Challenges and Countermeasures of Functionalized Graphene Materials in Water Purification

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Abstract

This article focuses on the application of functionalized graphene materials in the field of water purification. Firstly, the characteristics of functionalized graphene materials were introduced, and their great potential in water purification was expounded. Then, a series of challenges faced by this material in practical application were deeply analyzed, including high preparation costs, poor dispersion, potential secondary pollution, and technical bottlenecks for large-scale application. In response to these challenges, corresponding countermeasures have been proposed, such as optimizing the preparation process, surface modification to enhance dispersibility, strengthening safety assessment and supervision, and promoting industry-university-research cooperation to accelerate technology transformation. It aims to provide theoretical support and practical guidance for the further promotion and application of functionalized graphene materials in water purification.

Keywords: Functionalized graphene material; Water purification; Application challenges; Coping strategies.

1. Introduction

Water serves as the origin of life and stands as a vital and indispensable resource crucial for the progress of human society. Nevertheless, owing to the swift pace of industrialization and urbanization, the issue of water pollution has escalated dramatically, presenting a grave menace to both the ecological environment and human well-being [1]. Heavy metals, organic pollutants in industrial wastewater, as well as nutrients and pathogens in domestic sewage, constantly enter water bodies, leading to deterioration of water quality and imbalance of the water ecosystem [2]. Traditional water purification technologies such as physical adsorption, chemical precipitation, and biological treatment can alleviate water pollution problems to a certain extent, but they have limitations such as low treatment efficiency, high cost, and a tendency to cause secondary pollution [3]. Therefore, the development of new water purification materials and technologies that are efficient, environmentally friendly and economical has become a current research hotspot.

Graphene is a two-dimensional nanomaterial composed of carbon atoms. Since it was successfully manufactured in 2004, it has attracted people's attention because of its unique electronic structure and excellent physical and chemical characteristics, such as super-large specific surface area, super-strong electrical and thermal conductivity and strong adsorption capacity [4]. Functionalized graphene materials have new characteristics and functions by modifying the surface of graphene or adding specific functional groups, so it has shown great application potential in the field of water purification [5]. For example, Functionalized Graphene Materials can efficiently adsorb heavy metal ions and organic pollutants in water, and can also degrade organic pollutants through photocatalysis. At the same time, they also have certain antibacterial properties, which can inhibit the growth of microorganisms in water [6].

2. Characteristics of Functionalized Graphene Materials and Their Potential in Water Purification

2.1 Characteristics of Functionalized Graphene Materials

Graphene is a two-dimensional nanomaterial composed of carbon. Its structure is very special, and the carbon atoms are arranged in a hexagonal honeycomb. It has many powerful characteristics, such as its theoretical specific surface area can reach 2630 m^2/g g. With such a large specific surface area, it has many active sites and can absorb pollutants [7]. At the same time, the conductivity of graphene is also excellent, and the electron mobility can be as high as 2× 10 cm/ (v s) at room temperature. This feature makes it have great application potential in electrochemistry and catalysis [8]. In addition, the mechanical properties of graphene are also very strong, the highest tensile strength can reach 130 GPa, and the elastic modulus is about 1 TPa. [9].

Functionalized graphene was changed from graphene, and scientists changed its surface by chemical or physical methods. This change will add some different functional groups or nanoparticles, which will make its surface characteristics and chemical reactions different. Commonly used methods include REDOX approach, covalent bonding method, non-covalent bonding method and so on. Among them, REDOX method is the most commonly used method to manufacture functionalized graphene. It needs to oxidize graphite into graphene oxide first, and then change it back with reducing agent. In this redox process, some small parts containing oxygen (such as carboxyl, hydroxyl and epoxy groups) can be mounted on the surface of graphene [10]. The method of covalent bonding is like using chemical glue to firmly adhere specific small molecules to the surface of graphene. Non-covalent bonding methods mainly rely on intermolecular attraction, such as π -π interaction, hydrogen bonding and electrostatic adsorption, to absorb some molecules or polymers on the surface of graphene, which can also realize the functionalization of graphene.

Functionalized graphene materials keep the large specific surface area of graphene itself and the conductivity of super rods, and at the same time gain new skills. For example, when graphene is functionalized with amino groups, it becomes more dispersible in water and more hydrophilic, so that it can be more evenly dispersed in aqueous solution [11]; Functionalized graphene composites loaded with metal nanoparticles will show stronger catalytic activity, making them suitable for catalytic decomposition of organic pollutants [12].

2.2 Potential of Functionalized Graphene Materials in Water Purification

2.2.1 Adsorption Performance

Functionalized graphene materials are characterized by their large specific surface area and an abundance of surface functional groups, enabling them to effectively eliminate heavy metal ions and organic pollutants from water via both physical and chemical adsorption processes. For example, graphene oxide's surface is rich in oxygen-containing functional groups, including carboxyl, hydroxyl, and epoxy groups. These groups are capable of forming complex reactions with heavy metal ions, resulting in efficient adsorption. Additionally, functionalized graphene materials can adsorb organic pollutants in water, like dyes and pesticides, through mechanisms such as TT - TT interactions and hydrogen bonding.

2.2.2 Catalytic Performance

Certain functionalized graphene materials exhibit outstanding catalytic capabilities, enabling them to facilitate the breakdown of organic pollutants in aquatic environments. For example, by depositing transition metal oxides or precious metal nanoparticles onto graphene's surface to create functionalized graphene composites, one can leverage graphene's expansive specific surface area and excellent electrical conductivity. This, in turn, improves the catalyst's dispersion, stability, and catalytic activity. In the realm of photocatalytic degradation of organic pollutants, functionalized graphene materials can act as support for photocatalysts, aiding in the separation of photogenerated electron-hole pairs and boosting the overall efficiency of photocatalysis.

2.2.3 Antibacterial Performance

Functionalized graphene materials also possess certain antibacterial properties, capable of inhibiting or killing bacteria and microorganisms in water. Studies show that the sharp edges of graphene can damage the cell membranes of bacteria, leading to their death. In addition, the functional groups on the surface of functionalized graphene materials can also interact with the substances on the surface of bacterial cells, affecting the physiological functions of bacteria and thereby achieving the purpose of antibacterial. In water purification, the antibacterial properties of functionalized graphene materials can effectively prevent the breeding and spread of microorganisms in water, ensuring water quality safety.

3. Challenges Faced by Functionalized Graphene Materials in Water Purification Applications

3.1 The Preparation Cost is High

At present, the preparation methods of functionalized graphene materials mainly include chemical oxidation-reduction method, mechanical exfoliation method, chemical vapor deposition method, etc. Among them, the chemical REDOX method is one of the most commonly used preparation methods. However, this method requires the use of a large amount of strong acids, strong oxidants and other chemical reagents, which not only causes pollution to the environment, but also has a complex preparation process and high cost. Although the mechanical exfoliation method can obtain high-quality graphene, its output is low and it is difficult to meet the demands of large-scale applications. Chemical vapor deposition can produce large-area and high-quality graphene films, but the equipment is expensive, the preparation

conditions are strict, and the cost remains high. The high preparation cost severely restricts the large-scale application of functionalized graphene materials in water purification.

3.2 Poor Dispersion

Functionalized graphene materials, due to their high surface energy, are prone to agglomeration, resulting in poor dispersion in water bodies. Poor dispersion will affect the contact area between functionalized graphene materials and pollutants, reduce their adsorption, catalytic and other properties, and thus affect the water purification effect. In addition, agglomerated functionalized graphene materials are also difficult to recycle and reuse, increasing the cost of use. Therefore, how to improve the dispersion of functionalized graphene materials in water is an important challenge currently faced.

3.3 Potential Secondary Pollution

Functionalized graphene materials may release some harmful substances during the water purification process, causing secondary pollution to the water environment. For instance, the chemical reagents used in the preparation of functionalized graphene materials may remain in the materials and gradually be released during the water purification process. In addition, the functionalized graphene material itself may react with certain substances in water to generate new pollutants. The problem of secondary pollution not only reduces the purification effect of water bodies, but also poses potential threats to the ecological environment and human health.

3.4 Technical Bottlenecks for Large-scale Application

Although functionalized graphene materials have demonstrated excellent water purification performance in laboratory studies, they still face many technical bottlenecks in large-scale practical applications. For instance, how to achieve continuous, efficient preparation and large-scale production of functionalized graphene materials; How to design appropriate reactors and process flows to ensure the stable operation of functionalized graphene materials in the water purification process; How to conduct post-treatment on the treated water body to ensure that the water quality meets the discharge standards, etc. These technical bottlenecks have restricted the large-scale promotion and application of functionalized graphene materials in water purification.

4. Countermeasures

4.1 Optimize the Preparation Process to Reduce Costs

To reduce the preparation cost of functionalized graphene materials and minimize environmental pollution, researchers can develop green preparation methods. For instance, using biomass raw materials as reducing agents and stabilizers to replace traditional chemical reagents enables the green preparation of graphene. Biomass raw materials are widely available, low-cost and environmentally friendly, which can effectively reduce the preparation cost. In addition, it is also possible to explore the use of physical methods such as microwaves and ultrasonic waves to assist in the preparation of functionalized graphene materials, thereby enhancing the preparation efficiency and reducing energy consumption. By optimizing the preparation process and equipment, the large-scale production of functionalized graphene materials can be achieved. For instance, continuous flow reactors are adopted instead of traditional batch reactors to enhance production efficiency. Develop automated production lines to reduce manual operations and lower production costs. At the same time, strengthen cooperation with enterprises, establish industrial production bases, and promote the industrial development of functionalized graphene materials.

4.2 Surface Modification to Enhance Dispersibility

Certain hydrophilic functional groups or polymer chains are covalently bonded to the surface of functionalized graphene materials to boost their water dispersibility. For example, functional groups like amino and carboxyl can undergo reactions with oxygen-containing groups on graphene's surface, forming covalent bonds that enhance the dispersibility of the functionalized graphene. Moreover, polymers such as polyethylene glycol and polyvinyl alcohol can be grafted onto graphene's surface, creating a hydrophilic protective layer that prevents graphene from agglomerating.

Non-covalent bond modification, on the other hand, primarily involves adsorbing dispersants or surfactants onto the surface of functionalized graphene materials through non-covalent forces such as π - π interactions, hydrogen bonds, and electrostatic attractions, thereby improving their dispersibility. For instance, surfactants like sodium dodecylbenzene sulfonate and polyvinylpyrrolidone can be adsorbed onto graphene's surface via π - π interactions, forming a stable

dispersion system. The non-covalent bond modification approach offers the benefits of straightforward operation and minimal structural damage to graphene.

4.3 Strengthen Safety Assessment and Supervision to Prevent Secondary Pollution

Systematically carry out research on the environmental behavior and ecological toxicity of functionalized graphene materials in water bodies, and assess their potential environmental risks and health hazards. The research content includes the migration and transformation rules of functionalized graphene materials in water bodies, their acute and chronic toxic effects on aquatic organisms, as well as their accumulation and metabolic conditions within organisms. Through safety assessment research, a scientific basis is provided for the safe application of functionalized graphene materials. Relevant government departments should strengthen the supervision over the production and application of functionalized graphene materials, and formulate strict environmental standards and safety regulations. Enterprises are required to strictly control the use and discharge of chemical reagents during the production process to ensure the quality and safety of functionalized graphene materials. At the same time, strengthen the monitoring and management of water purification projects, regularly test the water quality of the treated water body, and prevent the occurrence of secondary pollution. 4.4 Promote industry-university-research cooperation and accelerate technology transformation. The government, universities and research institutions should enhance cooperation, establish industry-university-research cooperation platforms, integrate resources from all parties, and jointly carry out application research on functionalized graphene materials in water purification. Universities and research institutions are responsible for basic research and key technology development, while enterprises are responsible for technology transformation and industrial application. Through the cooperation among industry, academia and research, the transformation process of functionalized graphene materials from laboratory research to practical application can be accelerated. Strengthen the cultivation of talents in the field related to functionalized graphene materials, and improve the quality and innovation ability of talents. Colleges and universities should offer relevant majors and courses to cultivate compound talents who are proficient in both materials science and environmental engineering. Meanwhile, enterprises should enhance the training of their employees, improve their technical proficiency and operational capabilities, and provide talent support for the large-scale application of functionalized graphene materials.

5. Conclusion

Functionalized graphene materials, with their unique properties, have great application potential in the field of water purification. They can effectively remove heavy metal ions, organic pollutants and microorganisms from water, providing a new approach to solving water pollution problems. However, at present, functionalized graphene materials still face challenges such as high preparation costs, poor dispersion, potential secondary pollution and technical bottlenecks for large-scale application in water purification. To promote the wide application of functionalized graphene materials in water purification, a series of countermeasures need to be adopted, including optimizing the preparation process to reduce costs, surface modification to improve dispersion, strengthening safety assessment and supervision to prevent secondary pollution, and promoting industry-university-research cooperation to accelerate technology transformation, etc. Through continuous research and exploration, it is believed that functionalized graphene materials will play a significant role in the field of water purification and contribute to ensuring water resource security and ecological environment health.

In the future, with the continuous development of materials science and environmental science, the research on functionalized graphene materials will become increasingly in-depth. On the one hand, researchers will continue to explore new functionalization methods and preparation processes to further enhance the performance of functionalized graphene materials and reduce costs. On the other hand, the integrated application of functionalized graphene materials with other water purification technologies will be strengthened to form a more efficient and environmentally friendly water purification system. Meanwhile, with the continuous improvement of people's environmental protection awareness and the support of policies, the large-scale application prospects of functionalized graphene materials in water purification will be very broad.

REFERENCES

[1] Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. Annual review of environment and resources, 35, 109-136.

[2] Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., ... & Davies, P. (2010). Global threats to human water security and river biodiversity. nature, 467(7315), 555-561.
[3] Gupta, V. K., Carrott, P. J. M., Ribeiro Carrott, M. M. L., & Suhas. (2009). Low-cost adsorbents: growing approach to wastewater treatment—a review. Critical reviews in environmental science and technology, 39(10), 783-842.
[4] Novoselov, K. S., Geim, A. K., Morozov, S. V., Jiang, D. E., Zhang, Y., Dubonos, S. V., ... & Firsov, A. A. (2004). Electric field effect in atomically thin carbon films. science, 306(5696), 666-669.
[5] Yang, Y., Song, S., & Zhao, Z. (2017). Graphene oxide (GO)/polyacrylamide (PAM) composite hydrogels as efficient cationic dye adsorbents. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 513, 315-324.
[6] Zhao, D., Gao, X., Wu, C., Xie, R., Feng, S., & Chen, C. (2016). Facile preparation of amino functionalized graphene oxide decorated with Fe3O4 nanoparticles for the adsorption of Cr (VI). Applied Surface Science, 384, 1-9.
[7] Castro Neto, A. H., Guinea, F., Peres, N. M., Novoselov, K. S., & Geim, A. K. (2009). The electronic properties of graphene. Reviews of modern physics, 81(1), 109-162.
[8] Bolotin, K. I., Sikes, K. J., Jiang, Z., Klima, M., Fudenberg, G., Hone, J., ... & Stormer, H. L. (2008). Ultrahigh electron mobility in suspended graphene. Solid state communications, 146(9-10), 351-355.
[9] Lee, C., Wei, X., Kysar, J. W., & Hone, J. (2008). Measurement of the elastic properties and intrinsic strength of monolayer graphene. science, 321(5887), 385-388.
[10] Dreyer, D. R., Park, S., Bielawski, C. W., & Ruoff, R. S. (2010). The chemistry of graphene oxide. Chemical society reviews, 39(1), 228-240.
[11] Wang, X., Zhi, L., & Müllen, K. (2008). Transparent, conductive graphene electrodes for dye-sensitized solar cells. Nano letters, 8(1), 323-327.
[12] Liang, Y., Wang, H., Sanchez Casalongue, H., Chen, Z., & Dai, H. (2010). TiO2 nanocrystals grown on graphene as advanced photocatalytic hybrid materials. Nano Research, 3(10), 701-705.