Research Progress of Treatment Method of Metal Ion in Wastewater

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Abstract. Along with the rapid development of urbanization in China, a series of environmental problems have accompanied, especially industrial effluents containing heavy metals such as lead, cadmium, mercury, etc., which have caused great damage to water, soil and earth, and have caused great harm to human health. In this article, new processes such as adsorption, membrane separation, chemical precipitation, ion exchange, bio-adsorption, and bio-reduction are introduced. The technology has shown excellent results in a variety of working conditions, opening up new ways for the treatment of heavy metal pollution in water. The development of this topic is of great and urgent practical significance for the protection of ecological environment and the promotion of sustainable development in China.

Keywords: Wastewater, metal ion, removal techniques.

1. Introduction

In the process of large-scale industrialization and urbanization in China, the discharge of sewage has attracted widespread attention. Organic pollutants, nitrogen, phosphorus, heavy metals and organometallic compounds are important factors affecting the effectiveness of sewage treatment. In these water bodies, heavy metals are an important pollutant, which cause great harm to the surrounding environment and ecology. Among them, harmful ions such as Cu, Cd, Pb, Zn, Hg, etc., even if only a very small amount of Cu, Cd, Pb, Zn, Hg, etc., are present in domestic sewage, will gradually accumulate in the water, thus causing a series of environmental problems. In addition, these metal ions have the potential to enter the human body through the food chain, potentially posing a health hazard that could lead to diseases of the nervous system, liver and several other organs. Therefore, the problem of metal ion pollution needs to be given great attention and effectively addressed [1].

How to efficiently remove heavy metal elements from wastewater has become a hotspot and difficulty in current environmental research. To solve this problem, a variety of wastewater treatment technologies have been proposed, mainly including physical, chemical and biological methods. In terms of physical methods, adsorption is a commonly used technique for metal ion removal, which can efficiently remove metal ions from wastewater by adsorption through the selection of suitable adsorbents, such as nanomaterials, graphene oxide, etc. [2]. Recent research advances have shown that some novel nanomaterials such as metal-organic framework materials (MOFs) and two-dimensional materials (e.g., two-dimensional graphene oxide) exhibit higher adsorption capacity and selectivity in adsorption of metal ions [3]. In terms of chemical methods, the chemical precipitation method precipitates metal ions into solid particles by adding appropriate precipitating agents, followed by solid-liquid separation [1]. In the sewage treatment process, a method of ion exchange is used whereby a new ion is substituted in its place in the sewage treatment process [3]. These methods are also effective in removing metal ion contamination under certain circumstances. In terms of biological methods, biosorption and bioreduction utilise microorganisms or biomaterials in living organisms, such as bacteria and algae, to interact with metal ions and remove them from solution or reduce them to less soluble forms [4]. These biological methods can, to some extent, improve the environmental friendliness of wastewater treatment and reduce the use of chemicals. In addition to this, in terms of membrane separation technology, researchers are continuing to optimise the structure of membrane materials to improve the retention efficiency of metal ions [2]. Electrochemical methods

also show potential in metal ion removal, and researchers are deeply exploring their reaction mechanisms to achieve more efficient wastewater treatment [4].

This article will systematically introduce physical technology, chemical technology and biological technology for the removal of metal ion.

2. Physical Technology

Physical technology methods utilise differences in the physical properties of substances to achieve pollutant removal without the need for chemicals, easy to operate and low energy consumption. It is widely used for organic matter, inorganic salts, heavy metals and other pollutants, with high removal efficiency, reduced by-products, environmental friendliness and sustainability.

2.1. Adsorption

The adsorption method, is based on the principle that metal ions in wastewater are adsorbed onto its surface by adsorbents to achieve effective removal. The choice of adsorbent is crucial, and common adsorbents include graphene, activated carbon, ion exchange resin, oxides, porous materials, polymers, etc. These adsorbents have different adsorption properties and characteristics, and suitable adsorbent materials can be selected according to the types and concentrations of pollutants in wastewater. The mechanism of adsorption can be categorized into chemisorption and physisorption based on chemical bonding and non-covalent interactions respectively, which helps to achieve efficient removal of pollutants of different natures.

Polymerized pyrrolidone (PPy) can be used as an adsorbent material due to its conductivity and hydrophilicity. According to Krason et al., polymerized porous polymers modified with polymerized pyrrolidone exhibited excellent copper ion removal performance with adsorption capacity up to 172.4 mg/g. Zhang et al. demonstrated that modified graphene adsorbent exhibited excellent adsorption performance for lead ions at pH 6 with an adsorption capacity of up to 200 mg/g, which significantly outperformed the conventional adsorbent [1].

2.2. Membrane Process Separation

Membrane Process Separation, the basic principle of which is the effective separation of metal ions from other components of wastewater through the selective permeability of membranes. This method is based on mass transfer and diffusion processes on membranes, and also, the metal ions in it were separated. Membrane separation technology involves a variety of materials and techniques such as microfiltration, ultrafiltration, nanofiltration and reverse osmosis membranes [2].

2.2.1. Microfiltration membranes

Microfiltration membranes are usually made of porous materials and are used to separate larger molecules, particles and suspended substances by means of screening. Researchers such as Zhang et al. conducted a study on polyamide microfiltration membranes in the removal of heavy metal ions. The results of the study showed that this microfiltration membrane has a very high removal efficiency of lead ions in wastewater treatment, thanks to its microporous structure, which effectively prevents the permeation of lead ions, allowing the removal rate to reach more than 90%. This study provides an effective technological way for wastewater purification [3].

2.2.2. Ultrafiltration membranes

Moarefian etal used a polyethylene glycol sulfonate-based film to remove copper from sewage. Experiments proved that the composite film had good selective permeability to copper ions, and its removal rate of copper-containing sewage could reach more than 98%. Meanwhile, the stability of the film was proved through repeated tests. The implementation of this project will lay the foundation for the development and application of sewage deep purification technology [4].

2.2.3. Nanofiltration membranes

Nanofiltration membranes, as a novel separation technology, have an important role in the removal of various organics and some metal ions from water bodies. Recently, Gebru et al. used polyether ester nanofiltration membranes for the separation of heavy metal ions from water bodies. It was demonstrated that this new porous film has good pore size and molecular sieve properties, especially for Cr adsorption, which reached more than 90%. The implementation of this project will lay the foundation for the application of nano-filtration technology in the treatment of heavy metal ions in water, and will also provide key technical support for solving the environmental problems in China's water environment. The innovation of this technology will not only play a positive role in promoting environmental protection, but also play a positive role in promoting water quality management in the future [5].

2.2.4. Reverse osmosis membranes

Reverse osmosis, as an effective water treatment method, has been applied to the separation of various dissolved pollutants in water. In recent years, Kheriji and other scholars have carried out a systematic study on the Cd adsorption characteristics of polysulfide membranes, and found that polysulfide membranes are highly effective in removing Cd, with a removal rate of more than 95%. This project will reveal the excellent performance of RO in Cd ion removal and lay a theoretical foundation for the development of Cd ion removal technology. The successful implementation of this project will lay a theoretical foundation for the application of RO in water bodies, and will also lay a foundation for the treatment and utilization of RO in water bodies.

3. Chemical Technology

The chemical technology method utilises chemical reactions to achieve wastewater treatment, and efficiently removes organic matter, heavy metals and other pollutants by adding appropriate agents to make the pollutants undergo precipitation, oxidation, reduction and other reactions. With its precise control and strong adaptability, it can effectively transform pollutants in wastewater into harmless substances and achieve deep purification. With flexibility and high treatment efficiency in wastewater treatment, chemical technology methods are an important means of solving specific pollution problems and provide strong support for environmental protection [6].

3.1. Chemical Precipitation

Chemical precipitation, the core principle of which is to remove metal ions from wastewater by adding appropriate chemical reagents that react with the reagents to form insoluble precipitates. The method relies on a reaction equilibrium by adjusting parameters such as pH, reagent concentration and reaction time. Chemical precipitation methods can be classified as alkali metal precipitation, sulphide precipitation and hydroxide precipitation based on the chemical reagents used and the type of reaction [7]. In the process of use, depending on the type and content of heavy metals contained in the wastewater, the appropriate sedimentation method should be selected in order to achieve the reduction of the impact of heavy metals on the ecosystem.

3.1.1. Alkali metal precipitation method

Alkali metal precipitation methods often use sodium hydroxide (NaOH) and potassium hydroxide (KOH) as reagents for adjusting the pH of the wastewater and inducing the formation of precipitates from metal ions [8].

3.1.2. Sulphide precipitation methods

Sulphide precipitation methods are often employed to remove copper ions from water. Studies have demonstrated that hydrogen sulphide gas (H_2S) or hydrogen sulphide salt reagents (e.g., sodium sulphide) can react with copper ions to produce copper sulphide precipitates that are insoluble in water. Brockman and his team used sodium sulphide to treat wastewater containing 50 mg/l of copper

ions, and the results showed that the copper ions were removed with a removal efficiency of approximately 85%. This approach has significant potential for removing copper contamination from wastewater [9].

3.1.3. Hydroxide precipitation method

Mella and other scholars used NaOH as a chemical agent, which can effectively remove Cr from water with a removal rate of up to 98 per cent. This approach provides an efficient and feasible solution for the treatment of chromium contaminated wastewater. On the other hand, the hydroxide precipitation method performed well in treating wastewater containing iron ions with a removal rate of more than 95% [10].

3.2. Ion substitution Technology

The core idea is to use solid ion exchangers to replace heavy metals in water and to achieve efficient removal of heavy metal ions from water by adsorption on their surfaces. Based on this, the project will also systematically investigate the migration and transport of a variety of metal ions and their adsorption properties in the aqueous system. It was shown that the fabricated composites had excellent adsorption properties for Cu ions up to 105.2 mg/g at pH of 5 [12].

4. Biotechnology

Bioprocess is an efficient and environmentally friendly wastewater treatment technology, helping to maintain environmental health and sustainability by effectively improving the quality of wastewater through the adsorption and purification of microorganisms, plants, and other organisms. By means of biosorption, degradation, and transformation, these organisms convert hazardous substances in wastewater into safer forms, thus mitigating negative impacts on the natural environment and supporting the sustainable use of water resources. This approach, also commonly referred to as "biological wastewater treatment technology". The biotechnological approach utilises biological resources found in nature, such as organisms like bacteria, algae and plants, which are capable of interacting with pollutants in wastewater in a highly specific manner to achieve specific adsorption, reduction or transformation of wastewater. Of particular note is the ability of these organisms to interact with metal ions in the effluent in a specialized manner, thus effectively reducing the concentration of harmful substances in the effluent. The key to this biotechnological approach is to utilise the biodiversity of nature to combat pollution problems and achieve efficient removal of toxic substances through the specific reactions of organisms. This not only helps to improve the quality of the environment, but also provides an environmentally friendly and sustainable solution for ecosystem restoration. Therefore, biotechnological approaches have important application prospects in wastewater treatment and environmental protection [13].

4.1. Biosorption

The main mechanism is to use microorganisms, biomass or their metabolites as adsorbent materials, and use the interaction between microorganisms and heavy metals to achieve efficient removal of heavy metals. Bio absorption technology can be divided into microbial absorption method and biomass absorption method according to the type of organisms or organisms they use. This new technology makes full use of the unique characteristics of microorganisms to achieve efficient and stable adsorption and immobilization of heavy metal ions in wastewater, which is of great practical significance for improving the quality of wastewater treatment and reducing heavy metal pollution. Through the biological activity and adsorption capacity of microorganisms, this technology effectively reduces the harm of harmful substances to the environment and ecosystems, improves the efficiency of wastewater treatment, provides strong support for environmental protection and sustainable development, and opens up a new prospect for the sustainable use of clean water resources and the effective treatment of wastewater pollution.

4.1.1. Microbial adsorption

Microbial adsorption is a process of adsorption and chelation of metal ions using active microorganisms, such as bacteria, algae and fungi, which interact with metal ions through specific functional groups on their cell surfaces. In microbial adsorption studies, it is commonly observed that the adsorption capacity of bacteria for lead ions varies between 5 and 300 mg/g. As an example, Gundogdu et al.'s research team used a microbial strain called Bacillus subtilis for lead ion adsorption, which was shown to adsorb lead ions at about 100 mg per gram. This process not only helps to clean up metal contamination in wastewater, but also demonstrates the potential of microbial applications in environmental governance [13].

4.1.2. Biomass adsorption

Biomass adsorption is a method that uses biomass such as plants, mycelium, algae and other living organisms' substances, using their cell walls or cell tissues with functional groups such as polysaccharides and proteins, to interact with the metal elements and thus adsorb them from the sewage and then remove them from the wastewater. Ni ions from sewage were absorbed by using seaweed bioenergy by Srivastava et al. The experiment proved that algal biomass has good absorption performance for heavy metal ions, and its absorption capacity can reach up to 28.7 mg/g. This technology can not only reduce the heavy metal content in sewage, but also provide a new idea for environmentally friendly sewage treatment [14].

4.2. Biosorption

Bioreduction, the basic principle of which is the reduction of metal ions in wastewater to solid metal precipitates through the metabolic process of microorganisms. In this process, the microorganisms use the organic matter in the wastewater as an electron donor to reduce the metal ions to elemental metals and precipitate them on the cell surface or in the extracellular environment to achieve removal [15].

4.2.1. Precipitation of metal sulphides

Sulphate-reducing bacteria reduce metal ions in wastewater to metal sulphide precipitates using hydrogen produced by the metabolism of organic matter. Jalali K K et al. used sulphate-reducing bacteria to reduce copper ions in wastewater to copper sulphide precipitates. Tests have proved that, as long as the appropriate process parameters are selected, the removal rate of copper salts by this process can reach more than 90% [15].

4.2.2. Solid metal precipitation

The solid metal precipitation method removes heavy metals by converting metal ions into solid metal precipitation. Liu et al. showed that modified graphene adsorbent exhibited excellent adsorption performance for lead ions at pH of 6, with an adsorption capacity of up to 200 mg/g, which significantly exceeded that of the conventional adsorbent.

5. Summary

Efficient removal of heavy metal ions from wastewater is of vital importance for maintaining ecological balance and safeguarding human health. Heavy metal pollution not only poses a threat to water bodies and ecosystems, but also may cause a series of health problems. Therefore, finding effective solutions to remove heavy metals from wastewater is one of the urgent tasks for current and future environmental protection. This endeavour will help to ensure a clean water supply and reduce negative impacts on ecosystems, while safeguarding the health and sustainable development of human society. This paper intends to systematically review different types of wastewater treatment processes in terms of adsorption, membrane separation, chemical precipitation, ion exchange, biological adsorption and biological reduction, with a view to laying the foundation for the development and application of wastewater treatment technologies.

Adsorption of heavy metal ions using adsorbents is highly efficient and simple, and is suitable for deep purification of low-toxicity sewage. Membrane method can carry out efficient removal of tiny particles and metal ions, but it is widely applicable and the operation process is cumbersome. Chemical precipitation is a simple, can be used for higher levels of heavy metal pollutants, but in the use of the process must be generated by the appropriate treatment of the precipitate. Ion exchange is used in the separation of some specific metals, but they must be treated. Microbial adsorption and reduction are a good treatment method, but its application is narrow.

The integration and innovation of this technology is the future development direction of this field, and it is also an urgent problem to be solved in this field. The implementation of this project can lay the foundation for the effective treatment of water, air, liquid and gas pollutants in China's water ecosystems, as well as the sustainable development of water and air ecosystems.

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