DOI: 10.54254/2755-2721/72/20240987

Application prospects of graphene in environmental science

Chenglin Song

The Experimental High School Attached to Beijing Normal University, Beijing, 100032, China

Charliesong@pku.org.cn

Abstract. Nanomaterials and graphene, as cutting-edge materials, have play a crucial role in environmental governance. The introduction of nanomaterials brings new hope to environmental governance. Graphene not only improves the efficiency and cost-effectiveness of water treatment but also drives innovation and development in environmental technologies. This article provides a summary and analysis review starting from the characteristics of nanomaterials and Graphene, comprehensively reviewing Graphene's advantage in environmental technologies and discovered its application in this area. The research summarized the conclusion that Graphene's characteristics make it suitable for addressing environmental issues such as water pollution, its composites can play an important role in water treatment process including water purification, heavy metal adsorption, organic compound adsorption and removal through different preparation and reaction mechanisms. By introducing Nanopore structures and artificially designed stacking structures on graphene membranes, the permeation performance could be modulated and improved. By the way of physical and chemical adsorption, ion exchange, electrochemical and photocatalysis, Graphene and its oxide could be applied to remove heavy metal ion and organic substances from polluted water. The article also introduced the main preparation methods of Graphene and its potential secondary pollution problem. This article provides valuable insights for scientific research and engineering practices in environmental protection and sustainable development.

Keywords: Nanomaterials, graphene, environmental science, wastewater treatment, secondary pollution.

1. Introduction

Nowadays, environmental problems have become one of the serious challenges globally. It refers to the phenomenon of declining environmental quality and damaged ecosystems caused by human activities. It includes air pollution, water pollution, soil pollution and other types of problem. Air pollution mainly originates from industrial emissions, vehicle exhaust and coal combustion, resulting in increased nitrogen oxides, particulate matter, and volatile organic compounds in the atmosphere, affecting air quality and human health. Industrial emissions and vehicle exhaust continuously release particulate matter and harmful gases, exceeding the standards and exacerbating respiratory diseases. The main cause of water pollution comes from industrial emissions, overuse of agricultural fertilizer and chemical residue, pesticides, industrial wastewater and urban sewage, which will lead to an excess of heavy metals, organic substances and nutrients in water, disrupting aquatic ecosystems and water resource sustainability, threatening biodiversity and human health. Soil pollution comes from industrial waste,

DOI: 10.54254/2755-2721/72/20240987

chemical factory wastewater, pesticide and fertilizer residues and their leakage. It will lead to the accumulation of harmful and toxic substances, affecting crop growth and soil ecological functions [1]. The increasingly severe pollution directly leads to the destruction of ecosystems, affecting natural ecological balance and sustainable development.

In addition to environmental pollution, water scarcity is also one of the significant issues, especially in arid and densely populated areas where water resources are scarce, the imbalance between supply and demand is severe, which has become a barrier to the economy and social development. Industrial wastewater, agricultural pollution and urban sewage has led to water problems. Excessive heavy metal concentration and organic matter and deteriorating water quality. not only affecting crop growth and causing biological toxicity, but also affecting human health and disrupting the balance. All these facts are making water scarcity issues more severe. Therefore, water treatment has become an important topic for addressing this problem and maintain the balance of aquatic ecosystem.

Environmental problems are becoming increasingly prominent, highlighting the urgent need for innovative technologies to address the challenges. The article firstly introduces the characteristics of nanomaterials and its value in environmental science. Next, focusing on graphene as a highly characteristic nanomaterial, to discuss its unique physical and chemical properties. Then, the article focuses water treatment as the key area, analyzing different mechanisms and principles of graphene in water purification technology, modification methods, technical applications on adsorption and removal of harmful substances such as heavy metal ions and organic compounds. It demonstrates significant importance of graphene and its oxides, composites to environmental science. Finally, it also introduces three main preparation methods of graphene and briefly outlined the potential secondary pollution issues. This article provides a comprehensive understanding of graphene and its role in water treatment application

2. Nanomaterials in environmental science

Nanomaterials are special types of material with their dimension at nanometer scale, a typical nanometer ranges from 1 to 100. The nanoscale dimensions give these materials many unique properties of physical, chemical and biological manifestation which differ significantly from their macroscopic counterparts. Common nanomaterials include nanoparticles, nanotubes (such as single-walled and multi-walled carbon nanotubes), nanowires (such as metal nanowires and oxide nanowires), nanosheets (such as graphene and graphene oxide (GO)), nanosheets (such as titanium dioxide and silicon nanospheres), nanocomposites and so on [2]. Due to their structural characteristics, these nanomaterials have broad research value in materials science, environmental science, biomedical science and other research categories including electronic devices, energy storage and Bio-science fields.

The application features of nanomaterials are as follows [3]: (i) Nanomaterials exhibit strong surface area effects because of their specific big surface area. This gives nanomaterials unique applications in catalysis, adsorption, surface modification, and so on. (ii) Nanomaterials show quantum size effect. When materials are reduced to the nanoscale, their electronic structure is influenced by the quantum size effect, leading to changes in their electronic, optical and magnetic properties. Quantum dots are typical examples of nanomaterials that exhibit the quantum size effect. (iii) Some nanomaterials show excellent mechanical properties, such as nanocrystalline materials with ultra-high hardness and strength, suitable for the preparation of high-performance structural materials. (iv) The optical properties of nanomaterials are influenced by their size and structure, exhibiting a lot of unique optical effects such as fluorescence, plasmon resonance and nonlinear optics, and so on. These properties find extensive applications in sensors, optoelectronic devices. (v) Nanomaterials have significant applications in the biomedical field, such as nanodrug carriers, nanobiosensors, nanomedical devices for drug delivery, disease diagnosis and treatment.

Nanomaterials play an important role in environmental governance, mainly in the following aspects: (i) Due to the large specific surface, Nanomaterials can be used for adsorption and decomposition of pollutants, widely applied in wastewater treatment. For example, nanoparticles can adsorb heavy metal ions in water; nanophotocatalysts can use light energy to decompose organic pollutants into harmless

DOI: 10.54254/2755-2721/72/20240987

substances; nanomembrane tech can be used for water filtration and desalination, and nanoscale iron oxides are used for organic compound removal and heavy metal ion adsorption [4]. (ii) Nanomaterials also play a role in atmospheric pollution control. For instance, nanophotocatalysts can be used for the photolysis and decomposition of harmful gases by purifying air quality. (iii) Nanomaterials can be used in environmental monitoring, such as nanosensors for detecting trace pollutants in the environment, improving the monitoring sensitivity and accuracy. (iv) Nanomaterials can also aid in resource recycling. For example, using nanomaterials to extract useful substances from wastewater or utilizing nanocomposites for waste reuse.

Overall, nanomaterials have great potential and broad application prospects in environmental science area, effectively improving control efficiency and reducing their negative impacts. Among nanomaterials, graphene stands out for its advantages and promising applications in environmental governance. The application prospects in water treatment technology will be a good practice.

3. Application of graphene in the field of environmental science

Graphene, a two-dimensional crystalline nano-material composed of carbon atoms, exhibits molecular structure consisting of a single layer of carbon atoms distributed in a honeycomb-like pattern. Specifically, graphene’s molecular structure comprises individual hexagonal carbon atom rings connected by covalent bonds, forming a mesh-like structure on a plane [5]. Each carbon atom ring is surrounded by three covalent bonds connected to adjacent carbon atom rings, providing graphene with a stable structure and excellent performance characteristics. In graphene's molecular structure, each carbon atom forms four covalent bonds, with three connecting to adjacent carbon atoms and the fourth bond linking to carbon atoms or other atoms outside the plane, such as hydrogen or oxygen atoms, forming functionalized graphene materials [6]. This unique arrangement of carbon atoms endows graphene with outstanding properties such as excellent electron transport performance, mechanical strength, thermal conductivity, etc., Thus holding wide-ranging application prospects in various fields, especially in environmental science.

3.1. Structural characteristics and advantages of graphene

Graphene, with its single-layer carbon atom two-dimensional lattice structure, possesses unique advantages compared to other nanomaterials: (i) Graphene, in a two-dimensional structure, consists of a single layer of carbon atoms. It as an extremely thin thickness typically only one atomic layer thick. This gives graphene high flexibility and strength, along with excellent electrical and thermal conductivity. (ii) Graphene exhibits an excellent electrical conductivity of up to 200,000 S/cm, several times that of copper and even of ten times higher, making it one of the best-known conductive materials [7]. This makes graphene widely applicable in fields such as electronic devices and conductive materials; (iii) Single-layer graphene has high transparency. The transparency rate of up to 97.7%, and even multilayer graphene with a thickness of a few atomic layers maintains high transparency. This makes graphene highly valuable in optical and display applications [8]. (iv) Graphene shows extremely high strength. The strength exceeds 130 GPa, several times that of steel, showcasing excellent mechanical properties and durability, suitable for producing high-strength composite materials. (v) Graphene boasts an extremely high thermal conductivity of over 5000 W/mk, several times that of copper, making it suitable for high-performance heat dissipation materials and thermal interface materials. (vi) Graphene exhibits good chemical stability and is not easily oxidized or corroded in conventional environments, ensuring a long service life.

Therefore, as a special nanosheet material, graphene's advantages such as lightness, flexibility, electrical conductivity, transparency, high strength and excellent thermal conductivity make it a promising new material with wide-ranging applications. Particularly in the field of environmental pollution control, graphene demonstrates extensive potential, showcasing significant research significance. Figure 1 is the schematic diagrams of graphene and its derivatives [9].

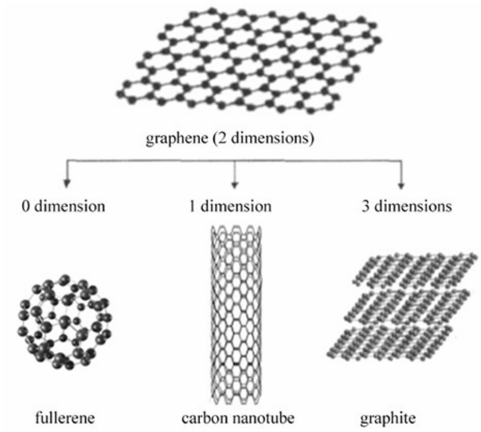

Figure 1. Schematic diagrams of graphene and its derivatives [9].

3.2. Application of graphene in water treatment

Water scarcity is one of the greatest challenges worldly wide with 70% of the earth covered by seawater and severe water pollution. As a result, desalination of seawater and wastewater treatment are gaining increasing attention. The development of nanotechnology has advanced traditional membrane materials, with sub-nanometer channels enabling high-speed transport of water molecules and desalination by blocking large molecules. Graphene, as a nanomaterial, has been widely studied in water treatment because of its unique electrical, thermal and optical mechanical features. Its single atomic layer and high surface area make it an excellent material for separation membranes and adsorbents in water treatment research.

Graphene's characteristics that make it suitable for addressing environmental issues such as water pollution, as graphene has an extremely high surface area, it can provide numerous active adsorption sites that facilitate the organic compounds adsorption, heavy metal ion and other pollutant in water [9]. In the meanwhile, graphene exhibits outstanding adsorption capacity, efficiently adsorbing pollutants such as organic compounds, dyes and residual pharmaceuticals. The pore structure of graphene can be controlled through preparation methods and processing techniques to achieve controllable pore size and distribution, thereby enhancing adsorption performance and selectivity. More important, graphene has good chemical stability and strong corrosion resistance against various chemicals, which make it suitable for water purification in different environmental conditions. Graphene can decompose organic pollutants into harmless substances through photocatalysis process, exhibiting good water treatment effects under light conditions. Pollutants adsorbed onto graphene are easily regenerated through thermal treatment, chemical treatment, or physical methods, enabling the regeneration and recycling of graphene.

Considering its characteristics, graphene can effectively improve the efficiency and effectiveness, promoting environmental protection and sustainable development. However, further optimization of graphene preparation methods, improvement of key technologies such as water purification, heavy metal and organic compound adsorption, waste treatment are needed for broader applications in practical settings.

3.2.1. Modification of graphene for water purification. Graphene, with its sp2-hybridized carbon atoms tightly arranged in a honeycomb crystal structure, exhibits unique mass transport properties. By introducing nanopores or artificially designed stacking structures on the graphene membrane matrix, it can serve as a highly permeable selective permeation membrane, showing tremendous potential in water purification filtration, separation, and seawater desalination. Examples of applications involving the introduction of nanopores or artificially designed stacking structures on the graphene membrane matrix [10].

Introducing nanopore structures on graphene membranes enables selective permeation of molecules of different sizes. The size of nanopores can be controlled by adjusting preparation conditions, such as using electron beam or ion beam techniques for controlled etching, or employing templating methods to prepare graphene membranes with specific pore sizes. In the selective permeability case, Nanopore structures can restrict the passage of specific molecule sizes, achieving selective permeation of solutes, such as for separating and purifying impurities or molecules in a solution. In the high permeability case, Graphene membranes exhibit high permeability due to their single-layer structure and high surface area, maintaining a high transmission rate. Figure 2 is the water and small-sized ions and molecules permeate superfast in the GO membrane.

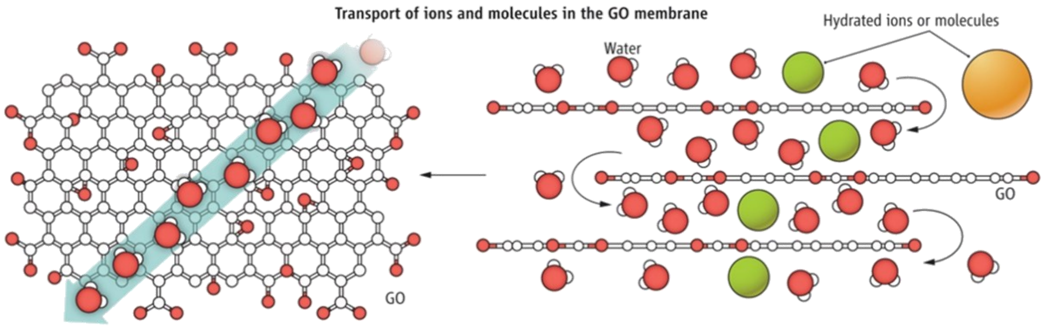

Figure 2. Water and small-sized ions and molecules (compared with the void spacing between stacked GO nanosheets) permeate superfast in the GO membrane, but largerspecies are blocked [11].

In addition to nanopore structures, artificially designed stacking structures can also be used to modulate the permeation performance of graphene membranes. Stacking multiple layers of graphene membranes can increase the selectivity of the permeation membrane, such as controlling the passage of specific molecules through interlayer gaps [12]. Or introducing functional groups or nanomaterials, such as GO, carbon nanotubes, etc., in the stacking structure can enhance the membrane's selectivity and stability.

Both of these methods can also be used for gas separation and purification, such as separating oxygen and nitrogen, applied in oxygen production and gas molecule sieving. Overall, graphene membranes, as highly permeable selective permeation membranes, achieve water purification treatment by introducing nanopores or artificially designed stacking structures.

3.2.2. Adsorption of heavy metal ions. Rapid development of industry has led to the contamination of heavy metal ions, which pose a serious hazard to human health. Graphene's two-dimensional atomic structure gives it a natural advantage in adsorption performance. For instance, its high surface area allows for effective adsorption sites far greater than carbon nanotubes, compared to traditional adsorbents, graphene and its composite materials exhibit higher adsorption rates due to their porous structures, enabling rapid adsorption of heavy metal ions [13]. Some studies have shown that functionalized graphene materials can efficiently adsorb organic compounds and heavy metal ions in water, while also decomposing pollutants into harmless substances through photocatalysis, aiding in improving water purification efficiency and reducing pollutant concentrations.

The main mechanisms by which graphene removes heavy metal pollution are physical and chemical adsorption. For the physical method, Graphene's abundant π-π bonds and porous structure can be used to the physical adsorption of heavy metal ions on its surface or within its pores, achieving pollutant removal. In the chemical adsorption case, functional groups on graphene' surface (such as hydroxyl and carboxyl groups) can undergo chemical reactions with heavy metal ions, forming chemical complexes or precipitates that fix the heavy metal ions on the graphene surface, then enhancing its reaction capacity.

Several common methods for graphene-based removal of heavy metal ions in water treatment include: (i) Graphene's π electron structure gives it strong adsorption capabilities for heavy metal ions [14]. By exposing graphene to a solution containing heavy metal ions, these ions are adsorbed by the π electrons on the graphene surface, leading to removal. (ii) GO or reduced GO (rGO) with abundant functional groups (such as hydroxyl and carboxyl groups) can undergo ion exchange reactions. By contacting the solution containing heavy metal ions with functionalized graphene, coordination or ion exchange reactions occur between the heavy metal ions and functional groups, leading to remove heavy metal ions. (iii) Electrochemical removal. Utilizing graphene's conductivity, heavy metal ions are transferred to the graphene surface or interior under the influence of an electric field, leading to removal. This method typically requires electrochemical techniques such as electroadsorption or electroreduction. (iv) Composite graphene with other adsorbents or functional materials to form nanocomposite materials, exhibiting synergistic effects in removing heavy metal ions, thus enhancing removal efficiency and selectivity. (v) Photocatalytic removal. Utilizing the photocatalytic activity of graphene surfaces combined with photocatalysts to activate the photocatalytic removal of heavy metal ions. This method typically involves using visible light or UV light to excite the photocatalytic activity on the graphene surface.

3.2.3. Adsorption and removal of organic pollutants. Organic pollutants are widely present in various wastewater and urban water systems, significantly impacting aquatic ecosystem health. The application of graphene in adsorbing phenols, oil pollution, antibiotics, pesticides, and humic acids in wastewater has garnered attention.

Graphene's adsorption and removal principles for oil pollution. Graphene's abundance of π-π bonds and highly structured surface give it excellent oil-water separation capabilities. Oil pollutant molecules can be adsorbed by graphene through physical or chemical adsorption, achieving oil pollution removal and recovery. This can be achieved using graphene nanocomposite materials or graphene foams. Graphene nanocomposite materials enhance adsorption performance and mechanical strength by combining graphene with other materials such as nanoparticles. Graphene foam materials utilize graphene's porous structure and high surface area for efficient oil pollutant adsorption and separation.

Graphene's adsorption and removal principles for oil pollution. Graphene's abundance of π-π bonds and highly structured surface give it excellent oil-water separation capabilities. Oil pollutant molecules can be adsorbed by graphene through physical or chemical adsorption, achieving oil pollution removal and recovery. This can be achieved using graphene nanocomposite materials. For Example, rGO/titanium dioxide (TiO_2) is an excellent graphene composite material. The reduced rGO/TiO_2 composite material exhibits excellent performance in adsorbing oil pollution [15], this composite material combines the high surface area of rGO with the photocatalytic properties of TiO_2. rGO, subjected to reduction-oxidation treatment, provides abundant adsorption sites, while TiO_2 serves as an outstanding photocatalyst capable of generating reactive oxygen species under light conditions, facilitating the decomposition of oil pollutants. rGO/TiO_2, either in direct contact with oil pollution or placed in oil-water separation devices, can accelerate the decomposition process of oil pollution under light conditions, where the TiO_2 component generates reactive oxygen species. rGO/TiO_2 functions effectively both as an adsorbent for oil pollution and as a photocatalyst, demonstrating favorable oil pollution treatment effects. Figure 3 is Schematic structure of the rGO/TiO_2 composite illustrating adsorption of oil on graphene sheets

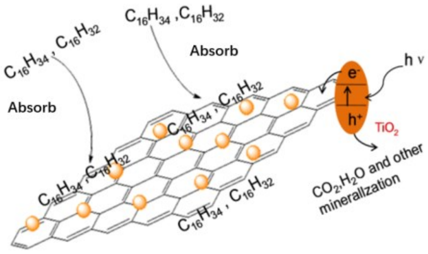

Figure 3. Schematic structure of the rGO/TiO_2 composite illustrating adsorption of oil on graphene sheets, and the role of graphene during the photocatalytic degradation of oil [16].

DOI: 10.54254/2755-2721/72/20240987

Graphene's adsorption and removal principles for antibiotics. Graphene's rich functional groups and highly structured surface enable it to adsorb antibiotic molecules through chemical adsorption, electrostatic interactions, etc., achieving antibiotic removal and degradation. This can be achieved using GO or graphene composite materials. GO increases surface active functional groups, enhancing antibiotic adsorption capacity. Graphene composite materials combine graphene with other adsorbent materials like activated carbon, enhancing adsorption performance and selectivity.

Graphene's adsorption principles for phenolic pollutants. Graphene's abundant aromatic structure and π-π bonds allow it to undergo π-π stacking or chemical adsorption with phenolic pollutants, achieving adsorption and removal [17]. This can be achieved using graphene-based composite materials or functionalized graphene. Graphene-based composite materials combine graphene with other adsorbent materials like GO, activated carbon, enhancing adsorption performance and removal efficiency.

Graphene's adsorption and removal principles for pesticides. Graphene's high surface area and chemical reactivity enable it to adsorb, degrade, or transform pesticide molecules through physical or chemical adsorption, thus achieving pesticide removal. This can be achieved using graphene-based composite materials and GO. Graphene-based composite materials combine graphene with other adsorbent materials like activated carbon, titanium dioxide, which will enhance adsorption performance and removal efficiency. GO modify graphene surfaces, enhancing selective adsorption and catalytic degradation capabilities for specific pesticides.

3.2.4. Graphene's other application prospects. In water treatment, graphene-based materials offer innovative solutions for water purification and remediation, its exceptional mechanical strength and flexibility make it suitable for filtration membranes, enabling the removal of pollutants from water with high efficiency and durability. Moreover, graphene's conductivity could be harnessed to monitor the real-time status of water quality. By functionalizing graphene with specific molecules or nanoparticles, it can selectively detect and quantify pollutants in water, providing valuable data for environmental monitoring and management. Additionally, graphene-based photocatalysts show promise for water treatment applications. When coupled with light sources, graphene can catalyze the degradation of organic pollutants through photocatalysis, offering a sustainable approach for wastewater treatment.

Graphene can also be used in gas adsorption and separation, such as carbon dioxide capture and storage [18]; manufacturing electrochemical sensors for detecting chemicals in the environment, such as toxic gases and heavy metal ions; graphene composite materials can also be used to produce environmentally friendly batteries and supercapacitors, promoting the development of renewable energy sources.

In summary, graphene as a water purification material has advantages such as high efficiency, controllability, and environmental friendliness, making it important and promising for improving water quality and addressing water pollution issues. Further research and optimization of graphene's preparation methods, functionalization, waste treatment, and other key technologies are needed to achieve its widespread application in the field of water purification.

3.3. Graphene's major preparation methods

The preparation methods of graphene mainly include three ways, which are mechanical exfoliation, chemical vapor deposition (CVD) and chemical oxidation-reduction methods. Mechanical exfoliation can produce large-area graphene flakes and is more suitable for the field of water purification. Its principle involves using mechanical force, such as tape stripping or blade stripping, to peel off graphene layers and obtain graphene monolayers. It has simple operation and low cost advantages, but low yield and difficult to control the quality and morphology of monolayer graphene.

CVD is a method where carbon atoms are deposited on a metal substrate through thermal decomposition of precursor gases like methane to form graphene. In this method, precursor gases (such as methane) required for graphene growth, along with carrier gases (such as hydrogen), are introduced into a reaction chamber. At high temperatures (approximately 1000°C), the precursor gases decompose to form carbon atoms, which then deposit on the metal substrate to form a graphene film [19]. The advantages keep fast growth rate, strong controllability, and suitability for large-area preparation. But it requires high temperatures and specialized equipment, resulting in higher costs.

Chemical exfoliation (GO method) refers to reducing GO solution using a reducing agent (such as reducing sugars or sodium bisulfite) to obtain graphene [20]. It is good for producing a large quantity, but involves handling oxides, and the reduction process may affect the quality of graphene.

Lastly, the chemical oxidation-reduction method (Brooks method) utilizes nitric acid, sulfuric acid mixed with graphene for oxidation treatment, followed by reduction using a reducing agent (such as sodium bisulfite) to obtain graphene [21]. Its advantage lies in a relatively simple preparation process with lower costs, but it leads to significant environmental pollution and requires high safety standards for operator. Figure 4 is the route to synthesize graphene via reduction of GO.

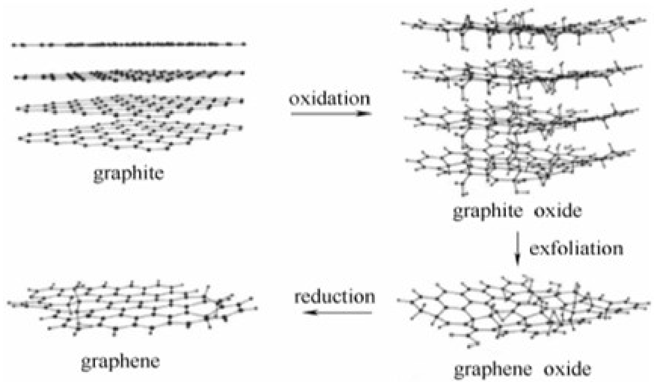

Figure 4. Route to synthesize graphene via reduction of GO [22].

Graphene, as a material with high adsorption efficiency and chemical reactivity, has diverse preparation methods, involving GO, graphene-based composite materials, functionalized graphene, and other technologies [23]. These methods include using graphene as a carrier, combining it with other nanomaterials like iron oxide, zinc oxide to create composite nanomaterials for water purification; placing graphene materials in water or constructing graphene membranes for filtration to effectively remove impurities; utilizing graphene's photocatalytic properties to convert solar energy into chemical energy and decompose organic substances in water; and employing ion exchange technology to exchange ions in water with functional groups on graphene's surface to remove heavy metal ions and harmful substances.

In conclusion, different graphene preparation methods have their applicable scenarios and characteristics. Choosing the appropriate method requires considering practical needs, costs, and equipment conditions. With the continuous development of graphene technology, more efficient and cost-effective preparation methods may emerge in the future.

4. Secondary pollution issues

Although nanomaterials have extensive prospects for environmental governance applications, their safety issues cannot be overlooked. Graphene may lead to potential secondary pollution and negative impacts in environmental governance. Especially GO, which is widely used in environmental remediation, sensor devices, photovoltaic cells and medical diagnostics, due to its excellent adsorption capacity, strength, flexibility, conductivity and optical properties [24]. The special structure and large surface area of GO also enriches and accumulates harmful substances in the soil, atmosphere and water environment during use, recycling, and disposal processes, that will ultimately affect health and ecosystem. GO, as a promising new material, must always be mindful of its negative impact and potential risks on the ecological environment while being widely applied [25].

The potential hazards include: (i) Biological toxicity. Graphene nanomaterials with high surface area and unique chemical properties may have toxic effects on organisms. Particularly concerning are microbes and aquatic organisms, where graphene's presence may lead to ecosystem imbalance and reduced biodiversity. (ii) Environmental pollution. During the preparation, application, and disposal of graphene, pollutants such as wastewater, exhaust gases and solid waste may be generated. These pollutants may contain graphene and its derivatives, causing pollution and harm to the environment. (iii) Health risks. The tiny size and specific morphology of graphene particles may result in their long suspension in the air, potentially entering the respiratory tract or bloodstream of humans, posing potential risks to human health such as respiratory diseases or blood poisoning. (iv) Persistence and bioaccumulation. Given graphene's unique structure and chemical properties, some graphene nanomaterials may be persistent and bio-accumulative, causing long-term effects on the environment and ecosystems. Figure 5 is the Distribution diagram of Small Few-Layer-Graphene (small S-FLG) and Large Few-Layer-Graphene (L-FLG) in zebrafish.

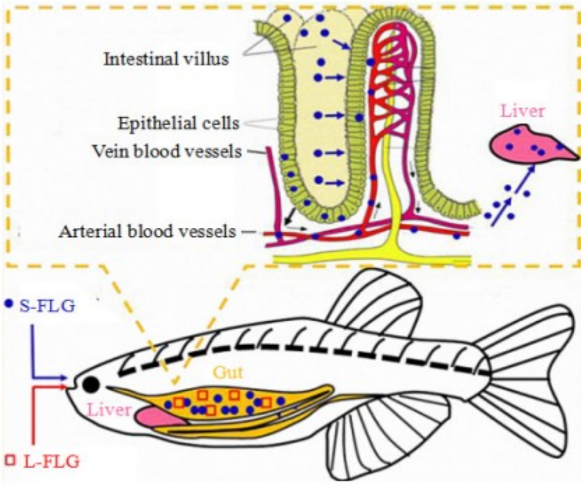

Figure 5. The Distribution diagram of Small Few-Layer-Graphene (Small S-FLG) and Large Few-Layer-Graphene (L-FLG) in zebrafish. GO can be taken up and retained by zebrafish. Large pieces of FLG mainly accumulate in the intestines, while small pieces of FLG are distributed in both the intestines and liver [26].

To mitigate graphene's negative environmental impact, effective measures and management practices are needed. This includes strict control over the production and application processes of graphene and its derivatives to reduce emissions and leaks of pollutants. It also involves strengthening environmental risk assessment and monitoring on graphene, promptly identifying and addressing potential environmental issues. Developing green and eco-friendly graphene preparation and application technologies can reduce resource consumption and environmental impact. Additionally, enhancing research on graphene safety and toxicity mechanisms, establishing corresponding safety standards and management policies are crucial. In conclusion, by considering principles of environmental protection and sustainable development, we can maximize the advantages of graphene in environmental governance while minimizing or mitigating its potential negative impacts.

5. Conclusion

Nanomaterials and graphene play a crucial role in environmental governance. Nanomaterials, with their unique physical and chemical properties, have advantages in pollutant adsorption, decomposition, removal, and monitoring. Graphene, as a nanomaterial with a single-layer structure and excellent physicochemical properties, demonstrates tremendous potential in environmental governance and water treatment, particularly in water purification filtration, adsorption of heavy metals and organic compounds. However, nanomaterials also pose secondary pollution issues in their application, necessitating enhanced research on their bio-toxicity and environmental impact. Further optimization and refinement of preparation methods, functional treatment, and waste management of nanomaterials are essential to ensure their sustainability and safety in environmental governance. In summary, while

DOI: 10.54254/2755-2721/72/20240987

nanomaterials and graphene play a critical role in environmental governance, ongoing efforts in technological innovation and safety management are necessary to promote environmental protection and sustainable development.

References

[1] Pumera M 2011 Ene. & Environ. Sci. 4 668-674
[2] Geim A K and Novoselov K S 2007 Nat. mat. 6 183-191
[3] Kim K S, Zhao Y, Jang H, et al. 2009 Nat. 457 706-710
[4] Chen J, Zhang W and Yang H 2011 Small 7 1876-1902
[5] Lee J, Kim J, Hyeon T and Lee C 2016 Chem. Soc. Rev. 45 2423-2453
[6] Robinson J T, Perkins F K, Snow E S., Wei Z and Sheehan P E 2008 Nano let. 8 3137-3140
[7] Zhao G, Zhao G, Shao D, Zhang L, Zhang Z, Li F 2015 J. nano. res. 17(2), 66
[8] Ali I, Alothman Z A, Alwarthan A and Umar K 2014 J. Molec. Liq. 192 60-68
[9] Hu Y J, Jin J, Zhang H, et al. 2010 Wuli Huaxue Xuebao 26 2073-2086
[10] Jiang J, Zhu L, Zhu L, Wang D, Zhang X and Zhu B 2016 Environ. Sci. & Tech. 50 8772-8782
[11] Mi B 2014 Sci. 343 740–742
[12] Song S, Liu L, Kuang Y, Liu Z and Xiao R 2016 Ind. & Eng. Chem. Res. 55 6930-6940
[13] Yang D, Velamakanni A, Bozoklu G, Park S, Stoller M, Piner R D and Ruoff R S 2009 Carbon 47 145-152
[14] Li Z, Wang X and Zhang D 2019 Front. Environ. Sci. & Eng. 13 63
[15] Jin G, Ma L and Pan C 2021 Water Poll. and Treat. 9 10-19
[16] Ji Q, Yu X, Zhang J, Nie Z, Yang H and Yi S 2017 Mater. Rev. 31 368-37
[17] Wang X, Wang W, Zhang J and Zhao J 2016 China Environ. Sci. 36 1757-1762
[18] Liu Y, Zhang R and Liu H 2017 Coll. and Surf. B: Bio. 145 702-718
[19] Wei J, Li Y, Liu S and Zhang X 2018 Chem. Eng. J. 334 2408-2428
[20] Zhang M C, Guan K C, Shen J, et al. AIChE Journal 2017 63 5054-5063
[21] Chen L, Shi G, Shen J, et al. Nat. 2017 550 380-383
[22] Liu F. Fan F, Lu Y, Zhang S and Zhao C 2016 CIESC Journal 5 0438-1157
[23] Li Z, Zheng Y, Zhang R, Jiang Z 2022 CIESC Journal 73 2370-2380
[24] Lanphere J D, Luth C J, Walker S L 2013 Environ. Sci. & Tech., 47 4255-4261
[25] Selck H, Handy R D, Fernandes T F, et al. 2016 Environ. Toxi. and chem. 35 1055-1067
[26] Hu J, Lao Z, Wu K and Fan H 2017 Eco. and Environ. Sci. 26 2169-2176