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Biomass-derived biosorbents for metal ions sequestration: Adsorbent modification and activation methods and adsorbent regeneration

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ABSTRACT

Heavy metals released from industrial activities pose a significant threat to the environment and public health due to their reported toxicity even at trace levels. Although there are several available methods to treat or remove heavy metals from water and wastewater, the research focuses on development of technological solutions which sound environmental friendly and economically feasible, able to reduce the costs and maximize the efficiency. In this framework, the biosorption process, which uses cheap and non-pollutant materials, may be considered as an alternative, viable and promising, technology for heavy metal and metalloid ions sequestration and ultimately removal technology in the waste water treatment. However, there is as yet little data on full-scale applications for the design and testing of adsorption units using single biosorbents and their combinations to sequester heavy metal ions from multi-metal systems. Immediate research and development is hence earnestly required in this specific direction to further make progress this blooming technology and widen its scope of application to real situations needing heavy metal pollution remediation. This review provides a comprehensive appraisal of the equilibrium modeling of a number of biosorption processes as well as the structural, chemical and morphological modifications and activation of biosorbents. Further the relative merits of the methods used to recover sequestered heavy metal ions and regenerate biosorbents through desorption routes and their future applications are discussed.

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Introduction

Heavy metal contamination of aqueous media and industrial effluents is one of the significant environmental problems due to the toxic nature and accumulation of these metal ions in the food chain, because they are non-biodegradable [1,2]. Although several adverse health effects of heavy metals have been known for a long time, exposure to heavy metals continues, and is even increasing in some parts of the world, in particular in less developed countries, though emissions have declined in most developed countries over the last 100 years. For example, mercury is still used in gold mining in many parts of Latin America. Arsenic is still common in wood preservatives, and tetraethyl lead remains a common additive to petrol, although this use has decreased dramatically in the developed countries. Heavy metal contamination exists in wastewater of many industries such as metal plating, mining operations, surface finishing industry, tanneries, paper and pulp industries, chlor-alkali, fertilizer and pesticide industry, radiator manufacturing, smelting, energy and fuel production, aerospace and atomic energy installation, alloy industries, electroplating and batteries industries [3–11].

While many of the heavy metals are needed by biological systems at the micronutrient level, higher concentrations are known to produce a range of toxic effects. A high exposure to lead (Pb) causes encephalopathy, cognitive impairment, behavioral disturbances, kidney damage, anemia and toxicity to the reproductive system [12]. Chromium (Cr) is widely accepted to exert toxic effects in its hexavalent form due to its strong oxidation properties [13,14]. Human exposure to Cr(VI) compounds is associated with a higher incidence of respiratory cancers [15,16]. After it reaches the blood stream, it damages the kidneys, causes irritation and corrosion of skin, the liver and blood cells through oxidation reactions [17]. Cadmium (Cd) has been established as a very toxic heavy metal. Due to its acute toxicity, Cd has recently joined lead and mercury in the most toxic "Big Three" category of heavy metals with the greatest potential hazard to humans and the environment [18]. Symptoms of acute poisoning include headaches, nausea, vomiting, weakness, pulmonary edema and diarrhea. A disease known as "Itai–Itai" in Japan is specifically associated with cadmium poisoning, resulting in multiple fractures arising from osteomalacia. High dose of copper (Cu) concentrations can lead to weakness, lethargy, anorexia and damage to the gastrointestinal tract [19]. Human exposure to highly nickel (Ni) polluted environments can cause skin allergies, lung fibrosis, and cancer of the respiratory tract [20,21]. The exact mechanisms of nickel-induced carcinogenesis are not known and have been the subject of various epidemiologic and experimental investigations. Table 1 summarizes the anthropogenic sources of heavy metals in the environment.

There are several methods for removing heavy metal ions from aqueous solutions and mainly consist of physical, chemical and biological techniques and technologies. Conventional methods for removing toxic metal ions from aqueous solution have been recommended, such as chemical precipitation [37], filtration [38], ion exchange [39], electrochemical treatment [40], membrane technologies [41], floatation [42,43], adsorption on activated carbon [44,45], evaporation and photocatalysis [46–48,50]. Table 2 shows the treatment technologies for the removal of heavy metals from wastewaters and related advantages and disadvantages.

However, chemical precipitation and electrochemical treatment are ineffective, especially when metal ion concentrations in aqueous solution are low, and also alongside these removal techniques produce large quantity of sludge which require further treatment [10]. Ion exchange, membrane technologies and activated carbon adsorption process are extremely expensive when treating large amount of industrial effluent and wastewater containing heavy metal ions in low concentration, they cannot be used at large industrial scale. Despite its extensive use in the water and wastewater treatment technologies, activated carbon remains an expensive material.

Table 1
Significant anthropogenic sources of heavy metal in the environment.

Industry	Metals	Pollution arising	References
Electroplating	Cr, Ni, Zn, Cu	Liquid effluents from plating processes	[22,23]
Batteries	Pb, Sb, Zn, Cd, Ni, Hg	Waste battery fluid, contamination of soil and groundwater	[24]
Paints and pigments	Pb, Cr, As, Ti, Ba, Zn	Aqueous waste from manufacture, old paint deterioration and soil pollution	[25]
Landfill leachate	Zn, Cu, Cd, Pb, Ni, Cr, Hg	Landfill leachate, contamination of ground and surface water	[26,27]
Electronics	Pb, Cd, Hg, Pt, Au, Cr, As, Ni, Mn	Aqueous and solid metallic waste from manufacturing and recycling process	[28]
Metalliferous mining	Cd, Cu, Ni, Cr, Co, Zn, As	Acid mine drainage, tailings, slag heaps	[29,30]
Fertilizers	Cd, Cr, Mo, Pb, U, V, Zn	Run-off, surface and groundwater contamination, plant bioaccumulation	[31,32]
Manures sewage sludge	Zn, Cu, Ni, Pb, Cd, Cr, As, Hg	Land spreading threat to ground and surface water	[31,33]
Specialist alloys and steels	Pb, Mo, Ni, Cu, Cd, As, Te, U, Zn	Manufacture, disposal and recycling of metals. Tailings and slag heaps	[34,35]
Paper and pulp	Zn, Cu, Cd, Pb, Ni, Fe, Mn	Wastewater effluents	[36]