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Application of nanoparticle technology in water and wastewater treatment: A Mini-Review

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Abstract

Water is the superlative important substance for human life. Water has been the only element that cause gave rise to life for human civilizations from the beginning until now. Many different methods have been used to treat water to date. These mentioned nanoparticles are used for three groups of pollutants such as pesticides, microorganisms, and heavy metals. This review article summarizes the recent achievements of nanotechnology in the field of water and wastewater treatment by reviewing recent international library and descriptive articles. Nanoscience with its increasing progress in recent years regarding nanotechnology of water and wastewater treatment compared to some common treatment methods has had effective and efficient effects. Nanomaterials with unique properties with commercial products, nano photocatalysts, metal oxides and active membranes are widely used. Of course, for large-scale and industrial use, there is still room for improvement. New technologies will also enable the recycling and reuse of materials, energy and water. In the new nanotechnology, by using various methods, water can be recycled from polluted effluents for agricultural, industrial and even domestic uses. Also, the use of nanotechnology in order to reduce the adverse effects of the environment is considered as one of the management solutions and nanotechnology is known as compensating for environmental damage caused by industrial waste.

Keywords: Nano-composite, wastewater treatment, Disinfection, Nanomembranes.

1 Introduction

Water is one of the most essential elements of life on Earth, and although more than 70% of the earth's surface is covered with water, less than 3% of it is freshwater (1-4). The availability of safe and clean water is one of the most important issues facing human beings, and gradually as the amount of water consumption increases, pollutants also cause contamination of water resources in various ways, and this issue will become more critical in the future (5-7). Contaminated water contains unwanted and harmful substances and this affects water quality. Undoubtedly, such water is unsuitable for use (8). Methods of pollution of water resources includes commercial, residential, industrial activities, agricultural lands, etc. Sewage characteristics are very diverse and depend on the source of wastewater production, which includes pathogenic or non-pathogenic, organic and inorganic microorganisms. Today, various physical, chemical and biological treatment processes are used for water and wastewater treatment, each of which has advantages and disadvantages (9-14). Nanotechnology has found various applications in various industries in the short time since its emergence. As a result, the water industry, as one of the foundations of life, is no exception and in its various parts, including the construction of dams, protection of water transmission pipelines, water and wastewater treatment, water desalination, etc., nanotechnology is used (15,16). Nanomaterials are usually defined as materials with dimensions smaller than 100 nanometers in at least one dimension. In this dimension of the scale, some of the new properties depend on the size, such as high surface-to-volume ratio, reactivity, high solubility, and nanoparticle adsorption capacity (16). A review of research activities around the world shows that water treatment is one of the most important areas of application of nanotechnology in the water and wastewater industry, and by using it, water treatment costs will be significantly reduced. In this research, by reviewing recent articles, the use of nanotechnology in wastewater treatment has been briefly introduced.

2. Materials and Methods

The use of nanomaterials in wastewater treatment can be used in various forms such as catalyst, adsorbent, catalytic membrane, bioactive nanoparticles, biometric membrane, polymer and nanocomposite membrane, and so on. This study is a review by searching reputable Iranian and international databases including Science Direct, Elsevier, Spring Link, PubMed Central, BioMed Central, CIVILICA, Magiran, Google Scholar

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2.1 Absorption: Nanoscopic

The use of nanomaterials has two other main advantages as adsorbents over activated carbon: First, it can be synthesized easily and cheaply. Second, smaller amounts of these nanomaterials are required to effectively remove contaminants. For this reason, it is expected that in the future, the use of nanomaterials in adsorption applications will be more economical than activated carbon.

2.2 Water and wastewater treatment through Nanomembranes

Nanofiltration membranes are one of the latest advances in membrane technology. Today, nanofiltration is used in various stages of the water treatment process, such as reducing the hardness and amount of water salts, decolorizing and removing microbial and chemical contaminants. Nanofiltration is a form of filtration that uses membranes to separate various fluids or ions. Nanofiltration is referred to as milder reverse osmosis because, it has larger membrane cavities than reverse osmosis membranes. Because these membranes operate at much lower pressures and pass through some minerals, NF can be used in cases where high removal of organic matter is required as well as in medium removal of minerals. The advantage of this method over reverse osmosis is that nanofiltration usually works at higher recycling rates, thus saving total water consumption due to lower concentration flow rates. Nanofiltration has created optimal conditions in terms of energy cost and ion repellency and pore dimensions, among other methods (17). Nanofilter is a semi-permeable membrane that is located between reverse osmosis and ultrafiltration processes and is used to separate carbon-based organic particles including microbial contaminants and polyvalent ions (18-20).

2.3. Water and wastewater treatment through Nanocatalysts

High efficiency, economic efficiency, low chemical waste, low heat and energy consumption, high safety and optimal use of raw chemicals are the advantages of nanocatalyst. For economical saving and optimal use of nanocatalysts, it is usually makes of composite and its surface is chemically modified. High active levels and excellent selectivity in nanocatalysts increase the reaction rate and efficiency. Nanocatalysts have the advantages of homogeneous (high level) and heterogeneous (separable) catalysts. Nanocatalytic structures are very diverse; It is also easy to separate and change their function by chemical modification. Neutral iron nanoparticles (NZVI) are used for on-site and off-site treatment of groundwater. It is both an adsorbent and a reducing agent, it also causes organic contaminants to be broken down into carbon compounds with less toxicity, and the agglomerated heavy metals to adhere to the soil surface. NZVI can be injected directly into groundwater sources for wastewater treatment, or it can be used in membranes for external applications (21).

2.4 Nanostructured catalytic membranes

These porous materials are made of silicon oxide, alumina and a special compound called zeolites. Recently, in some research studies, zeolites have been used whose porosity dimensions are around nano. In new nanoporous materials, the dimensions of the pores and pores of these materials are about 5 to 40 nanometers. Porosity can be regular or irregular. According to extensive research on porous nanomaterials, the scientific principles governing the production of these materials have been largely determined, so that researchers are now able to produce regular porosities with specific and uniform geometry and with predetermined dimensions for the required engineering applications.

Molecular separation in membranes make the molecular selection with great precision in the catalytic process in porous materials. Nanoporous materials have been found in abundance in nature in biological systems and in minerals and have long been used in various industries. Recent advances in nanoscale scientific understanding and manipulation have changed the way these materials are used, which is the use of the intrinsic properties of these materials, and have led to guided designs to obtain the required properties. An important example of this material is the different types of membranes whose size control over porosity has been increased to atomic accuracy (22). A summary of the capabilities of some nanoparticles in water and wastewater treatment to remove some contaminants is shown in Table 1.

Table 1. Introduction some of nanoparticles in the removal of some pollutants (7)

Type of Nanoparticle	Type of pollutants removed
Photocatalysts	Removal of Microbes, Removal of Inorganic Contaminants, Removal of Organic Contaminants, Removal of Heavy Metals.
Nanofiltration	Water softening, types of particles typically, Removed Removing Salts.
Nano Scale metal Oxide	Heavy metals Radionucleides
Nanosorbents (Carbon Nanosorbents, Biosorbents, Metal Oxide Nanosorbents, Zeolites as Sorbents)	Removal heavy metal ions

2.5 Separation and physical adsorption

Nowadays, more attention has been paid to the adsorption process as an efficient and useful method for removing heavy metals and pollutants compared to other mentioned technologies. Adsorption is a mass transfer process in which the material to be adsorbed is separated from the environment by an adsorbent based on physical or chemical methods. Nanomaterial adsorption process with many advantages such as low operating costs, elimination of clogging and sedimentation problems (in membrane processes), economical and cost-effective, easy to use and design, flexibility, non-production of toxic and dangerous pollutants and convenience in large-scale generalization is a promising alternative to traditional methods (19,23). In adsorption using nanomaterials, adsorbents can be easily reduced during the reversible and desorption process and prepared for later use. Several different methods (thermal, pressurized and electrochemical) are available to reduce the adsorbents. Various adsorbents have been developed to remove heavy metals and contaminants from water and wastewater, but in the meantime, attention to two key factors: cost-effectiveness and technical applicability have a great impact on the selection of adsorbents suitable for heavy metal treatment. In general, an ideal adsorbent should have properties such as area, large surface area (high adsorption capacity), proper distribution of pore size and volume, mechanical stability, adaptability, easy reduction, accessibility, cost-effective, environmentally friendly, ease of operation, It has high absorption speed and high selectivity. In addition to adsorption, membrane separation is an important step in water treatment that provides access to water from unusual sources such as municipal wastewater. Contamination separation by membrane separation method is basically based on size (24).

2.6 Nanoparticles as disinfection

The last step in water treatment is the removal of very small organisms. Chlorine is currently used as a disinfectant, but even after purification, there will be a lot of organic compounds in the water. Chlorine removes microorganisms from water, but reacts with organic pollutants to produce non-degradable and toxic by-products that cannot be removed from water. The transfer of these substances to the environment and their use in agriculture and other industries can cause dangerous health problems. Some nanoparticles, especially silver nanoparticles, are important branches of nanotechnology due to their catalytic and antimicrobial properties in the disinfection stage of water and wastewater treatment systems (25, 26).

Wastewater treatment with the help of optical nanocatalyst can replace the third stage of treatment, ie disinfection with chlorine to remove living organisms and organic compounds simultaneously and turn wastewater into a suitable source of water. Microorganisms naturally convert large organic compounds into smaller particles; But since these compounds are biodegradable, we must use some kind of energy to break them down. This energy is supplied by ultraviolet rays of sunlight and is used in conjunction with optical catalysts. The energy released by the reaction of the optical catalyst cell can kill microorganisms and decompose non-degradable compounds. This process is economically viable due to the possibility of reusing optical catalysts. One of the advantages of this process is its low cost due to the reuse of optical catalysts. Catalytic particles are either homogeneously dispersed in solution or deposited in membrane structures, allowing contaminants to be chemically decomposed.

3 Discussion and findings

At this stage, the introduction of some nanoparticles and nanocomposites effective in water and wastewater treatment is mentioned.

3.1 Metal oxide nanoparticles

Metal nanoparticles include: iron oxide nanoparticles, manganese oxide, aluminum oxide, titanium oxide, magnesium oxide, zinc oxide, nickel oxide and cerium oxide. Providing high surface area and optimal efficiency in the capacity of adsorption of heavy metals from aqueous media are important features of these particles. These compounds have special physical and chemical properties and unique processes and mechanisms and are highly used in the adsorption of impurities. Another feature is their porous support, which provides a unique separation (27-30).

3.1.1 Titanium oxides

In industrial water treatment using TIO_2 photocatalyst, it has been proven that many different chemicals are detoxified and removed from the water and purified. These chemicals include compounds toxic families Organic, ketones, aldehydes pesticide, ethers furans, alkenes dioxins, alkenes PAHS-alkenes PCB, herbicides, phenols alcohols- cyanide compounds are amine-esters. In addition to removing contaminants from water, photocatalysts have been shown to be effective in removing the color, taste, flavor, and odorous and disturbing compounds of water. Studies have shown that TIO_2 effectively removes bacteria and viruses from water (30).

3.1.2 The role of nanomaterials based on metal oxide

In addition to abundant studies and widespread use of nZVI and nanoscopic scale iron oxide adsorbents, some other metal oxides have a high specific surface area, microporous structure, and sufficient traction for other pollutants. Nanoscopic scale metal oxides, which are widely used, include aluminum oxide, zinc oxide, manganese oxide, and cerium oxide (31-35).

Alumina is a classic adsorbent, and relative to alpha alumina, the gamma-alumina form has more absorption power. Nanoscopic scale gamma-alumina, with its high specific surface and good adsorption capacity, is a promising adsorbent. The maximum permeability is 96.6% at 25 mg/L, of which nanoscopic scale alumina is an effective adsorbent for TI (III) from aqueous solutions, which has a 100% adsorption efficiency at pH 4.5 (28, 32).

Among the available adsorbents, nano-sized metal oxides, including nano-sized ferric oxides, manganese oxides, aluminum oxides, titanium oxides, magnesium oxides, and cerium oxides, have been defined as adsorbents for the removal of contaminants from gaming systems. This is partly due to the high level and high activity created with little impact. Recent research suggests that many MnOs have high adsorption potentials for heavy metals in terms of high capacity and selectivity, which can lead to high removal of toxic substances to meet increasingly restrictive regulations (36).

3.2 Carbon-based nanosorbents

Carbon-based materials such as activated carbon, carbon fiber, aerogels and nanostructured carbon have been well used as adsorbents. Activated carbon is used as a highly efficient adsorbent to remove various pollutants. The term activated carbon basically refers to a carbonic material with a high micropore volume, high specific surface area, good pore distribution and high adsorption capacity. Almost all carbonaceous materials can be used to produce activated carbon. But their properties will vary depending on the raw materials and the activation method. Although activated carbon is a good adsorbent for water treatment, its high cost has limited use (37).

Carbon nanotubes (CNTs) are materials that belong to the carbon family. These materials are classified into two groups: single-walled nanotubes and multi-walled nanotubes. Carbon nanotubes are used as adsorbents to remove metal ions and organic and inorganic impurities in water sources. These adsorbents effectively separate metal ions from the wastewater. The capacity to absorb heavy metals in single-walled nanotubes is greater than that of multi-walled ones. Single-walled carbon nanotubes (SWCNTs) have a strong affinity for many organic compounds due to their high specific surface area. However, the most important weakness of single-walled carbon nanotubes, which limits their use, is their high cost. Multi-walled carbon nanotubes are cheaper, but their relatively low adsorption capacity limits their use. Modification of multi-walled carbon nanotubes (MWCNTs) increases their adsorption capacity for different compounds, so that its can be adapted to selective applications (37). Carbon nanotubes absorb bacteria with three unique properties. First, the microbial adsorption capacity on CNT is much higher than other commercial adsorbents, and second, CNT has selective adsorption properties with kettles. A feature not seen in other adsorbents. Finally, the kinetics of bacterial uptake on the CNT is almost instantaneous, which makes it suitable for use in applications (37).

3.2.1 Nanocomposites of organic supports

Nanocomposite production methods are divided into two groups: physical and chemical. The main problem in preparing this type of membrane is to create suitable transverse connections between organic and inorganic phases. The presence of voids in the interface between organic and inorganic phases causes membrane defects and will strongly affect the membrane performance in terms of permeability and selectivity.

One of the suitable methods for removing sulfide from wastewater is the adsorption process. Polyaniline nanocomposite is a suitable adsorbent for removing sulfide from wastewater. Polyaniline nanocomposites are used to remove sulfates. Perchlorates can be removed using polypyrrole graphene nanocomposites. Chitosan is a biodegradable, biocompatible and bioadhesive polymer that has attracted much attention in the elimination of pollutants. Chitosan nanoparticles, due to their small size and large surface-to-volume ratio, have better physicochemical, antibacterial and biological properties than the corresponding bulk state. Chitosan-based nanocomposites have received much attention as contaminant removal adsorbents in water treatment; Because it offer better properties than pure polymer (18, 37, 46-49).

3.2.2 Inorganic Nanocomposites and Their Applications

Polymer nanocomposites are two-phase systems that include a polymer matrix and mineral nanoparticles. Clay nanoparticles are among the nanoparticles that have been studied a lot. The reason for this attention is their cheapness, easy access, and good performance and processability. Among the various adsorbents, chitosan polymer composites are among the materials that have attracted the attention of many researchers in recent years as stabilizers for heavy metals. The preparation of polymer composites with the achievement of more efficient properties has increased the efficiency of adsorbents in the removal of heavy metals.

Chitosan-Biochar nanocomposite has been used to remove heavy metals such as lead, copper and cadmium from aqueous solutions. The results of their experiments showed that the presence of amine, hydroxyl reactive amine functional groups in the structure of chitosan increased the adsorption capacity of heavy metals by chitosan-biochar composite compared to pure biochar. The researchers also reported that amine groups react strongly to the metal ions lead, copper and cadmium. In addition, nitrogen atoms have free electrons that react with the cations of these metals (38). Chitosan-clay nanocomposite used aqueous solutions to remove heavy metals copper and nickel. The results experiments showed that this composite, with the use of high specific surface area of clay and abundant amine and hydroxyl functional groups in the structure of chitosan, provide sufficient adsorption positions for copper and nickel ions (39).

3.3 Magnetic Iron Oxide Nanoparticles

Iron oxides exist in many forms in nature, the most common of which are Magnetite (Fe_3O_4), Hematite (α-Fe_2O_3) and Maghemite (γ-Fe_2O_3) (40). The fabrication and application of iron oxide nanoparticles has been extensively studied in recent years due to their nano-dimensions, extreme paramagnetic properties, large volume to volume ratio, and easy synthesis, coating, and structural modification (40). Other properties of magnetic nanoparticles include low toxicity, chemical neutrality, good biocompatibility, easy separation and acceptable stability (41).

All these properties have led to the recognition of magnetic nanoparticles as powerful adsorbents for the removal of pollutants, especially heavy metals, and a number of laboratory studies have shown that these nanoparticles in various forms have the ability to effectively remove heavy metals from water or wastewater (42-46). One of the general problems in the application of nanoscale particles is the tendency to accumulate, the cohesion of these particles in solution, which will reduce the efficiency of adsorption and separation (43-47). In addition to the problem of nanoparticle aggregation, the presence of some materials in the environment that are easily adsorbed nanoparticles (such as phosphate) will have an adverse effect on the adsorption of heavy metals due to competition in the occupation of active adsorbent spaces (44-50).

To solve these two major problems, it is possible to use selective reactivity of iron nanoparticles with different functional groups, in addition to surface modification and improving the stability of nanoparticles to create selective adsorption on these particles. A variety of stabilizers, electrostatic surfactants and polymers have been proposed to improve the structure and stability of iron nanoparticles (45-51).

4 Conclusion

Today, due to lack of water resources; effective wastewater treatment is one of the most important prerequisites for developing countries. Therefore, the development and implementation of advanced treatment systems with high efficiency and the need for small capital is essential. Advances in nanoscience and engineering show that many common problems related to water quality are solved or greatly improved by nanoparticles and other products and processes resulting from nanotechnology. Several natural and engineered nanomaterials have high antimicrobial properties, by various mechanisms such as damage to cell compounds and viruses (Tio_2, ZnO, Fullerol). In the same perspective, nanomaterials have shown significant applications in wastewater treatment due to their unique properties such as large surface area, many active sites and very good adsorption capacity, among which magnetic nanoparticles of iron oxides to the reason for features such as its ability to regenerate and easily detach by applying a magnetic field, easy and low cost synthesis, acceptance of functional groups and therefore high selectivity in adsorption of metal ions as an ideal nano-adsorbent for the removal of metal ions have been noticed in recent years.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

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