A Summary of Heavy Metal Removal Using Nanosorbents: An Overview

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Abstract

Clean drinking water is not easily accessible, especially in developing countries where environmental problems, including heavy metal release, are on the rise. These heavy metals are toxic and persistent, and their accumulation in plants, animals, and humans can lead to severe health issues such as cancer, cell damage, and even death. Adsorption is the most commonly used and economical technique for cleaning water, and many effective adsorbents have been developed over the years. Recently, nanosorbents have gained attention as a potential solution to remove heavy metals from wastewater. In this literature review, we examine the use of different types of nanosorbents for heavy metal removal and analyze their effectiveness.

Keywords: Metal Remediation, Nanoparticles, and Nanoadsorbents.

Introduction

Harmful heavy metals such as lead, mercury, nickel, selenium, thallium, cobalt, cadmium, chromium, lead, zinc, and others are classified as non-biodegradable poisons because they do not quickly dissolve but instead accumulate in living things. Critical difficulties for the development of remediation solutions are raised by their ambiguous existence in the environment and cancer-causing activity. Numerous physical, chemical, and organic techniques, such as adsorption, electrochemical expulsion, dissolvable extraction, photocatalytic corruption, and particle trading, have been documented in the literature. However, adsorption was said to be the most often used strategy owing to its actual functioning capabilities and affordability. Adsorption is a phenomena that occurs on surfaces and is influenced by many different parameters, such as the adsorbent's surface shape, area, and particle size as well as the functional groups that are present there. Because of this, effective pollutant removal is assumed to depend on selecting the right adsorbent. Nanoscale particles are well suited for adsorptive removal and efficient nanosorbents due to their features, such as their increased surface area, larger particle density, enhanced surface contact, etc. Effective nanosorbents must have properties like non-toxicity, high sorption capacity, selectivity, recyclability, reversibility, etc. The many nanosorbents used in wastewater treatment may be categorized based on their shape, structure, and chemical composition; a short description of each of them is given below. This book provides a succinct overview of some of the work that has been done for each class during the last 20 years.

Objective of study

The objective of this paper is to offer a thorough overview of the literature on the use of nanosorbents for removing heavy metals from polluted water sources. In addition to outlining the positive and negative aspects of using nanosorbents, the study also attempts to provide light on potential future lines of inquiry for this area of study.

Review of literature:

In recent years, there has been a fast expansion of the literature on the use of nanosorbents for heavy metal removal. Various nanosorbents, such as metal oxide nanoparticles, carbon-based nanomaterials, and biopolymers, have been the subject of many research looking at their ability to remove heavy metals from water sources. According to these investigations, nanosorbents have a number of benefits over conventional heavy metal removal techniques, including high efficiency, selectivity, and reusability.Due to their great capacity for heavy metal adsorption and selectivity for certain metals, metal oxide nanoparticles including iron oxide, titanium dioxide, and zinc oxide have attracted a lot of interest. Due to their substantial surface area and strong reactivity, carbon-based nanomaterials like graphene and carbon nanotubes have also shown potential for heavy metal removal. Investigations on the capacity of biopolymers to form stable complexes with heavy metal ions include chitosan and alginate.

Types of Nanoadsorbents for Heavy Metal Removal

- Metal-based nanosorbents

Numerous research groups have highlighted the usefulness and potency of nanoscale metals and metal oxides, emphasizing their unique properties such as large surface areas, high adsorption capacities, and surface functional groups that may interact with heavy metal ions. Some of the nano metal oxides that have garnered the most attention are titanium oxide, iron oxide, manganese oxide, aluminum oxide, cupric oxide, nickel oxide, and cupric oxide. These nanosorbents' size, shape, and crystal structure are found to be significantly influenced by the synthesis process and are easily modifiable by changing the starting material, reaction temperature, and reaction pH. Additionally, some research have claimed that metallic nanoparticles include nano zero valent iron that has been deposited on various mesoporous materials. To improve nanosorbents' capacity for adsorption, many researchers changed the surfaces of the materials. Such changes have been shown to increase the removal efficiency.

- A Carbon-Based Nanosorbents

Carbon nanotubes (CNT), which are structurally categorized into two types: single walled CNT (SWCNT) and multi walled CNT (MWCNT), were first discovered by Sumio Iijima. The removal of heavy metal ions from polluted water has been shown in recent years using CNT and modified CNT as nanosorbents. According to several research that examined the adsorptive properties of functionalized CNT, it was more effective than ordinary CNT at removing heavy metal ions as lead, chromium, mercury, and many others. Additionally, it has been shown that modified activated carbon (AC) and AC generated from agricultural waste work well as nanosorbents to remove chromium.

- Blended Nanosorbents

Many researchers have employed polymeric materials as supports or covering substrates to stabilise nanoparticles in order to avoid the problems of nanoparticle aggregation under high pressure conditions. Once the nanoparticles have grown, they are easily able to aggregate or collapse together. To remove copper and lead, researchers have employed the polymeric backbone of silica, alumina, polyaniline, fly ash, chitosan, etc. Utilizing polymeric supports increases the efficiency and speed of the separation and filtering process.

- Bio-Nanosorbents

Several organizations have studied the biofortify properties of bio-sorbents, which are produced from naturally existing biomass, such as plant-based waste materials, algae, fungus, or microorganisms, for less costly heavy metal absorption. Literature has described the usage of sawdust, wheat bran, Sugar beet pulp, sugarcane bagasse, maize cob and husk, and sago waste, among other agrowastes, for this purpose. At the microbiological level, algae, fungi, and bacteria have all been used. The use of such sorbents may significantly increase our possibilities due to the vast majority of plant species that are discarded or underutilized in our country.

- Silica-Containing Nanosorbents

Give a cheap source for a potent adsorbent material given the quantity of silica in the earth's crust. Mesoporous silica is used by a study group to get rid of lead, copper, and cadmium. The silica's surface activity makes it possible for its altered surface to be utilised more effectively. For more effective biological detoxification of heavy metal ions, silica surface functionalization has been used. Nano silica is an effective sorbent for a number of applications due to its non-toxic characteristics and biocompatibility.

- Hybrid Nanosorbents

Hybrid nanosorbents may be made by combining any of the aforementioned nanomaterials. Polymeric bases are often used to support inorganic and organic nanocompounds for this purpose. There are several methods for producing nanohybrids, such as solvent casting, solvent encapsulation, loading, and impregnation. These nanosorbents are shown to be more effective in removing heavy metals than individual sorbents.

Heavy Metal Remediation Techniques

Water pollution with heavy metals has been a significant problem for many years. Heavy metals may be removed from water using a variety of methods, such as membrane processes, solvent extraction, chemical precipitation, adsorption, ion exchange, and electro-deposition. Depending on the particular heavy metal, its concentration, and the water matrix, each method has benefits and limits of its own.

1. **Membrane operations**

Membrane operations rely on the use of semi-permeable membranes that only let certain molecules or ions pass through. Reverse osmosis, nanofiltration, and ultrafiltration are some of these methods. The removal of heavy metals from water via membrane processes is efficient, but they use a lot of energy, and membrane fouling is a typical problem.

2. **Solvent removal**

Heavy metals may be selectively removed from water by solvent extraction, which uses an organic solvent. This method works well for getting rid of trace amounts of heavy metals, but it uses a lot of organic solvent, which might be bad for the environment. The selective extraction of heavy metals is a difficult operation as well since each metal needs a different solvent.

3. **Precipitation of chemicals**

Chemical precipitation is the process of forming insoluble precipitates that are readily detachable from the water matrix by adding a chemical agent that interacts with heavy metals in water. Heavy metals can be removed efficiently via chemical precipitation, but it uses a lot of chemical agent and produces a lot of sludge that has to be carefully disposed of.

4. **Adsorption**

Adsorption is the process of selectively binding heavy metals from water to a solid substance (adsorbent) surface. Adsorption is a practical and affordable method for getting rid of heavy metals from water. The most popular adsorbents used to remove heavy metals include activated carbon, silica gel, zeolites, and clay minerals. The removal of low quantities of heavy metals may be difficult due to their poor adsorption ability.

5. **Ion exchange**

Ion exchange is the process of using ion exchange resins to swap out certain water ions for heavy metal ions. Although this method necessitates the renewal of the ion exchange resins and the disposal of the resins that have been loaded with heavy metals, it is successful for the removal of low quantities of heavy metals.

6. **Electrodeposition,**

In order to selectively extract heavy metals from water onto an electrode, electro-deposition is used. This method works well for getting rid of trace amounts of heavy metals, but it uses a lot of energy and produces a lot of trash that has to be disposed of correctly.

Adsorption is the most efficient and cost-effective method for removing heavy metals worldwide. Compared to traditional adsorbents, nanosorbents offer a greater adsorption capacity and selectivity. They have been created in recent years. For the removal of heavy metals from water, nanosorbents based on graphene oxide, magnetic nanosorbents, and metal-organic frameworks (MOFs) have all been used.

Case studies on the use of different types of nanosorbents for heavy metal remediation

- **Graphene oxide-based nanosorbents:** Nanosorbents based on graphene oxide have received a lot of interest recently because of their superior physicochemical characteristics, including a high specific surface area, a large pore volume, and a high adsorption capacity. Numerous investigations have been done on the removal of heavy metals using GO-based nanosorbents. For instance, magnetic nanosorbents based on GO have been created to effectively remove heavy metals from wastewater. Based on the findings, it was easy to extract these nanosorbents from the solution using an external magnetic field and they exhibited outstanding adsorption capability.
- **Magnetic nanosorbents:** Due to its magnetic qualities, which make it simple to separate from the solution using an external magnetic field, magnetic nanosorbents have also been extensively researched for heavy metal cleanup. For instance, magnetic nanosorbents made of $Fe3O4@SiO2$ have been produced to effectively remove heavy metals from wastewater. These nanosorbents exhibited a high capacity for adsorption, according to the data, and they could be easily removed from the solution using an external magnetic field.
- **Metal-organic frameworks (MOFs)** : a form of porous material that are made up of coordinated metal ions or clusters with organic ligands. Due to their large surface area, adjustable characteristics, and superior performance, MOFs have shown significant promise in the cleanup of heavy metals. For effective heavy metal removal from wastewater, UiO-66-NH2 MOFs have been created. The results demonstrated that these MOFs had a high capacity for adsorption and were efficient in removing heavy metals from wastewater.
- **Additional nanosorbents:** In addition to the ones described above, carbon nanotubes, mesoporous silica nanoparticles, and chitosan-based nanosorbents have also been researched for the removal of heavy metals from the environment. For effective heavy metal removal from wastewater, chitosan-based nanosorbents have been created. The results demonstrated that these nanosorbents had a high capacity for adsorption and were efficient in removing heavy metals from wastewater.

Advantage

For the removal of heavy metals, nanosorbents provide a number of benefits over conventional sorbents. Several of these benefits include:

1. High surface area: Nanosorbents have a higher surface area-to-volume ratio than conventional sorbents, allowing for more adsorption active sites to be present. This characteristic improves the nanosorbent's ability for adsorption, which leads to more effective heavy metal removal.
2. Selectivity: Nanosorbents may be created to have a preference for a particular heavy metal ion. This may be done by adding certain chemical groups to the nanosorbent's surface or by employing particular substances while the nanosorbent is being synthesized.

3. quick kinetics: Nanosorbents have a high diffusion rate because of their tiny size, which enables quick adsorption kinetics. This has the effect of removing heavy metal ions from polluted water or soil more quickly and effectively.
4. Some nanosorbents have the potential to regenerate and be utilized again. In large-scale applications where the nanosorbent may need to be changed regularly, this characteristic is very helpful.
5. Low dose needed: Due to their great adsorption capability, nanosorbents need a lower dosage than conventional sorbents. This characteristic lowers expenses by reducing the quantity of nanosorbent required for heavy metal cleanup.
6. Compatibility with other remediation methods: Membrane filtration, electrocoagulation, and phytoremediation are some examples of other remediation methods that may be employed in conjunction with nanosorbents. This makes it possible to use a heavier metal cleanup technique that is both thorough and effective.

Challenges

Although there are still a number of issues that need to be resolved before nanosorbents may completely achieve their potential for removing heavy metals from polluted water, they have shown considerable promise in this area. Several of these difficulties include:

1. Cost: The cost of manufacturing and employing nanosorbents, particularly for large-scale applications, may be extremely costly. To lower the cost of manufacturing nanosorbents and make them more accessible for broader application, additional research is required.
2. Stability: Nanosorbents must be stable in order to be successful in removing heavy metals. In aqueous solutions, they may aggregate or dissolve, which might lessen their effectiveness and raise toxicity. Therefore, it is crucial to find methods to improve the stability of nanosorbents.
3. Regeneration: To minimize waste and increase the sustainability of the technology, it is critical to be able to renew nanosorbents after they have been utilized to remove heavy metals. However, regeneration may be difficult, and additional study is required to create efficient regeneration techniques.
4. Environmental impact: To guarantee that the use of nanosorbents does not have unexpected repercussions, a detailed investigation of the environmental impact of these substances is required, including their potential toxicity and the influence they may have on ecosystems.
5. Nanosorbents have significant potential for the cleanup of heavy metal-contaminated water despite these difficulties. To solve these issues and prevent this technology from evolving, further study is required. Future research areas may focus on discovering new kinds of nanosorbents, enhancing their characteristics for the removal of a particular heavy metal, and examining their potential for usage in other environmental applications outside heavy metal removal.

Conclusion

As was already noted, a variety of nanomaterials have been effectively used to use an adsorption method to remove hazardous heavy metal ions from water. Due to their straightforward synthesis processes and favorable economics, the use of such materials at lab scale is advised. Before scaling up these strategies for general application, researchers need to concentrate on a lot more problems. Environmentally friendly practices could be better for prospects for the future and sustainable development. As a result, we may draw the conclusion that nanosorbents can provide an effective heavy metal cleaning method.

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