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Review Paper

A review on the adsorption of heavy metals ion from industrial wastewater with biosorbents

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1. ABSTRACT

In this article, the removal of heavy metal ions from water environments with an environmentally friendly method is discussed. Industrial effluents contain toxic heavy metals such as mercury, lead, cadmium and chromium (VI); copper, nickel, cobalt and zinc are not toxic, but increasing their amount in the environment is a serious concern. The adsorption capacity of different biosorbents is affected by several factors, including pH, temperature, contact time, biomass dose, and the initial concentration of heavy metals. Also, biosorption kinetics and isotherms are also investigated. Banana peel in agricultural residues and Chlorella minotissima in algae, fungi and bacteria showed a high adsorption capacity. The pseudo-second-order kinetic model showed a high correlation coefficient. Therefore, it is chemical adsorption in which metal ions stick to the adsorbent surface by forming a chemical bond. The Langmuir model has a better fit with the experimental data, which indicates the adsorption of a single layer.

Keywords: Heavy Metals, Adsorption, Biosorbents, Kinetics.

2. INTRODUCTION

Toxic heavy metals often enter the ecosystem through agricultural and industrial activities, and their presence in the environment may be harmful to humans, plants, and animals. The discharge of heavy metals from industries has adverse effects on the environment. Conventional treatment technologies to remove heavy metals from aqueous solutions are not cost-effective and produce large amounts of toxic chemical sludge. Biosorption of heavy metals by biomass of microbial or plant origin is an innovative and alternative technology to remove these pollutants from aqueous solutions. Biological adsorption is considered a cost-effective method for treating wastewater with low concentration of heavy metals. In this article, the environmental effects of heavy metals, conventional methods for removing heavy metals from industrial wastewater, conventional methods for removing heavy metals, various conventional adsorbents, and various biological adsorbents are reviewed. Also, factors affecting biological adsorption such as pH, temperature, ionic strength, initial pollutant concentration, size of biological adsorbent, and stirring speed were studied. Different kinetic equations and finally different isothermal models of surface adsorption were investigated. In past articles, a part of these topics is usually mentioned and there is no comprehensive research that examines all the angles, including the collection of different bio-attractants, kinetics and isotherms.

3. ENVIRONMENTAL EFFECTS OF HEAVY METALS

An increase in the concentration of heavy metals destabilizes the ecosystem because heavy metals enter the food chain through soil or water. Some of these heavy metals are arsenic, chromium, cadmium, lead, nickel, mercury, and zinc. When metal ions become a part of the food chain, there will be a great tendency to increase

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their concentration in living tissues, and when their concentration exceeds the permissible concentration, they cause severe health disorders.

4. CONVENTIONAL METHODS AND ADSORBENTS

Sedimentation is the most common method for removing toxic heavy metals down to parts per million (ppm) levels from water. Other methods include ion exchange, electrocoagulation, cementation, reverse osmosis, and electrodialysis. The primary adsorbents used to remove metal ions are commercial adsorbents. Common adsorbents are activated carbons, ion exchange resins (organic polymer resins), and inorganic materials such as activated alumina, silica gel, zeolites, and molecular sieves.

5. DIFFERENT BIOSORBENTS

New materials of bioadsorbents have been recently noticed due to their high adsorption capacity and their availability in almost unlimited amounts. Algae, bacteria, and fungi can be mentioned among these adsorbents. Algae are divided into several completely independent categories: red algae, brown algae and, green algae. Bacteria are a major group of single-cell living organisms belonging to prokaryotes that exist in soil and water as symbionts with other organisms. Bacteria can be found in many forms such as cocci (such as streptococci), rods (such as Bacillus), spirals (such as Rhodospirillum), and filaments (such as Spharotillus). Fungal cell walls and their components play an important role in biosorption and adsorb suspended metal particles and colloids. Fungi are present in natural environments and important industrial processes. Their most important role is as a decomposer of organic matter, with the cycle of nutrients at the same time as a pathogen and symbiosis with animals and plants. Tables 1and 2 show the adsorption of heavy metals on agricultural waste, fungi, bacteria and algae.

Table 1. Agricultural waste biosorbents for the separation of heavy metal ions

Bioadsorbents	Metal ion	Removal (%)	Maximum adsorption ($mg.g^{-1}$)	References
Peel of banana	Cu(II)	88.94	-	[1]
Peel of banana	Pb(II)	99.79	-	[1]
Bean shell	As(V)	98.75	-	[2]

Table 2. Adsorption of heavy metal ions by algae, fungi and bacteria

Bioadsorbents	Heavy metal ion	Initial concentration (ppm)	Time (min)	pH	T(°C)	Isotherm model	Adsorption capacity (mg.g-1)	References
Chlorella minotissima (green algae)	Zn (II)	392.4	0.5-180	6	28	Langmuir	123.5	[3]
	Mn (II)	219.6	0.5-180	6	28	Langmuir	34.5	
	Cd (II)	67	0.5-180	6	28	Langmuir	303.03	
	Cu (II)	25.4	0.5-180	4	28	Langmuir	16.2	
Saccharomyces cerevisiae (mushroom)	Cu (II)	5-50	60	6	25	Langmuir	9.91	[4]
	Ni (II)	5-200	60	6	25	Langmuir	7.87	
	Zn (II)	5-50	60	6	25	Langmuir	10.99	
Bacillus subtilis (bacteria)	Zn (II)	8	10	6	35	-	99.2	[5]

6. BATCH/CONTINIOUS BIOSORPTION STUDIES

Discontinuous tests evaluate the basic information required, such as biosorbent efficiency, laboratory conditions such as pH, temperature, ionic strength, amount of biosorbent, size of biosorbent, concentration and initial stirring speed, biosorption rate, and the possibility of biomass regeneration. Continuous biosorption is considered the best study to evaluate the technical feasibility of a process for real applications.

7. ADSORPTION KINETICS

Adsorption kinetics modeling is done to determine the amount of biosorption and analyze a specific reaction. Many kinetic models have been used in the removal of pollutants from water and wastewater, including pseudo-first-order, pseudo-second-order, and intraparticle diffusion models. The main kinetic model was the second-order quasi-kinetic model, which represents the chemical adsorption process, in which metal ions adhere to the adsorbent surface by forming a chemical bond (usually covalent).

8. ADSORPTION ISOTHERMS

Adsorption isotherms are investigated to describe the adsorption system. Adsorption isotherm shows the relationship between the concentration of the adsorbed substance on the biosorbent and in the adsorption medium. In most of the numerous studies investigated, adsorption processes using linear forms of one-parameter adsorption isothermal model (Henry), two-parameter adsorption isothermal models (Langmuir, Freundlich, Dubinin-Radushkevich, Temkin, Harkin-Jura and Elovich) and three-parameter adsorption models (Red Peterson) have been reviewed. In general, the main isothermal models used are Langmuir, Freundlich, and Dubinin-Radoshkevych models, and the Langmuir model generally has a better fit with experimental data. The Langmuir model suggests monolayer adsorption on a homogeneous surface without interaction between adsorbed molecules. This model relates the coverage of molecules on a solid surface to the concentration of an aqueous medium when the solid surface is at a constant temperature. In the simultaneous adsorption of heavy metals, a higher adsorption capacity is obtained for a metal that has a lower hydration enthalpy and greater electronegativity. Adsorption of heavy metal ions is largely influenced by the properties of heavy metal ions, such as ionic radius, hydration energy, hydrated radius, and electronegativity, which lead to different adsorption capacities for different heavy metal ions.

9. CONCLUSION

Among the agricultural residues, banana peel showed a high adsorption capacity (99.79% removal) and among algae, fungi, and bacteria, Chlorella minotissima showed a high adsorption capacity of 303.03 mg/g adsorbent for cadmium. The pseudo-second-order kinetic model showed a high correlation coefficient compared to other kinetic models. Hence, it was a chemical adsorption process in which metal ions adhere to the surface of the adsorbent by forming a chemical bond. The Langmuir model mainly has a better fit with the experimental data, which indicates the adsorption of a single layer on a homogeneous surface.

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