A Review on the Removal of Heavy Metal Ions from Wastewater Using Ion Flotation with Graphene Oxide and Functionalized Graphene Oxide Nanocollectors

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ABSTRACT

The development of technology has led to an increase in heavy metal pollution due to their high toxicity and detrimental effects on human health and the environment. Various methods exist for the removal of heavy metals from wastewater. Among them, ion flotation is an efficient technique for the removal of heavy metal ions from aqueous solutions, offering high efficiency and low operational costs. This method has the potential to remove both inorganic and organic anions and cations, and it is considered one of the most advanced wastewater treatment technologies. In recent years, the use of graphene oxide nanocollectors and functionalized graphene oxide in this process has attracted significant attention. These nanocollectors exhibit remarkable performance in removing heavy metal ions from wastewater due to their high specific surface area, good stability, ease of synthesis, high efficiency, and reusability. Studies have shown that surface modification of graphene oxide with appropriate functional groups improves selectivity and enhances the efficiency of ion flotation. This article reviews recent advances in the removal of heavy metal ions from wastewater using ion flotation. It also explores adsorption mechanisms, the influence of various parameters, and optimization methods for the ion flotation process using graphene oxide and functionalized graphene oxide nanocollectors, and offers suggestions for future research on graphene-based nanocomposites and natural adsorbents.

KEYWORDS

Ion Flotation, Graphene Oxide, Adsorption Mechanism, Desorption, Heavy metal ions.

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1. Introduction

With their rapid development, various industrial sectors have increasingly caused environmental problems that adversely affect living organisms and natural ecosystems. One of the most significant issues is the generation of large volumes of wastewater contaminated with heavy metals, which, due to their high solubility in aquatic environments, pose a serious threat to all living organisms. The most common pollutants classified as heavy metals include cadmium, zinc, lead, chromium, nickel, copper, vanadium, platinum, silver, tin, mercury, arsenic, and titanium, all of which are characterized by a density equal to or greater than 5 g/cm^3 [1, 2].

Various methods have been employed to remove heavy metals from industrial, mining, and domestic wastewater, including coagulation and flocculation, adsorption, electrochemical precipitation, chemical precipitation, membrane filtration, reverse osmosis, and advanced oxidation processes [3, 4]

One of the most efficient methods for removing heavy metals from aquatic environments is flotation. This technique offers several advantages, including nearly 100% removal, low operational costs, a simple process, high selectivity, and short residence time. Flotation has been widely applied in wastewater treatment for the removal of heavy metals. Various flotation techniques, including froth flotation, dissolved air flotation (DAF), ion flotation, and precipitate flotation, have been employed to remove metal ions from aqueous solutions [4, 5].

2. Ion flotation

Ion flotation was first introduced in 1959 by Sebba for the removal and separation of aluminum ions. Ion flotation is recognized as one of the most suitable methods for the removal of inorganic and organic anions and cations from aqueous solutions [6, 7].

One of the drawbacks of the ion flotation method is the high consumption of collectors and chemical reagents. In order to achieve nearly complete removal of the target species using this technique, the minimum effective collector concentration must be at least equal to the 1:1 stoichiometric ratio with the target ion and lower than the critical micelle concentration (CMC) of the collector. Collectors play a crucial role in ion flotation. In recent years, nanocollectors have been employed in ion flotation processes. Graphene oxide (GO), as a nanocollector with unique properties, exhibits high potential for application in ion flotation [6, 8]

The use of GO as a collector in the ion flotation process has demonstrated high efficiency in the removal of heavy metal ions from wastewater. One of the key challenges associated with the application of these nanocollectors is their reuse in successive treatment cycles. Table 1 presents a summary of the results obtained from various studies on the use of graphene oxide and functionalized graphene oxide nanocollectors for the removal of heavy metal ions via the ion flotation method.

Table 1. A summary of ion flotation studies using graphene oxide and functionalized graphene oxide nanoco

Ions	Nanocollector	Removal (%)	References
Pb	GO	99	[9]
Ni	AFGO	100	[6]
Cu	GO	99	[10]
Cu	AMID@GO	99	[11]
Pb	IDA@GO	95	[12]
Heavy metal ions	FGO	95-99	[13]
Zn	GO	90	[14]
Mn	GO	89.4	[15]
Cr	GO	86	[16]
Zn and Mn	GO	90-91	[17]

3. Challenges with the use of GO as a collector

There are numerous challenges associated with the industrial-scale application of ion flotation using graphene-based collectors; these challenges include the following:

After the ion flotation process, the desorption and recovery of the graphene oxide nanoparticles used in the process can pose a technical challenge. If these nanoparticles are not properly desorbed and recovered, they may themselves become a new environmental contaminant, leading to increased operational costs. One of the major challenges of the ion flotation process is its scalability from laboratory-scale studies to a continuous industrial process. Another existing challenge is the actual ion removal efficiency when treating real industrial wastewater. Additionally, the use of graphene and graphene oxide nanoparticles is limited by their high production costs, which are particularly complex and expensive at the industrial scale. Furthermore, the potential toxicity of graphene-based nanoparticles to human health and the environment has not yet been fully understood.

Future research could focus on developing new methods and collectors with higher ion adsorption capacities to minimize collector consumption and make the process more economically viable. In the field of heavy metal ion removal, evaluating the performance of nanocollectors under real and industrial wastewater conditions, as well as assessing their selectivity in multi-ion environments, are aspects that have not been thoroughly addressed in some previous studies. Therefore, it is recommended that these aspects be comprehensively investigated in future research.

For future research in the field of heavy metal ion removal, the use of graphene/metal oxide photocatalytic nanocomposites, graphene/natural adsorbent hybrids, and the investigation of the effect of graphene surface oxidation intensity should be considered. In all existing studies, graphene oxide and functionalized graphene oxide nanoparticles have been examined as collectors, whereas nanostructures such as bentonite, montmorillonite, and molybdenite nanoparticles also possess the necessary potential to be used as nanocollectors due to their unique physical and chemical properties.

4. Conclusions

The use of graphene oxide and functionalized graphene oxide nanocollectors in this process demonstrates remarkable performance in the removal of heavy metal ions from wastewater, owing to their high specific surface area, suitable stability, ease of synthesis, high efficiency, and reusability. Investigating the adsorption mechanisms, the effects of process parameters, and optimization methods indicates that surface functionalization of graphene oxide with appropriate functional groups enhances both the selectivity and the removal efficiency of ions from aqueous solutions via ion flotation. Research findings have shown that these nanocollectors exhibit high potential for the removal of ions such as copper, lead, nickel, zinc, manganese, and cadmium. Despite the significant advantages of ion flotation, challenges such as high collector consumption and the feasibility of industrial-scale implementation still remain. Future research could focus on developing new collectors with higher adsorption capacities, reducing chemical usage, and improving operational conditions, in order to establish this method as a sustainable and cost-effective solution for industrial wastewater treatment.

5. References

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