

Research progress on photocatalysis technology in environmental remediation

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Abstract. In this rapidly changing world, environmental deterioration has reached a level that cannot be ignored. Photocatalysis technology, as a revolutionary solution, holds promising prospects for application in the field of environmental remediation. This study delves into the latest advancements of photocatalysis technology in air purification, water purification, and soil remediation, with a focus on the preparation, modification techniques of various photocatalysts such as titanium dioxide (TiO₂), ZnO, and their heroic performance in combating pollution. We reveal how photocatalysis technology effectively converts pollutants into harmless substances, showcasing its amazing potential and challenges, and make exciting predictions for future research directions. Through this study, we hope to contribute to the continuous improvement of the environment and draw a more beautiful blueprint for the earth's tomorrow.

Keywords: Photocatalysis Technology, Environmental Remediation, Titanium Dioxide, ZnO, Innovative Advances

1. Introduction

With the acceleration of industrialization and modernization, environmental issues have become a major challenge to human survival and development. The decline in air quality, water pollution, and soil degradation not only threaten biodiversity but also directly affect human health and well-being. Against this backdrop, seeking efficient and eco-friendly environmental remediation technologies has become a common goal for scientists worldwide. Photocatalysis technology, with its unique ability to convert sunlight into chemical energy and thereby degrade pollutants, offers an attractive solution. This technology not only represents a significant breakthrough over traditional environmental protection methods but also signals a new way of thinking, challenging our existing notions of energy, environment, and sustainable development. However, despite the great potential demonstrated by photocatalysis technology in theoretical and laboratory studies, its practical application still faces many challenges. How to improve the activity, stability, and applicability of photocatalysts and realize large-scale application are urgent problems to be solved. In this context, this study aims to explore the current status and future development of photocatalysis technology in environmental remediation, in hopes of providing new ideas and solutions for the current environmental crisis.

2. Preparation and Modification of Photocatalysts

The preparation and modification of photocatalysts are crucial to the efficiency and applicability of the photocatalytic process in environmental remediation. Through scientific and reasonable preparation and modification, the activity, stability, and durability of photocatalysts in environmental remediation can be significantly improved.

2.1. Traditional Methods of Photocatalyst Preparation

Traditional photocatalysts, such as titanium dioxide (TiO_2), can be prepared by various methods, including sol-gel, hydrothermal, and solvothermal techniques. Each method has its characteristics; for instance, the sol-gel method can produce photocatalysts with good dispersibility and high purity, while the hydrothermal method can obtain photocatalysts with good crystallinity at lower temperatures. Each method seeks to optimize the structure and performance of the photocatalyst to achieve higher efficiency in environmental remediation [1].

2.2. Development Trends in New Photocatalysts

With technological progress, researchers are constantly exploring new photocatalysts, such as doped TiO_2 and ZnO-based photocatalysts. These new types of photocatalysts usually have higher light utilization efficiency and stronger pollutant degradation capability. By introducing non-metal or metal elements into the photocatalyst, the light response range can be effectively expanded, enhancing photocatalytic efficiency.

2.3. Surface Modification Techniques for Photocatalysts

Surface modification is one of the important means to enhance the performance of photocatalysts. By modifying the surface of photocatalysts, such as applying noble metal loading, preparing composite structures, or surface doping, the efficiency of electron-hole pair separation can be effectively increased, thereby enhancing photocatalytic activity. This method not only improves photocatalytic efficiency but also expands the application range of photocatalysts, enabling them to degrade a wider variety of pollutants [2].

2.4. Impact of Photocatalyst Modification on Environmental Remediation Efficiency

The preparation and modification of photocatalysts have a direct impact on their efficiency in environmental remediation. By optimizing the structure and properties of photocatalysts, their degradation rate and efficiency for pollutants can be significantly improved. Moreover, modified photocatalysts can work stably under a wider range of environmental conditions, such as maintaining high photocatalytic activity under visible light irradiation. Therefore, the preparation and modification of photocatalysts are not only important areas of scientific research but also key to advancing the practical application of environmental remediation technologies.

3. Application of Photocatalysis Technology in Environmental Remediation

Photocatalysis technology, known for its efficiency and environmental friendliness, has been widely applied in the field of environmental remediation. Through the photocatalytic process, harmful gases in the air, organic pollutants in water bodies, and contaminated soil can be effectively degraded, offering a feasible technological path for environmental purification and restoration.

3.1. Air Purification

3.1.1. Degradation Mechanism of Harmful Gases: In the realm of air purification, photocatalysis technology can effectively degrade various harmful gases, such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). Under light irradiation, photocatalysts generate electron-hole pairs, which can react with water (H_2O) and oxygen (O_2) to produce highly oxidative

hydroxyl radicals ($\text{OH}\cdot$) and superoxide anions (O_2^-), thereby oxidizing and degrading harmful gases [3].

3.1.2. Experimental Research and Case Study Analysis: Numerous experimental studies have demonstrated the effectiveness of photocatalysis technology in air purification. For example, modified titanium dioxide photocatalysts have significantly improved the removal efficiency of NO_x . Moreover, there are practical applications, such as photocatalytic road coatings and air purifiers, showcasing the vast potential of photocatalysis technology in real-world air purification.

3.2. Water Purification

3.2.1. Degradation Mechanism of Organic Pollutants: In water purification, photocatalysis technology exhibits strong capabilities, especially in removing organic pollutants and heavy metal ions. The core of this technology lies in the generation of highly reactive species, such as hydroxyl radicals and superoxide anions, under light conditions. These reactive species possess strong oxidative power, capable of attacking and breaking down the chemical structures of organic pollutants, ultimately transforming them into carbon dioxide, water, and other harmless small molecules. A significant advantage of this process is its minimal secondary pollution, making photocatalysis technology more environmentally friendly compared to traditional chemical treatment methods.

3.2.2. Removal Effects on Heavy Metal Ions: Besides degrading organic pollutants effectively, photocatalysis technology also excels in removing heavy metal ions from water. Through photocatalytic reactions, heavy metal ions can be transformed into their stable, insoluble forms, such as oxides or sulfides, and removed from the water as precipitates. This aspect is crucial for water quality purification, as heavy metal contamination not only poses severe environmental impacts but also directly threatens human health [4].

The advantages of photocatalysis technology in water purification not only demonstrate its immense potential in environmental remediation but also indicate the direction for future research and technological improvements. To further enhance the purification efficiency and application range of photocatalysis technology, researchers need to continue exploring more efficient photocatalysts, optimize the design of photocatalytic systems, and address challenges in practical applications, such as the recycling and long-term stability of photocatalysts.

3.2.3. Experimental Research and Case Study Analysis: Many experimental studies have shown that photocatalysis technology can effectively treat various types of organic polluted water, such as dye wastewater and pesticide-contaminated water bodies. In practical applications, photocatalytic reactors have been used for industrial wastewater treatment, demonstrating good treatment effects and broad application prospects.

3.3. Soil Remediation

3.3.1. Degradation Mechanism of Organic Pollutants: Photocatalysis technology primarily relies on its ability to degrade organic pollutants in soil remediation, transforming harmful organic compounds in the soil into harmless substances. This process utilizes the highly reactive radicals, such as hydroxyl radicals, generated by photocatalysts under light conditions to directly attack pollutant molecules, breaking their chemical structures and thus achieving remediation goals [5].

3.3.2. Remediation Effects on Heavy Metal Contaminated Soil: For soils contaminated with heavy metals, photocatalysis technology also shows certain remediation potential. Specific photocatalysts can induce heavy metal ions to transform into their stable, insoluble forms, such as sulfides or oxides,

thereby being immobilized in the soil or removed through subsequent treatments. This method is significant for reducing the mobility and bioavailability of heavy metals in the environment.

3.3.3. Experimental Research and Case Study Analysis: In recent years, many laboratory studies have focused on the application of photocatalysis technology in soil remediation. Through laboratory simulation experiments, scientists have confirmed the effectiveness of photocatalysis technology in degrading various organic pollutants in soil, such as petroleum hydrocarbons and pesticide residues. Moreover, there are case studies where contaminated soil was directly treated with photocatalysts, not only verifying the efficacy of photocatalysis technology but also providing valuable experiences for its application in real environments.

4. Challenges and Future Directions for Photocatalysis Technology

Despite the enormous potential and advantages demonstrated by photocatalysis technology in the field of environmental remediation, there are still a series of challenges to overcome in its promotion and application.

4.1. Strategies to Improve Photocatalysis Efficiency

Currently, enhancing the efficiency of photocatalysis remains a primary focus of research efforts. This includes developing new, highly efficient photocatalysts, optimizing the structure and composition of photocatalysts, and improving the design of photocatalysis systems. For example, the fabrication of nanostructured photocatalysts using nanotechnology not only increases the specific surface area of the photocatalysts but also provides more active sites, thereby enhancing photocatalytic efficiency [6].

4.2. Challenges in Large-Scale Application of Photocatalysis Technology

The large-scale application of photocatalysis technology still faces issues related to cost, stability, and sustainability. Finding ways to produce photocatalysts at low cost, ensuring their long-term stable use while maintaining photocatalytic efficiency, are urgent problems that need to be addressed in current research and technological development. Moreover, developing photocatalysis systems that can work efficiently under natural sunlight is key to advancing the practical application of photocatalysis technology.

4.3. Future Research Directions and Prospects

Looking ahead, research on photocatalysis technology will delve deeper into the essence of photocatalytic mechanisms, explore more unknown photocatalyst materials, and new phenomena and effects during the photocatalytic process. Additionally, combining modern technological means such as artificial intelligence and big data to optimize the design and synthesis of photocatalysts, predict photocatalytic performance, and accelerate the discovery and application process of photocatalytic materials will be crucial. Furthermore, integrating photocatalysis technology with other environmental protection technologies, such as biotechnology and adsorption technology, will be an important direction for future research, aiming to achieve more comprehensive and efficient environmental remediation effects.

In the process of promoting photocatalysis technology, designing suitable photocatalysis systems for different environmental pollution problems, including the selection of appropriate photocatalysts, light sources, and reactor designs, is key to realizing the application of photocatalysis technology. At the same time, the integration and intelligence of photocatalysis systems are also future development trends, facilitating the monitoring of system operation status, real-time adjustment of operating conditions, and ensuring optimal treatment effects.

As society's awareness of environmental protection continues to strengthen and the demand for sustainable development becomes increasingly urgent, research and application of photocatalysis technology in the field of environmental remediation will continue to receive attention. Due to its unique advantages, such as high efficiency, environmental friendliness, and wide application potential,

photocatalysis technology is expected to play an increasingly important role in environmental remediation in the future, contributing to the realization of green development and the construction of a beautiful Earth.

5. Conclusion

In this study, we have thoroughly explored the cutting-edge progress and significant achievements of photocatalysis technology in the field of environmental remediation, especially its applications in air purification, water purification, and soil remediation. Through continuous innovation and improvement, photocatalysis technology has demonstrated great potential in addressing contemporary environmental challenges. However, despite numerous advances, the practical application of this technology still faces challenges in terms of efficiency enhancement, cost reduction, and sustainability. Future research needs to deepen the understanding of photocatalysis mechanisms on the basis of developing more efficient and environmentally friendly photocatalysis systems. Additionally, interdisciplinary collaboration and the integrated application of technologies will be key to achieving large-scale application of photocatalysis technology in environmental remediation. With technological progress and increased societal awareness of environmental protection, photocatalysis technology is expected to become an important force in future environmental restoration efforts, contributing to the creation of a cleaner and more sustainable global environment.

References

- [1] Zhan X, Lei T, Wang L, et al. Enhanced photocatalytic removal of tetracycline and methyl orange using Ta₃N₅@ZnIn₂S₄ nanocomposites [J]. Journal of Photochemistry & Photobiology, A: Chemistry, 2024, 451 115538-.
- [2] Chengula J P, Charles H, Pawar C R, et al. Current trends on dry photocatalytic oxidation technology for BTX removal: Viable light sources and highly efficient photocatalysts. [J]. Chemosphere, 2024, 351 141197-141197.
- [3] Lifang H, Mengting X, Xin H, et al. Photocatalytic degradation of tetracycline hydrochloride by ZnO/TiO₂ composite photocatalyst [J]. Journal of Materials Science: Materials in Electronics, 2023, 34 (36):
- [4] Mengjiao W, Junfeng C, Yushan W, et al. Research progress and prospect of metal-organic framework and covalent-organic framework for photocatalytic treatment of harmful algal blooms [J]. Journal of Water Process Engineering, 2023, 56
- [5] Zhiio Z. Research progress of semiconductor photocatalysis applied to environmental governance [J]. IOP Conference Series: Earth and Environmental Science, 2021, 631 (1): 012022-.
- [6] Nanotechnology - Photocatalytics; New Photocatalytics Findings from East China University of Science and Technology Described (Research Progress of Photocatalysis Based On Highly Dispersed Titanium In Mesoporous Sio₂) [J]. News of Science, 2019,