Linking Secondary School Chemistry with Modern Chemistry through Textbook Reading Materials: The Primary Principle of Photocatalytic Degradation of Organic Wastewater by Nano Ag-based Composite Materials

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Abstract. In the reading materials of the new standard high school chemistry textbooks, there are frontier contents of modern chemistry such as nanotechnology and new materials. In order to coordinate with teachers' teaching and improve the overall classroom effectiveness, this paper succinctly introduces the main principle of photocatalytic degradation of organic wastewater by nano Ag-based composite materials, a research topic in modern chemistry. It is provided as a link and bridge between secondary school chemistry and modern chemistry for frontline teachers to read and select.

Keywords: High school chemistry, Modern chemistry, Nano Ag-based composite materials, Photocatalysis, Organic wastewater.

1 Introduction

Since the reform and opening-up, with the continuous development of the national economy, people's living standards have been improving. However, along with this progress, various pollution problems have emerged. Among them, water pollution has a particularly prominent impact on the environment. With the proposal of the development concept "Lucid waters and lush mountains are invaluable assets," environmental issues have once again received widespread attention.

Traditional methods for water pollution control such as separation and conversion methods have shortcomings including low degradation efficiency and poor treatment effects. Photocatalysis technology, as a new type of green environmental protection technology, can utilize efficient photocatalysts to degrade organic dyes through photocatalytic reactions. From the perspective of ecological environment restoration and conservation of Earth's energy resources, photocatalysis technology has advantages

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such as economy, high efficiency, and non-toxicity, making it one of the most advantageous methods for addressing water pollution issues.

Since 1972, with the continuous development of photocatalysis technology, numerous photocatalysts have become well-known and utilized by people. However, there are still many issues such as limited application, poor stability, and low efficiency associated with many photocatalysts. Therefore, the preparation of efficient, stable, and high-performance photocatalysts remains a hot topic in recent years[1-3].

As photocatalysts, nano Ag-based composite materials have garnered significant research interest[4,5]. Compared to other noble metals, nano Ag particles exhibit surface plasmon resonance effects, resulting in extremely high visible light absorption rates. Acting as a medium for charge carrier transfer between semiconductors, they can effectively prevent electron-hole recombination. Therefore, under visible light, they demonstrate excellent performance in degrading organic dyes.

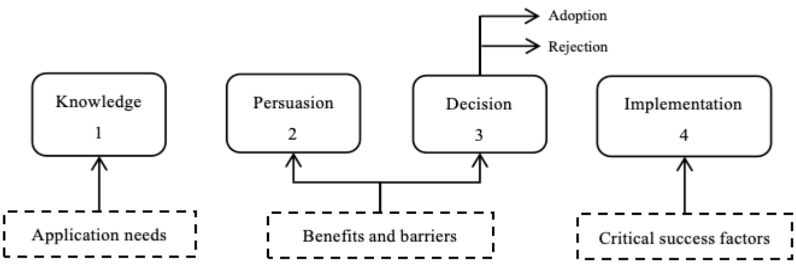

Fig. 1. Research Theoretical Framework.

Regarding the application of nano Ag-based composite materials in photocatalysis technology, this study will follow an innovative decision-making framework, details of which can be found in Figure 1. It will briefly introduce the basic principles of photocatalysis technology for degrading organic dyes, common synthesis methods of nano Ag-based composite materials, and how to apply them as photocatalysts for degrading organic dyes in water bodies. Furthermore, it will analyze the advantages of these materials compared to other photocatalysts in terms of performance and the obstacles encountered in current research. Finally, we will compare the strengths and weaknesses of different synthesis methods in terms of photocatalytic performance. By integrating these methods, key success factors will be proposed, and prospects for future research directions will be discussed.

2 Application Needs

2.1 The Basic Principle of Photocatalytic Technology for Degrading Organic Dyes

Organic synthetic dyes (such as methylene blue, Methyl Orange, Rhodamine B, Fuchsin basic, Congo red, etc.) are commonly used in various industrial processes. Due to their indiscriminate usage, these dyes are discharged as industrial wastewater into reservoirs uncontrollably, causing extremely severe pollution to water bodies and leading to adverse structural changes in the ecological environment[6]. As humans consume aquatic organisms, these toxic dyes accumulate continuously within aquatic environments, indirectly affecting human beings. Once these organic dye components are ingested, they strongly impact various self-regulatory systems in the human body, including the respiratory system, digestive system, and nervous system, posing a significant threat to human health. Therefore, it is imperative to devise advanced strategies for the degradation of these organic dyes in water bodies[7].

Photocatalysis technology is an emerging green environmental protection technique, details of which can be found in Figure 2. It utilizes the unique property of semiconductor nano-materials to be activated by surface energy under visible light, thereby facilitating oxidation-reduction reactions at room temperature using light energy. This process effectively degrades organic compounds. The basic principle of this technology is as follows:

Photocatalysis technology harnesses the absorption of light by semiconductor materials, causing the electrons in the valence band to be excited by the energy from light, transitioning to the conduction band. This process creates photogenerated electrons in the conduction band and corresponding holes in the valence band. Due to the existence of a bandgap between the conduction and valence bands in semiconductor materials, photogenerated electrons and holes have a sufficiently long lifetime before recombination. This allows photogenerated electrons and holes to migrate directionally to the surface of the photocatalyst, where oxidation-reduction reactions involving energy and charge exchange occur. Consequently, this facilitates the production of hydrogen, the reduction of carbon dioxide, the production of oxygen, and the degradation of organic pollutants.

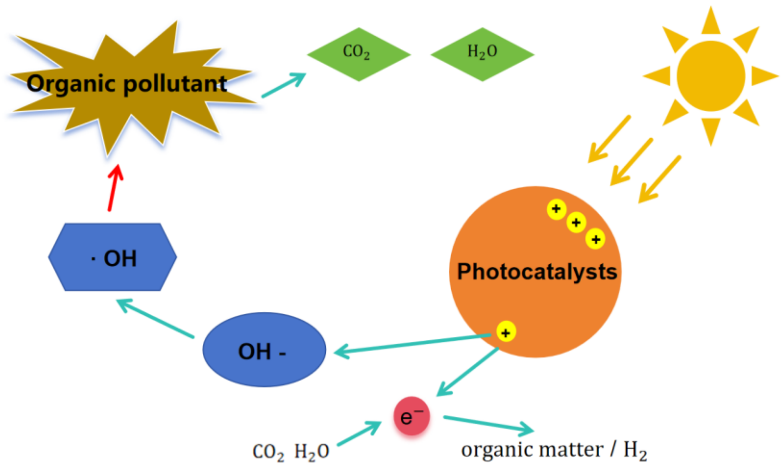

Fig. 2. Photocatalytic reaction mechanism.

2.2 The Basic Principle of Nano Ag-based Composite Materials as Photocatalysts for Degrading Organic Dyes

In recent years, compared to other photocatalysts, nano Ag-based composite materials have demonstrated superior photocatalytic performance in degrading organic dyes, making them more favored by researchers[8-10]. Many scholars have conducted extensive research on the use of nano Ag-based composite materials as photocatalysts for degrading organic dyes[11]. The basic principle of their use as photocatalysts for degrading organic dyes is as follows:

During synthesis or photocatalysis processes, nano Ag-based composite materials readily generate noble metal nano Ag. These nano Ag particles are prone to surface plasmon resonance effects around the conduction band of Ag-containing compounds, details of which can be found in Figure 3. Because the energy of photogenerated electrons excited by surface plasmon resonance effects is higher than that of electrons in the conduction band of semiconductor compounds, under the driving force of thermal dynamics or potential difference, the photogenerated electrons of nano Ag migrate to the conduction band of the semiconductor, thereby effectively degrading organic synthetic dyes.

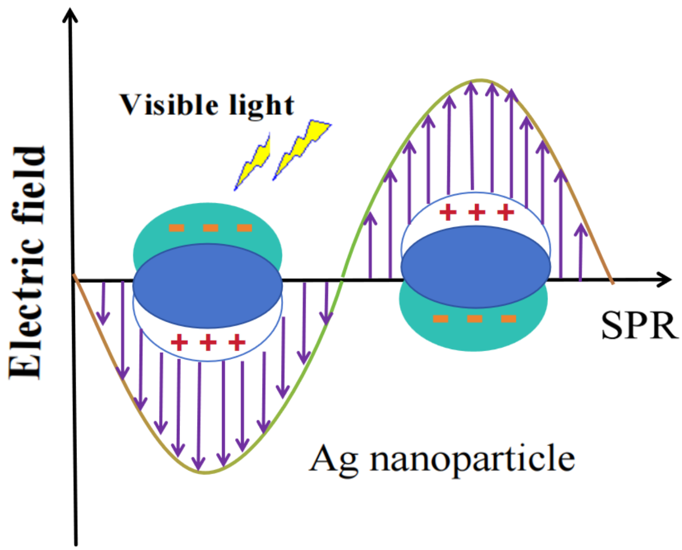

Fig. 3. Schematic of surface plasmon resonance effect of Ag nanoparticle.

3 Common Synthesis Methods and Their Adoption/Rejection

3.1 Hydrothermal Method

The hydrothermal method is a technique for chemical reactions conducted in a closed system under high temperature and pressure, commonly used in the preparation of nano Ag-based composite materials[12-16]. In hydrothermal reactions, precursors in the solution undergo corresponding physicochemical changes due to heating and pressure increase in the hydrothermal vessel, leading to the formation of the desired nano particles.

The hydrothermal method is widely employed due to its ability to produce nano-materials with good crystallinity and controllable morphology, a characteristic not exempt in the preparation of nano Ag-based composite materials. By optimizing reaction conditions, high-performance nano composite materials with specific characteristics and functions can be obtained. These materials hold significant application value in catalysis, sensing, electronics, biomedicine, and other fields. However, drawbacks are also evident; this method requires high equipment and energy consumption and entails certain safety risks.

3.2 Reduction Method

The reduction method is one of the most commonly used methods for preparing nano Ag-based composite materials, typically involving the reduction of Ag^+ to Ag using a chemical reducing agent to form nanoscale Ag particles[17-19].

In actual production and preparation, it is necessary to consider how to mitigate or eliminate the impacts of these drawbacks through post-treatment steps, such as washing, centrifugation, and filtration, to enhance the purity and dispersion of nano Ag. Additionally, selecting environmentally friendly reducing agents and stabilizers, along with optimizing synthesis conditions, can improve synthesis efficiency to some extent and reduce environmental impact.

3.3 Thermal Treatment Method

The thermal treatment method is an important approach in the preparation of nano Ag-based composite materials. It typically involves heating the precursor of metallic Ag or Ag-containing compounds to a certain temperature, causing their decomposition or reduction to form nanoscale Ag particles[20-22]. The thermal treatment process can be conducted in inert, reducing, or oxidizing atmospheres to control the composition and structure of the resulting products.

In practical applications, the thermal treatment method is often combined with other techniques to optimize the performance of nano Ag-based composite materials. For instance, nanoscale particles obtained through thermal treatment may further composite with organic materials such as polymers to improve their dispersibility, stability, and functionality. Despite some limitations in the preparation of nano Ag-based composite materials, the thermal treatment method remains a highly useful means due to its simplicity, controllability, and high purity.

The above provides a brief description of common synthesis methods for nano Ag-based composite materials and their respective advantages and disadvantages. For the detailed research framework, refer to Figure 4.

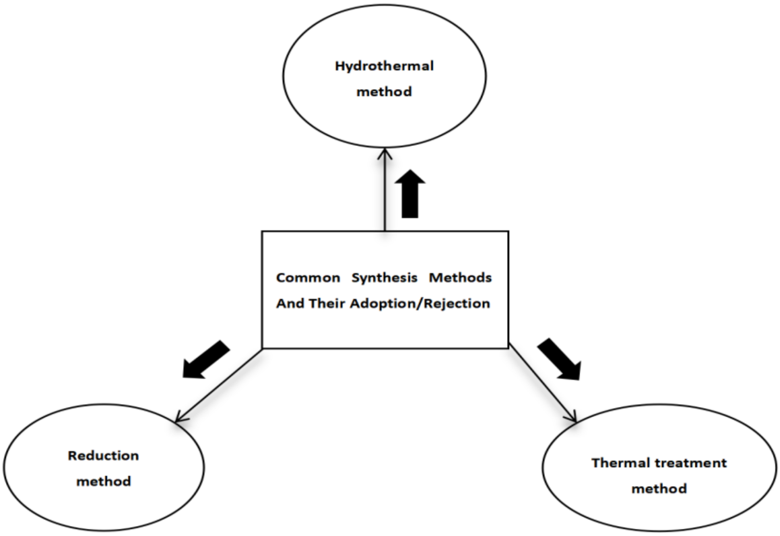

Fig. 4. The Specific Research Framework of This Section.

4 Benefits and Barriers

4.1 Performance Benefits of Nano Ag-based Composite Materials Compared to Other Photocatalysts

Compared to traditional semiconductor photocatalysts, the main reason for the high performance of nano Ag-based composite materials as photocatalysts in degrading organic dyes lies in the following factors: these materials readily generate noble metal nano Ag during synthesis or photocatalysis processes, and they exhibit a unique surface plasmon resonance effect under visible light.

Surface Plasmon Resonance (SPR) is a physical phenomenon based on collective oscillations of free electrons on the surface of a metal. When light of a certain frequency illuminates the metal surface (usually noble metals such as gold or Ag), the electromagnetic field of the light can excite the free electrons on the metal surface, causing them to oscillate at the same frequency as the incident electromagnetic wave. This oscillation mode forms at the metal-dielectric interface, known as Surface Plasmon Waves (SPW). When the frequency of the incident light matches the intrinsic frequency of the surface free electrons, resonance occurs, known as surface plasmon resonance. Under resonance conditions, the oscillation intensity of surface electrons reaches its maximum, leading to a significant increase in light absorption on the metal surface, which is highly beneficial for visible light absorption and carrier migration. This not only improves the utilization of visible light in the photocatalytic system but also significantly enhances its ability to degrade organic synthetic dyes.

4.2 Current Challenges Encountered in the Research of Nano Ag-based Composite Materials

Based on the research conducted by numerous scholars in recent years on nano Ag-based composite materials, two main issues have been identified regarding their use as photocatalysts:

Firstly, these materials lack sufficient stability, which is fundamental for the sustained action of photocatalysts. The Ag ions on the surface of nano Ag-based composite materials are easily reduced by photogenerated electrons, leading to photodegradation phenomena. This greatly affects the stability of nano Ag-based composite materials as photocatalysts. Although these materials generate noble metal nano Ag during the photocatalysis process, thereby enhancing their stability through surface plasmon resonance effects, excessive nano Ag can hinder light absorption, thereby hindering the improvement of photocatalytic efficiency.

Secondly, the use of noble metal Ag increases the cost of using photocatalysts, which is unfavorable for large-scale industrial production.

5 Critical Success Factors

The key factor in preparing ideal nano Ag-based composite materials as photocatalysts lies in finding a new synthesis method to address the shortcomings in their photocatalytic performance. If we can successfully resolve the issue of photodegradation of nano Ag-based composite materials in a new photocatalytic system, coupled with precise theoretical calculations to reduce experimental costs, we can produce ideal nano Ag-based composite materials. Applying these materials in photocatalytic systems will significantly enhance the degradation capability of organic synthetic dyes, thereby greatly improving their photocatalytic performance. This will be a key focus for future research and attention.

6 Conclusion

In summary, this paper compares the application requirements of nano Ag-based composite materials as photocatalysts and their specific mechanisms in photocatalytic systems. It introduces several common synthesis methods and briefly evaluates the advantages and disadvantages of each method. Additionally, it highlights the advantages of nano Ag-based composite materials over traditional catalysts in terms of photocatalytic performance, as well as the existing issues in current research stages. Finally, based on the ideal photocatalyst in industrial applications as a benchmark, key factors for preparing ideal nano Ag-based composite materials as photocatalysts are proposed, along with prospects for future research directions.

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