A Review on Heavy Metals Uptake by Plants through Biosorption

Kajal Sao, a, F. Khan a, Piyush Kant Pandey b and Madhurima Pandey c

a Ph.D Research Scholar, Department of Chemistry, National Institute of Technology (NIT), Raipur, 492010 (C.G.) India.

a* Professor and Head, Department of Chemistry, National Institute of Technology (NIT), Raipur, 492010 (C.G.) India.

b Principal, Bhilai Institute of Technology (BIT), Raipur, Kendri, New Raipur, 493661 (C.G.), India.

c Professor and Head, Department of Chemistry, Bhilai Institute of Technology (BIT), Durg, 491001 (C.G.) India.

Abstract. Heavy metals are among the most important sorts of contaminant in the environment. Several methods already used to clean up the environment from these kinds of contaminants, but most of them are costly and difficult to get optimum results. Currently, biosorption is an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmental friendly and potentially cost effective. This paper aims to compile some information about heavy metals sources, effects and their treatment. It also reviews deeply about biosorption technology, including the heavy metal uptake mechanisms and several research studies associated about the topics. Additionally, it describes several sources and the effects of heavy metals on the environment, the advantages of this kind of technology for reducing them, and also heavy metal uptake mechanisms in biosorption technology as well as the factors affecting the uptake mechanisms. Some recommended plants which are commonly used in biosorption and their capability to reduce the contaminant are also reported.

Keywords: Biosorption; Heavy metals; Contaminated Water; Plant Biomass

1. Introduction

Aqueous heavy metal pollution represents an important environmental problem due to their toxic effects and accumulation throughout the food chain. Heavy metals contaminants exist in aqueous wastewaters of many industries, such as metal plating facilities, mining operations and tanneries [1]. The contamination of water with substances which have adverse effect on human beings animal and plant is called water pollution. Water pollution is a worldwide problem and its control has become increasingly important in recent years. The conventional methods for the removal of these heavy metals from wastewaters include chemical precipitation, membrane separation, ion exchange etc [2]. The major disadvantage with conventional treatment technologies is the production of toxic chemical sludge and its disposal or treatment becomes costly affair and is not eco-friendly. Therefore removal of toxic heavy metals to an environmentally safe level in a cost effective and environment friendly manner assumes great importance [3-4].

Adsorption of pollutants on solid adsorbents is an effective method used for heavy metals removal from aqueous solutions, in special when the adsorbent used is not very expensive [2]. Thus, natural materials that are available in large quantities or certain waste products from industrial or
agricultural operations may have potential as inexpensive sorbents. The moss peat is one example of such low-cost sorbents which can be utilized for the heavy metals removal from aqueous solutions [5].

Many species of plants have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic, and other heavy metals. The objectives of this paper are to discuss the potential of biosorption technique on treating heavy metal-contaminated side, to provide a brief view about heavy metals uptake mechanisms by plant, to give some description about the performance of several types of plants to uptake heavy metals.

2. Effects of Heavy Metals on Human Health

The heavy metals hazardous to humans include lead, mercury, cadmium, arsenic, copper, zinc, and chromium. Such metals are found naturally in the soil in trace amounts, which pose few problems. When concentrated in particular areas, the table shows the sources, effects and permissible level some harmful toxic metals.

Table 1 Heavy metals and their effect on human health

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Major Sources</th>
<th>Effects of Human Health</th>
<th>Permissible Limit(PPM) by WHO [6]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>Pesticides, fungicides, metal smelters</td>
<td>Bronchitis, dermatitis</td>
<td>0.05</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Welding, electroplating, pesticide fertilizer Cd Ni batteries, nuclear fission plant</td>
<td>Kidney damage, bronchitis, gastrointestinal disorder, bone marrow, cancer</td>
<td>0.05</td>
</tr>
<tr>
<td>Lead</td>
<td>Paint, pesticide, smoking, automobile emission, mining, burning of coal</td>
<td>Liver, kidney, gastrointestinal damage, mental retardation in children</td>
<td>0.10</td>
</tr>
<tr>
<td>Manganese</td>
<td>Welding, fuel addition, ferromanganese production</td>
<td>Inhalation or contact causes damage to central nervous system</td>
<td>0.05</td>
</tr>
<tr>
<td>Mercury</td>
<td>Pesticides, batteries, paper industry</td>
<td>Damage to nervous system, protoplasm poisoning</td>
<td>0.001</td>
</tr>
<tr>
<td>Zinc</td>
<td>Refineries, brass manufacture metal Plating, plumbing</td>
<td>Zinc fumes have corrosive effect on skin, cause damage to nervous membrane</td>
<td>15</td>
</tr>
</tbody>
</table>

3. Need for the Removal of Heavy Metals

Continuous discharge of industrial, domestic and agricultural wastes in rivers and lakes causes deposit of pollutants in sediments. Such pollutants include heavy metals, which endanger public health after being incorporated in food chain. Excessive amounts of some heavy metals can be toxic through direct action of the metal or through their inorganic salts or via organic compounds from which the metal can become easily detached or introduced into the cell. Exposure to different metals may occur in common circumstances, particularly in industrial setting. Accidents in some environments can result in acute, high level exposure. Some of the heavy metals are toxic to aquatic
organisms even at low concentration. The problem of heavy metal pollution in water and aquatic organisms including fish, needs continuous monitoring and surveillance as these elements do not degrade and tend to biomagnified in man through food chain. Hence, there is a need to remove the heavy metals from the aquatic ecosystem.


The commonly used procedures for removing metal ions from aqueous streams include chemical precipitation, lime coagulation, ion exchange, reverse osmosis and solvent extraction [7]. The process description of each method is presented below:

**Reverse Osmosis:** It is a process in which heavy metals are separated by a semi-permeable membrane at a pressure greater than osmotic pressure caused by the dissolved solids in wastewater. The disadvantage of this method is that it is expensive.

**Electrodialysis:** In this process, the ionic components (heavy metals) are separated through the use of semi-permeable ion selective membranes. Application of an electrical potential between the two electrodes causes a migration of cations and anions towards respective electrodes. Because of the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed. The disadvantage is the formation of metal hydroxides, which clog the membrane.

**Ultrafiltration:** They are pressure driven membrane operations that use porous membranes for the removal of heavy metals. The main disadvantage of this process is the generation of sludge.

**Ion-exchange:** In this process, metal ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin. The disadvantages include: high cost and partial removal of certain ions.

**Chemical Precipitation:** Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. The large amount of sludge containing toxic compounds produced during the process is the main disadvantage.

**Phytoremediation:** Phytoremediation is the use of certain plants to clean up soil, sediment, and water contaminated with metals. The disadvantages include that it takes a long time for removal of metals and the regeneration of the plant for further biosorption is difficult.

Hence the disadvantages like incomplete metal removal, high reagent and energy requirements, generation of toxic sludge or other waste products that require careful disposal has made it imperative for a cost-effective treatment method that is capable of removing heavy metals from aqueous effluents.

5. Biosorption

Biosorption is a physiochemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind contaminants onto its cellular structure. Though using biomass in environmental cleanup has been in practice for a while, scientists and engineers are hoping this phenomenon will provide an economical alternative for removing toxic heavy metals from industrial wastewater and aid in environmental remediation [8]. The major advantages of biosorption over conventional treatment methods include:

- Low cost;
- High efficiency;
- Minimization of chemical and/or biological sludge;
- No additional nutrient requirement;
- Regeneration of biosorbent; and
- Possibility of metal recovery.

5.1 Biosorbent

Biosorbent materials are derived from raw microbial, seaweed or even some plant biomass through different kinds of simple procedures. They may be chemically pretreated for better
performance and suitability for process applications. Biosorbents are capable of directly sorbing metal ionic species from aqueous solutions. In this article, the technical feasibility of various low-cost adsorbents for heavy metal removal from contaminated water has been reviewed. Instead of using commercial activated carbon, researchers have worked on inexpensive materials, such as chitosan, zeolites, fly ash charcoal, algae, fungi and other plant bio-adsorbents, which have high adsorption capacity and are locally available. It is evident from our literature survey of about 50 papers that low-cost adsorbents have demonstrated outstanding removal capabilities for certain metal ions. Adsorbents that stand out for high adsorption capacities are chitosan (476.26, 94 mg/g of Cr6+ and Cd2+, respectively) [9] [10], waste slurry (1380, 55.6 mg/g of Pb2+ and Hg2+ respectively) [11] [12], and biomass Momordica charantia for arsenic (0.88mg/L) [13] etc. These adsorbents are suitable for inorganic effluent treatment containing the metal ions mentioned previously. It is important to note that the adsorption capacities of the adsorbents presented in this paper vary, depending on the characteristics of the individual adsorbent, the extent of chemical modifications, and the concentration of adsorbate.

5.2 Biosorption Mechanism

Metal biosorption is the removal of metal ions by inactive, nonliving biomass due to highly attractive forces present between the two [14]. Particularly, it is due to the presence of certain functional groups, such as amine, carboxyl, hydroxyl, phosphate, sulphydryl etc., on the cell wall of the biomass [15]. The process involves a solid phase (biomass) and a liquid phase containing metal ions (solution of metal ions/waste-water). Metal ions are attracted and bound to the biomass by a complex process that comprises of a number of mechanisms like adsorption on the surface and pores, ion-exchange, surface precipitation, complexation and chelation and entrapment in capillaries and spaces of polysaccharide network, due to the concentration causing diffusion through the cell wall and membrane. The complex nature of the mechanism is shown in Fig.1. To study the mechanism, it is necessary to have the exact information about the cell wall structure of the biomass as well as the solution chemistry.

![Mechanism of biosorption](image)

6. Factors Affecting the Biosorption

The investigation of the efficacy of the metal uptake by the microbial biomass is essential for the industrial application of biosorption, as it gives information about the equilibrium of the process which is necessary for the design of the equipment. The following factors affect the biosorption process:
1. Temperature seems not to influence the biosorption performances in the range of 20-350°C [16].

2. pH seems to be the most important parameter in the biosorptive process: it affects the solution chemistry of the metals, the activity of the functional groups in the biomass and the competition of metallic ions [17].

3. Biomass concentration in solution seems to influence the specific uptake: for lower values of biomass concentrations there is an increase in the specific uptake.

4. Biosorption is mainly used to treat wastewater where more than one type of metal ions would be present; the removal of one metal ion may be influenced by the presence of other metal ions. According to the location where the metal removed from solution is found, biosorption can be classified as:
   • Extra cellular accumulation/ precipitation
   • Cell surface sorption/ precipitation
   • Intracellular accumulation.

7. Conclusion

We have reviewed the sources and toxicology of heavy metals as well as the reason why they need to be removed from our environment. Conventional methods of removal are expensive. Hence, the uses of low-cost, abundant environmentally friendly biosorbents have been tested. Most studies in the biosorption field have been and are still being conducted to pinpoint the best biosorbent and alternative adsorbents with high adsorption capacity although biosorption is promising; its mechanism is not well elucidated. The advanced development of the biosorption processes requires further improvement in the direction of modeling, regeneration of biosorbent material and of testing immobilized raw biomasses with basic industrial effluents.

8. References


