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REMOVAL OF HEAVY METALS FROM WASTE WATER USING LOW-COST ADSORBENTS

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Abstract

Rapid industrialization and urbanization have significantly increased the discharge of heavy metals into water bodies, posing serious environmental and public health risks. Conventional wastewater treatment methods for heavy metal removal are often expensive and generate secondary pollutants. In recent years, the use of low-cost adsorbents derived from agricultural waste, industrial by-products, and natural materials has gained considerable attention as an economical and sustainable alternative. This research paper reviews and analyzes the effectiveness of various low-cost adsorbents such as activated carbon from agricultural waste, fly ash, rice husk ash, sawdust, and biochar for the removal of heavy metals like lead, cadmium, chromium, and nickel from wastewater. The adsorption mechanisms, influencing parameters, and comparative performance of different adsorbents are discussed. The study highlights that low-cost adsorbents can achieve significant removal efficiencies, making them suitable for practical wastewater treatment applications.

Keywords: Heavy metals, wastewater treatment, adsorption, low-cost adsorbents, sustainable water management

I. INTRODUCTION

Water pollution due to heavy metals is a major environmental concern worldwide. Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and mercury (Hg) are non-biodegradable, toxic, and tend to accumulate in living organisms. Industrial effluents from electroplating, mining, battery manufacturing, leather tanning, and textile industries are primary sources of heavy metal contamination in wastewater.

Exposure to heavy metals can cause severe health problems including neurological disorders, kidney damage, cancer, and developmental issues. Therefore, effective removal of heavy metals from wastewater before discharge is essential to protect ecosystems and human health.

Traditional treatment methods such as chemical precipitation, ion exchange, membrane filtration, and electrochemical techniques are effective but often involve high operational costs, complex maintenance, and sludge generation. Adsorption has emerged as a promising alternative due to its simplicity, efficiency, and economic feasibility. In particular, low-cost adsorbents derived from waste materials offer an environmentally friendly solution by converting waste into valuable resources.

II. SOURCES AND IMPACT OF HEAVY METALS IN WASTEWATER

Heavy metals enter wastewater through various anthropogenic activities. Industrial processes such as metal finishing, electroplating, pigment production, and fertilizer manufacturing contribute significantly to heavy metal pollution. Urban runoff and landfill leachate also act as secondary sources.

The environmental impacts of heavy metals include toxicity to aquatic life, bioaccumulation in food chains, and long-term degradation of water quality. Even at low concentrations, heavy metals can be harmful due to their persistence and cumulative effects. Hence, stringent discharge standards have been imposed by environmental regulatory bodies worldwide.

III. ADSORPTION AS A TREATMENT TECHNIQUE

Adsorption is a surface phenomenon in which pollutants adhere to the surface of a solid material. It is widely used for wastewater treatment due to its high efficiency and ease of operation. The effectiveness of adsorption depends on factors such as surface area, pore structure, functional groups, and affinity between adsorbent and adsorbate.

Low-cost adsorbents are particularly attractive because they are inexpensive, readily available, and often derived from waste materials. These adsorbents can be natural, agricultural, or industrial by-products and can significantly reduce treatment costs.

IV. TYPES OF LOW-COST ADSORBENTS

Agricultural Waste-Based Adsorbents

Agricultural wastes such as rice husk, coconut shell, banana peel, and sawdust have been widely studied for heavy metal adsorption. These materials contain cellulose, lignin, and functional groups that enhance metal binding.

Rice husk ash has shown high adsorption capacity for lead and chromium due to its silica-rich composition. Sawdust has demonstrated effective removal of cadmium and copper owing to its porous structure and surface functional groups.

Industrial By-Products

Industrial by-products such as fly ash, blast furnace slag, and red mud are generated in large quantities and pose disposal challenges. Utilizing these materials as adsorbents not only treats wastewater but also reduces solid waste problems.

Fly ash has been found effective in removing lead and zinc due to its high surface area and alkaline nature. Red mud exhibits strong affinity for chromium and arsenic removal.

Natural Adsorbents

Natural materials such as clay, zeolite, and laterite soil have been used as low-cost adsorbents. These materials possess ion exchange properties and large surface areas, making them suitable for heavy metal adsorption.

V. FACTORS AFFECTING ADSORPTION EFFICIENCY

pH of Solution

pH plays a crucial role in heavy metal adsorption. Most metals show higher removal efficiency at neutral to slightly alkaline pH levels. At low pH, competition between hydrogen ions and metal ions reduces adsorption.

Contact Time

Adsorption efficiency increases with contact time until equilibrium is reached. Initial adsorption is rapid due to the availability of vacant sites, followed by a slower phase.

Adsorbent Dose

Increasing the adsorbent dosage generally enhances metal removal efficiency due to the availability of more adsorption sites.

Initial Metal Concentration

Higher initial metal concentrations increase the adsorption capacity but may reduce percentage removal due to site saturation.

Adsorption Mechanisms

The adsorption of heavy metals onto low-cost adsorbents occurs through various mechanisms including physical adsorption, chemical adsorption, ion exchange, and complexation. Functional groups such as hydroxyl, carboxyl, and amino groups play a significant role in binding metal ions.

Comparative Performance of Low-Cost Adsorbents

Studies have shown that agricultural waste-based adsorbents can achieve removal efficiencies of 70–95% for heavy metals under optimized conditions. Industrial by-products exhibit comparable performance, particularly for chromium and lead removal. Natural adsorbents are effective but may require modification to enhance efficiency.

Overall, modified low-cost adsorbents often show improved adsorption capacity compared to raw materials.

VI. ADVANTAGES AND LIMITATIONS

Advantages

- Low cost and easy availability
- Environmentally friendly and sustainable
- High removal efficiency
- Reduction of solid waste disposal problems

Limitations

- Lower adsorption capacity compared to commercial activated carbon
- Need for regeneration and disposal of spent adsorbents
- Performance variability due to material heterogeneity

VII. CONCLUSION

The removal of heavy metals from wastewater using low-cost adsorbents is a promising and sustainable approach for water pollution control. Agricultural wastes, industrial by-products, and natural materials have demonstrated significant potential for heavy metal adsorption. Factors such as pH, contact time, and adsorbent dosage greatly influence removal efficiency. Although some limitations exist, low-cost adsorbents offer an economical alternative to conventional treatment methods, especially for developing countries. Further research should focus on adsorbent modification, regeneration techniques, and large-scale application to enhance practical feasibility.

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