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Review

Biosorption of heavy metal ions using wheat based biosorbents – A review of the recent literature

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ABSTRACT

Conventional technologies for the removal/remediation of toxic metal ions from wastewaters are proving expensive due to non-regenerable materials used and high costs. Biosorption is emerging as a technique offering the use of economical alternate biological materials for the purpose. Functional groups like carboxyl, hydroxyl, sulphydryl and amido present in these biomaterials, make it possible for them to attach metal ions from waters.

Every year, large amounts of straw and bran from *Triticum aestivum* (wheat), a major food crop of the world, are produced as by-products/waste materials. The purpose of this article is to review rather scattered information on the utilization of straw and bran for the removal/minimization of metal ions from waters. High efficiency, high biosorption capacity, cost-effectiveness and renewability are the important parameters making these materials as economical alternatives for metal removal and waste remediation. Applications of available adsorption and kinetic models as well as influences of change in temperature and pH of medium on metal biosorption by wheat straw and wheat bran are reviewed. The biosorption mechanism has been found to be quite complex. It comprises a number of phenomena including adsorption, surface precipitation, ion-exchange and complexation.

1. Introduction

Heavy metal ions have lethal effects on all forms of life and these enter the food chain through the disposal of wastes in water channels. From among various metal ions, lead, mercury, cadmium and chromium(VI) are at the top on the toxicity list (Volesky, 1994). Due to non-biodegradability, metal ions accumulate and their amounts are increased along the food chain. Hence, their toxic effects are more pronounced in the animals at higher trophic levels. Sources and toxicity of certain metal ions are listed in Table 1.

Owing to the toxic effects, the industries are advised that the waste waters be treated systematically to remove/minimize the metal contents in their wastes. A number of methods are already at operation and Table 2 compares selective techniques used for the purpose. Adsorption by activated carbon is the most efficient classical way as it removes more than 99% of certain metal ions but the cost of its production is prohibitive and it can not be regenerated and recycled. Generally, the materials employed in these methods are highly expensive and capital costs are much too high to be economical. These methods mostly treat the metal ions as a 'waste' only and eliminate recycling of materials. Some of the methods (e.g., precipitation and coagulation) produce concentrated and further toxic wastes, creating yet another disposal problem. Moreover, there are concentration limits to which these methods are economical and become ineffective or too expensive to treat wastes having metal ions in concentrations of 100 mg/L or below (Ceribasi and Yetis, 2001). Hence, there is a constant need to search for an optimal technology while considering its cost, materials employed and its efficiency.

2. Biosorption – an alternative solution

Biosorption is the removal of materials (compounds, metal ions, etc.) by inactive, non-living biomass (materials of biological origin) due to "high attractive forces" present between the two (Volesky and Holan, 1995).

Living as well as dead (metabolically inactive) biological materials have been sought to remove metal ions. It was found that various functional groups present on their cell wall offer certain forces of attractions for the metal ions and provide a high efficiency for their removal (Ashkenazy et al., 1997; Kuyucak and Volesky, 1988). The mechanisms of uptake by living materials (bioaccumulation) and removal by dead ones (biosorption) are entirely different. Use of dead materials has several advantages because

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Table 1
Sources and toxic effects of heavy metals on human beings.

Metal	Source	Toxic effect	References
Lead	Electroplating, manufacturing of batteries, pigments, ammunition	Anaemia, brain damage, anorexia, malaise, loss of appetite, diminishing IQ	Gaballah and Kilbertus (1998), Low et al. (2000), Volesky (1993)
Cadmium	Electroplating, smelting, alloy manufacturing, pigments, plastic, mining, refining	Carcinogenic, renal disturbances, lung insufficiency, bone lesions, cancer, hypertension, *Itai–Itai* disease, weight loss	Chen and Hao (1998), Godt et al. (2006), Low et al. (2000), Sharma (1995), Singh et al. (2006)
Mercury	Weathering of mercuriferous areas, volcanic eruptions, naturally-caused forest fires, biogenic emissions, battery production, fossil fuel burning, mining and metallurgical processes, paint and chloralkali industries	Neurological and renal disturbances, impairment of pulmonary function, corrosive to skin, eyes, muscles, dermatitis, kidney damage	Boening (2000), Manohar et al. (2002), Morel et al. (1998)
Chromium (VI)	Electroplating, leather tanning, textile, dyeing, electroplating, metal processing, wood preservatives, paints and pigments, steel fabrication and canning industry	Carcinogenic, mutagenic, teratogenic, epigastric pain nausea, vomiting, severe diarrhoea, producing lung tumors	Dupont and Guillon (2003), Granados-Correa and Serrano-Gómez (2009), Kobya (2004), Singh et al. (2009)
Arsenic	Smelting, mining, energy production from fossil fuels, rock sediments	Gastrointestinal symptoms, disturbances of cardiovascular and nervous system functions, bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy, liver tumor	Chilvers and Peterson (1987), Dudka and Markert (1992), Robertson (1989)
Copper	Printed circuit board manufacturing, electronics plating, plating, wire drawing, copper polishing, paint manufacturing, wood preservatives and printing operations	Reproductive and developmental toxicity, neurotoxicity, and acute toxicity, dizziness, diarrhoea	Chuah et al. (2005), Papandreou et al. (2007), Yu et al. (2000)
Zinc	Mining and manufacturing processes	Causes short term "metal-fume fever", gastrointestinal distress, nausea and diarrhoea	WHO (2001)
Nickel	Non-ferrous metal, mineral processing, paint formulation, electroplating, porcelain enameling, copper sulphate manufacture and steam-electric power plants	Chronic bronchitis, reduced lung function, lung cancer	Akhtar et al. (2004), Ozturk (2007)

Table 2
Some methods to remove metal ions from Wastewaters.

Method	Advantages	Disadvantages
Chemical Precipitation	• Simple • Inexpensive • Most of metals can be removed	• Large amounts of sludge produced • Disposal problems
Chemical coagulation	• Sludge settling • Dewatering	• High cost • Large consumption of chemicals
Ion-exchange	• High regeneration of materials • Metal selective	• High cost • Less number of metal ions removed
Electrochemical methods	• Metal selective • No consumption of chemicals • Pure metals can be achieved	• High capital cost • High running cost • Initial solution pH and Current density
Adsorption		
Using activated carbon	• Most of metals can be removed • High efficiency (>99%)	• Cost of activated carbon • No regeneration • Performance depends upon adsorbent
Using natural zeolite	• Most of metals can be removed • Relatively less costly materials	• Low efficiency
Membrane process and ultrafilteration	• Less solid waste produced • Less chemical consumption • High efficiency (>95% for single metal)	• High initial and running cost • Low flow rates • Removal (%) decreases with the presence of other metals

Source: (O'Connell et al. 2008).

there is no need of growing, no growth media is required and these materials are available as wastes or by-products. Biomass from algae (Hamdy, 2000; Seki and Suzuki, 1998), fungi (Guibal et al., 1992; Kapoor et al., 1999), bacteria (Ozturk, 2007; Pumpel et al., 1999), sea-weeds (Elangovan et al., 2008; Murphy et al., 2008), some higher plants (Joshi et al., 2003; Rahman et al., 2005), all of these have been effectively and successfully utilized in metal removal studies.

Volesky has shared his views about the biosorption process in his recent review (Volesky, 2007). He stated that currently 'biosorption of metals' is only the 'tip of the ice-berg' and in future, it must focus on utilization for purification and recovery of high valued proteins, steroids and drugs, that cost in thousands of dollars per gram. He termed this form to be "the best biosorption". Apart from Volesky's groups, a number of review articles have been published by several researchers. Recently, Sud et al. (2008) reviewed the use of certain cellulosic agricultural waste materials for the removal of heavy metal ions. Ahluwalia and Goyal (2007) have collected the dispersed information, covering from 1981 to 2006, about the use of microbial and certain plants derived biomass types. Similarly, use of *Saccharomyces cerevisiae* was compiled by Wang and Chen (2006). A number of other reviews are available in the literature (Davis et al., 2003; Lodiero et al., 2006; Nurchi and Villaescusa, 2008; Romera et al., 2006; Shukla et al., 2002).

Research in biosorption suggests the following advantages over other techniques (Modak and Natarajan, 1995).