Chapter 8
Biosorption Processes for Heavy Metal Removal in Aqueous Media

Joan Nyika
https://orcid.org/0000-0001-8300-6990
University of Johannesburg, South Africa

Megersa Olumana Dinka
https://orcid.org/0000-0003-3032-7672
University of Johannesburg, South Africa

ABSTRACT

Biosorption technique is a growing alternative to existent conventional treatment techniques used in heavy metal remediation and associated with the production of toxic sludge. This chapter demonstrated the use of the technique and its processes, the biosorbents used, and the sorbates that they target. Evidently, many plant by-products, bacteria, fungi, and algae species are used in the process in their living or dead forms to take up a variety of heavy metals. The process is regulated by factors such as biosorbent dosage, temperature, pH, and initial metal concentration. There is need to advance research on the technique to optimize its metal removal efficacy.

INTRODUCTION

Heavy metals describe elements of the periodic table elements (metalloids and metals) whose atomic density is five times greater than that of water or more than 4 g/cm^3 (Nyika & Dinka, 2023a). Examples of heavy metals include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), thallium (Tl) and antimony (Sb) among others. The metals occur naturally in the earth's crust but can be released during various anthropic activities such as mining, industrial activities and from solid waste and wastewater constituents (Priyadarshanee & Das, 2021). Continuous accretion of heavy metals has also resulted from the manufacture of paints, explora-

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tion of gas and oil, coal combustion and unscientific application of agricultural inputs (fertilizers and agrochemicals). The situation is more pronounced in contemporary society characterized with a rise in industrialization and the quest for economic development globally.

Heavy metals have a persistent, non-destroyable and non-biodegradable nature, which makes them to accumulate in environmental compartments, enter and get transferred in food chains to become health and environmental hazards (Nyika & Dinka, 2023b). Apart from occurring in rocks, the elements occur in compartments of the biosphere including the soils and water. The metals can accumulate on land and enter in soil systems to disrupt their ecosystem functions. They are then transferred to water resources to render them non-palatable and unsuitable for consumptive uses. From soils and water, they can be taken up the roots to accumulate in plants and food before their transfer from primary to secondary consumers. In trace amounts, some metals such as Cu, Zn and Fe can be useful in various physiological functions of the body though in higher concentrations they are toxic to the body. Other heavy metals apart from these essential ones are toxic to organisms even in minute levels. Their toxicity potential to organisms is dependent on the health state, genetics, gender and age of the organisms as well as the specific chemical species involved, the exposure route and the dose of the heavy metal ingested or inhaled (Pham . 2022). In higher animals for instance, ingestion of high concentrations of heavy metals is associated with immunological toxicity, hepatoxicity, carcinogenicity, nephrotoxicity, neurotoxicity and toxicity of reproductive systems (Nyika & Dinka, 2023a). Mercury and Cr ingestion by humans causes carcinogenic effects (Mitra et al., 2022). The poisoning of Pb in children results to intellectual dysfunctions among children while Cd and Hg toxicity have been associated with the Itai-itai and Minamata diseases, respectively. The main route of toxicity is through cytotoxicity (damaging and eventual death of cells), production of reactive oxygen species (ROS) to induce oxidative stress and the destruction of genetic material (DNA) in the organisms.

Heavy metals cannot be metabolized but they can be transformed to lesser toxic forms. As such, it is key to manage and control their release to the biosphere. Such advances require the application of chemical and physical techniques to treat the metals in polluted environs. Examples of physical techniques employed include reverse osmosis, membrane technology, ion exchange and filtration while some chemical techniques include redox reactions, electrochemical treatment and chemical precipitation. Although the techniques are effective in heavy metal remediation to some degree, they are sometimes labour and energy intensive, non-selective and non-specific to heavy metals, inefficient and expensive (Shamim, 2018; Redha, 2020). Some of the techniques also have low efficacy and produce secondary toxic waste and sludge as byproducts leading to extensive pollution (Priyadarshanee & Das, 2021). Owing to these challenges new advances on the use of biological techniques that employ microorganisms are being advocated in the scientific field (Shamim, 2018; Nyika & Dinka, 2023 a, b, c). Bioremediation techniques are preferred since they have a high recovery efficiency, are natural, safe, greener, less polluting, and cheaper compared to other conventional techniques (Pham, Kim, Chang, & Chung, 2022). This chapter explored the application of biosorption, a type of bioremediation technique for heavy metal removal from various environmental compartments and prospects, which could facilitate the wider application of the technique to alleviate pollution at field scale.

The Principles of Biosorption and Types of Biosorbents

Biosorption refers to a physicochemical and biological process in which microbes and plant biomass adsorb and absorb contaminants such as dyes and heavy metals in their ionic forms (Redha, 2020). The

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