACTERIA, FUNGI, AND ALGAE IN THE REMOVAL OF HEAVY METALS FROM WASTEWATER

The capacity of some microorganisms to withstand, bind, collect, and convert harmful metal ions makes them invaluable in the biological treatment of industrial effluent polluted with heavy metals. Bioremediation makes extensive use of bacteria due to their adaptability to polluted surroundings, diversified metabolic activities, and quick growth rate. The carboxyl, hydroxyl, phosphate, and amino groups found in bacterial cell walls have the ability to biosorb heavy metals. Additionally, certain bacterial species have the ability to bioaccumulate metals into their cells, facilitate precipitation, or convert harmful metal ions into less hazardous forms. Because of the vast surface

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area for metal binding provided by their mycelial networks, fungi are very excellent biosorbents. Metallic ion-interacting components such as chitin, glucans, proteins, and others are found in the cell walls of fungi. Rhizopus, Aspergillus, and Penicillium are just a few genera whose species have shown promise in the removal of lead, cadmium, chromium, copper, and zinc, among others. Extracellular metabolites produced by fungi may also aid in the precipitation and immobilisation of metals. Because of their ability to both internalise and externally adsorb metal ions, algae are among the most promising microbial groups for wastewater treatment. Metal binding is made easier by the presence of polysaccharides, proteins, and other functional groups in their cell walls. The value of algal biomass for integrated treatment systems is derived from its ability to remove nutrients and purify wastewater at the same time. Many variables affect how well microbes like algae, fungus, and bacteria work, including temperature, pH, starting metal concentration, biomass amount, contact duration, and competing ion presence. To further enhance stability, recovery, and operating efficiency, microbial biomass may be immobilised. Thus, these microbes provide long-term, cost-effective, and eco-conscious substitutes for traditional heavy-metal treatment techniques. Industrial wastewater treatment systems may benefit from their enhanced performance and wider metal-removal capabilities when used in microbial consortia.

CONCLUSION

To remove heavy metals from industrial effluent, microbial bioremediation is an attractive, long-term, and eco-friendly option. Microbial procedures use the inherent capabilities of microbes including bacteria, fungus, and algae to immobilise, accumulate, convert, and remove harmful metals, as opposed to traditional treatment techniques that may be energy intensive, chemically intensive, and produce secondary waste. Metal toxicity and mobility may be considerably reduced by mechanisms such biosorption, bioaccumulation, biotransformation, bioprecipitation, and enzymatic reduction. Phosphorus, temperature, metal concentration, microbial biomass, contact duration, and competing chemicals are some of the parameters that determine how successful microbial treatment is. An further way to boost treatment efficacy, stability, and biomass recovery is by using immobilised microorganisms. In conclusion, microbial bioremediation provides a long-term, cost-effective answer to the problem of managing industrial wastewater. Optimal operating conditions, integrated treatment technologies, effective microbial strains, and microbial consortia may improve heavy-metal removal, which in turn can help create wastewater treatment systems that are safer and better for the environment.

E-mail:* *editor.jslsci888@gmail.com

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***E-mail:* editor.jslsci888@gmail.com**

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