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A Review on Current Development of Animal Bone-Based Sorbent for Heavy Metals Removal from Contaminated Water and Wastewater

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Abstract. This review article presents the usage of various animal bones such as chicken bone, fish bone, pig bone, camel bone, and cow bone as reliable biosorbent materials to remove heavy metals contained in contaminated water and wastewater. The sources and toxicity effects of heavy metal ions are also discussed properly. Then specific insights related to adsorption process and its influential factors along with the proven potentiality of selected biosorbents especially derived from animal bone are also explained. As the biosorbents are rich in particular organic and inorganic compounds and functional groups in nature, they play an important role in heavy metal removal from contaminated solutions. Overall, after conducting study reports on the literature, a brief conclusion can be drawn that animal bone waste has satisfactory efficacy as effective, efficient, and environmentally friendly sorbent material.

Introduction

The increasing rate of industrialization and population globally has impacted the environmental sustainability regarding the increase in contaminated water and wastewater containing hazardous pollutants [1, 2]. To date, more research has focused on minimizing the threats posed by various pollutants including heavy metals in order to avoid their harmful effects [3-5]. Massive industrial activities have been the main factor of an increasing amount of contaminated water and wastewater containing heavy metals. Their existence is posing negative consequences to human health and other living creatures due to their carcinogenic and non-biodegradable characters [4, 6]. In accordance with this phenomenon, the effective and efficient treatment method to purifying wastewater in the first stage is an avoidable option.

Several available techniques including ion exchange, adsorption, filtration, membrane filtration and membrane bioreactor, sedimentation, electrodialysis, advanced oxidation processes, biological processes or integrated treatment system can be selected and applied to separate those heavy metals from wastewater solution [7-11]. Each of those techniques has its own advantageous and disadvantageous aspects. However, when it comes to several important targets like lower energy consumption, modest operation procedure, high removal efficiency, and environmentally friendly method, adsorption is one of the best candidates [12, 13].

To date, there are various types of adsorbents such as activated carbon, metal oxide, carbon-based materials, and metal organic framework that can be applied for trapping targeted pollutants contained in contaminated water and wastewaters. The increasing interest in circular economic perspective and keeping environmental sustainability has then led to better awareness of using organic materials derived from plant and animal wastes to be further reused as biosorbent [14]. Despite several articles already reviewed sorbent derived from low-cost materials, to the best of our knowledge, there is less specific discussion on the removal of heavy metals from contaminated water and wastewater using sorbent derived from animal bone. Therefore, this review article then corroborates the current usage of animal bone for heavy metals removal.

Heavy Metals

In the last decades, there has been an increasing attention to health and environmental damage caused by hazardous pollutants including heavy metals. These substances can penetrate the groundwater polluting water and soil [15, 16]. Beyond their permissible levels, heavy metals will cause damaging impact on human health and other living organism. Most of heavy metals contaminating environment are produced by various industries such as mining, pulp and paper, battery, textile, fertilisers, paints, pigments, steel and glass manufacturers, then followed by certain natural factors such as atmospheric reactions and volcanic eruptions [4, 17]. Water and wastewater contaminated by heavy metals must be sufficiently treated before they are disposed to open environment. Several harmful heavy metals along with their allowable values and toxicity effects are tabulated in Table 1 [4, 17-23].

Table 1. Heavy metals sources and toxicity effect

Heavy metal	Permissible limit (mg/L)	Toxicity effect
Mercury	0.01 mg/L by EU, 2 mg/L by EPA	Liver lung, paralysis, loss of memory, blindness, weak immunity
Lead	0.05 mg/L by WHO, 0.1 mg/L by EPA	Brain damage, anaemia, anorexia, vomiting, nervous systems and mental illness
Arsenic	0.01 mg/L by WHO	Lung, melanosis, keratosis, bladder, and kidney cancer, neurological disorder, liver
Copper	1.3 mg/L by USEPA, 1.0 mg/L by EPA	Liver damage and lung cancer, insomnia, osteoporosis, heart disease, cancer
Cadmium	0.003 mg/L by WHO, 0.005 mg/L by EPA	Bronchitis, lung cancer, anemia, kidney failure, lung fibrosis, emphysema
Chro-mium	<5 mg/L by WHO (Cr(III)), 0.1 mg/L by EPA (Cr(VI))	Necrosis, cancer, lung tumour, gastrointestinal, teratogenic, severe diarrhoea
Nickel	0.015 mg/L by USEPA 1 mg/L by EPA	DNA damage, dermatitis, cancer, chronic bronchitis, eczema

Adsorption Process

Adsorption process involves atoms, ions or, solid particles accumulating onto sorbent surface and forming a typical layer of the pollutant particles named sorbates. It takes place continuously until equilibrium condition is established. The quantification of sorbate-sorbent interactions is important to examine targeted pollutant uptake expressed as batch equilibrium isotherm related to mechanistic models or empirical equations [24, 25]. There are two main models commonly used to analyze isotherm mechanism including Freundlich and Langmuir. Freudlich model assumes that the adsorption occurs on the heterogeneous surface having unequal available sites with different adsorption energies. In contrast, Langmuir describes that the adsorption happens onto an ideal homogeneous uniform surface where all of the sites on the adsorbent surface are equivalent. Regarding the kinetic modelling, it may follow pseudo-first order, pseudo-second order, intra particle diffusion, or Elovich models [26].

Biosorbent Preparation and Comparative Analysis on Their Performance

The performance of biosorbent in adsorption process is affected by certain sorbent properties including surface area, pore structure, surface chemistry, particle size, along with the nature of sorbate like polarity, molecular weight, and molecular structure. Other than that, several operating and physicochemical conditions such as sorbent dosage, solution pH, contact time, temperature, initial sorbate concentration, and the existence of other ions are also considerable aspects influencing pollutant removal efficiency [4, 6]. Furthermore, several preparation modes such as drying, carbonization, pyrolysis, calcination, chemicals impregnation or hybrid activation systems can also be implemented to modify the characteristics of the sorbents for increasing their performance to enable higher adsorption capacity [7, 14, 17, 27]. A study reported that the effect of initial preparation on the biosorbent performance was significant. Compared to its raw version, calcinated and mineralized pig bone, for example, was found more effective for Pb(II) ions removal due to the increase in the adsorption capacity from 96.1 mg/g to 312.5 mg/g [28]. Other than that, the comparative assessment on the performance of biosorbent derived from animal bone with other prominent sorbent materials also shows interesting outcomes. While the adsorption capacity values of zeolite and cauliflower leaves-based sorbent were found to be 109.89 mg/g, 57.80 mg/g, and 177.82 mg/g, 53.96 mg/g for adsorbing Pb(II) and Cu(II) ions, respectively, cow bone-based activated carbon could have around 558.88 mg/g and 287.58 mg/g of adsorption capacity for adsorbing the same metals, respectively [29-31]. Therefore, it is worthy to utilize the potentiality of various animal bones abundantly available for being alternative materials to remove heavy metals and other recalcitrant pollutants contained in contaminated water and wastewater.

Biosorbent Derived from Animal Bone

Based on the estimation, there are millions of tons of bone waste that are produced each year by the meat industry. The increasing amount of its production could be expected around 40 million metric tons within the next decade resulting in a significant increase in bone waste globally [32]. The waste has been considered as organic waste disposed in landfills or rendering plants. It is then worthy to further valorize the bones. Along with carbon and other components, the existence of hydroxyapatite containing apatite calcium phosphate as an inorganic material present in all vertebrates bones has enabled the use of the bones as sorbent material [33]. This substance has unique features such as great biocompatibility, high biodegradability and ionic exchange properties. Therefore, many researchers have reported the use of animal bone for wastewater treatment, especially regarding its ability to remove heavy metal ions from aqueous solutions. Table 2 displays several findings on bone waste-based sorbent for heavy metals removal reported on the literature.

Table 2. The use of bone waste-based sorbent for heavy metals removal

Material	Metal	Activation Technique	Removal efficiency (%)/ ads. Capacity (mg/g)	Isoterm model	Kinetics	Ref.
Chicken bone	Cr(VI)	Pyrolysis 350ºC	58.195 mg/g	Langmuir	Elovich	[34]
	Pb	Pyrolysis 600ºC	263 mg/g	Langmuir	-	[35]
	Cd(II)	Fe and Mg coating	97%	-	Pseudo-first order	[36]
Mutton bone	Cr(VI)	Calcination 650ºC	93.85%	Langmuir	Pseudo-second order	[37]
Sheep bone	As(III) AS(V)	Pyrolysis 900 ºC	>4 mg/g >53 mg/g	Freudlich	Pseudo-first order	[38]
Cow bone	Cd(II) Cu(II) Pb(II)	Pyrolysis 600ºC	165.77 mg/g 287.58 mg/g 558.88 mg/g	Langmuir	Pseudo-second order	[29]
Fish bone	Cd(II)	Carbonization 500ºC	>140 mg/g	Langmuir	-	[39]
Camel bone	Cd(II) Pb(II)	Pyrolysis 800ºC	99.4% 99.89%	Langmuir	Pesudo-second order	[40]
	Pb(II) Cd(II) Co(II)	Pyrolysis 500ºC + magnetization by co-precipitation	344.8 mg/g 322.6 mg/g 294.1 mg/g	Langmuir	Pseudo-second order	[41]
	Cu(II)	NaOH/activation 900ºC	200 mg/g	Freudlich	-	[42]
Pig bone	Cd(II)	Pyrolysis 500ºC	73.5 mg/g	Langmuir	Pseudo-second order	[43]

Summary

In this current work, assorted biosorbents derived from animal bone to remove heavy metals have been presented. Comprehensive literature related to the sources and toxicity effects of those heavy metals on human health is also explained. The existence of environmentally friendly wastewater treatment technology is one of critical solutions. Therefore, biosorption can be great alternative to numerous treatment methods like membrane filtration, biological technique, and advanced oxidation processes. Eventually, biosorption process using organic natural materials including animal bones seems still well considered due to its high uptake, lower cost, abundant choices and availability. When it comes to comparative analysis with other natural based sorbents commonly used for heavy metals removal, the performance of animal bone-based sorbents are inclined to have better output. To conclude, implementing modification techniques on the animal bones materials as well as finding the optimum operating conditions could noticeably enhance their adsorption capacity and metals removal efficiency.

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