A Comprehensive Review of Cadmium Oxide Nanoparticles in Photocatalysis: Synthesis, Mechanisms and Applications

Mr. Deepak Singhwal

Research Scholar, Deenbandhu Chhotu Ram University Of Science And Technology Murthal Sonepat

Abstract

Cadmium oxide nanoparticles (CdO NPs) have emerged as important photocatalysis candidates, capturing the attention of both academics and engineers. This comprehensive study digs into the production processes, photocatalytic mechanisms, and many photocatalytic uses of CdO NPs. The synthesis of CdO NPs is thoroughly examined, with methods such as sol-gel, hydrothermal, and chemical vapour deposition covered in detail, allowing for a more nuanced knowledge of the nanoparticle's structural properties. These synthesis processes' physical and chemical features are significant elements influencing their photocatalytic activity. The review sheds information on charge carrier dynamics, surface reactions, and their interaction with photons, as well as the complicated photocatalytic pathways involving CdO NPs. It is emphasised the importance of bandgap engineering, defect states, and surface alterations in customising photocatalytic activity. The report also highlights CdO NPs' diverse potential in pollutant degradation, water purification, hydrogen synthesis, and solar energy conversion. They are excellent options for tackling environmental concerns and enhancing renewable energy technology due to their high photocatalytic efficiency and selectivity.

In summary, this study provides a thorough overview of CdO NPs in photocatalysis, emphasising their synthesis methodologies, mechanistic insights, and a wide range of applications. It emphasises their potential to significantly contribute to long-term energy and environmental solutions, while also addressing safety and toxicity issues connected with cadmium-based products.

Keywords: Nanoparticles, Sol-gel, Hydrothermal, Co-precipitation, Photocatalytic activity

Introduction

The historical practice of preparing and utilizing dyes can be traced back to ancient times. Initially, natural dyes were the primary choice, characterized by their biodegradability. However, in today's context, as the demand for dyes escalates across various sectors like textiles, paper, paint, leather, and more, there has been a proliferation of synthetic dyes. These artificial dyes are engineered to possess chemical and ultraviolet light resistance, ensuring biostability. Regrettably, this proliferation of synthetic dyes poses a significant environmental threat, particularly to aquatic ecosystems.(khodabakshi, 2012)

Setting aside the numerous traditional approaches to eliminating organic pollutants, the advanced oxidation process (AOP) has emerged as a cost-effective, expeditious, and environmentally friendly alternative (Gupta 2009). Among the plethora of semiconducting materials available, CdO, classified as an n-type semiconductor, emerges as a highly promising contender for applications in optoelectronics, solar cells, transparent electrodes, gas sensors, and photocatalysis. (Senthil kumar 2014)

However, a prominent challenge associated with utilizing this semiconductor lies in the swift recombination of photo-induced electron-hole pairs, a phenomenon that diminishes its photoactivity. Numerous approaches have been explored to address this issue, with particular emphasis placed on the development of composites involving noble metals, a strategy that has garnered noteworthy attention.(Ren 2010)

The incorporation of various metals, ranging from transition metals to alkali metals, plays a pivotal role in the photocatalytic degradation of a wide spectrum of environmental contaminants. This strategic doping strategy empowers the host material to undergo tailored modifications, finely tuned to the unique demands of its intended application. Each dopant brings forth its distinct set of properties, making it possible to engineer photocatalysts with enhanced efficiency and selectivity. This versatile approach not only expands the scope of photocatalysis but also contributes to the advancement of sustainable solutions for pollution remediation and energy conversion, marking a significant step towards a cleaner and more environmentally friendly future.(Aydina 2017)

Literature review

(Shamim 2022) Cadmium oxide (CdO) nanoparticles were successfully synthesized via the sol-gel reaction method employing ethanol as the precursor. This synthesis aimed to investigate their structural, optical, morphological, and photocatalytic attributes. The synthesized CdO nanoparticles were assessed for their photocatalytic efficacy in degrading methyl orange (MO) under visible light irradiation. Remarkably, the most favorable results were achieved within a mere 45-minute interval. This leads to the conclusion that, when prepared through the sol-gel approach at the nanoscale, cadmium oxide nanoparticles exhibit heightened effectiveness as photocatalysts.

(S. Kumar 2016) Utilizing a one-step hydrothermal technique, we successfully synthesized cadmium oxide (CdO) nanoparticles (NPs), reduced graphene oxide (rGO), and rGO-CdO nanocomposites. These synthesized materials were subjected to photocatalytic evaluation under UV irradiation. The outcomes of these photocatalytic assessments demonstrated that the inclusion of rGO-CdO nanocomposites as photocatalysts in the dye solution resulted in the degradation of approximately 80% of the MB dye, highlighting their potent photocatalytic activity.

(D. singhwal 2023) In this article, we delve into the characterization of cadmium oxide (CdO) nanoparticles, both in their pure form and as zinc (Zn) and silver (Ag) co-doped variants, all synthesized via the co-precipitation method. Our investigation centers on the photocatalytic properties of these prepared samples, employing Crystal Violet (CV) dye under natural sunlight radiation. Notably, our findings reveal a progressive enhancement in degradation efficiency as we transition from pure CdO to the co-doped CdO nanoparticles. Remarkably, the co-doped CdO nanoparticles exhibited a remarkable 98% degradation of the CV dye after an exposure of 120 minutes to sunlight, underlining their superior photocatalytic performance.

(S. Kumar 2017) Cadmium oxide (CdO) nanorods (NRs) were successfully synthesized through a straightforward co-precipitation technique, showcasing their potential for large-scale production. We examined the photocatalytic capabilities of these CdO NRs in the degradation of methylene blue (MB) dye, utilizing a UV light source equipped with an 8W tube. The remarkable photodegradation rate observed, even under low-power UV irradiation, can be attributed to the high surface area and synergistic effects present in the synthesized CdO NRs. This promising performance renders the entire process economically viable. The development of such cost-effective and efficient materials for photocatalysis and electrode applications holds great promise for advancing the next generation of photocatalysts and supercapacitor electrodes.

Objective of the study

- Comprehensive Literature Review: To give a thorough review of the available literature on cadmium oxide (CdO) nanoparticles as photocatalysts, including their production techniques, structural features, and diverse applications.
- Synthesis techniques: To investigate and summarise the numerous synthesis techniques used for CdO photocatalysts, emphasising their benefits, limits, and recent advances.
- Photocatalytic Mechanisms: To understand the basic photocatalytic mechanisms that underpin CdO nanoparticles, with a focus on charge carrier dynamics, surface reactions, and the effect of defects.

Research Methodology

A systematic research technique was used to guarantee a complete and rigorous study of the current literature in this review paper on cadmium oxide nanoparticles (CdO NPs) as photocatalysts. The resulting study methodology gave an organised strategy to completing the review, encouraging transparency, credibility, and dependability in information synthesis from many sources.

Analysis

What is a Photocatalyst?

A photocatalyst is a substance that expedites a chemical reaction when exposed to light, typically in the presence of a specific reactant. This process, known as photocatalysis, is widely utilized in various applications, including environmental cleanup, water purification, air decontamination, and renewable energy production.

At its core, photocatalysis involves the absorption of photons, which are particles of light, by the surface of the photocatalyst. This absorption leads to the generation of electron-hole pairs, where electrons are excited to higher energy levels and leave behind positively charged "holes." These electron-hole pairs can then engage in chemical reactions with other molecules or compounds that come into contact with the photocatalyst's surface.

Degradation Efficiency of a photocatalyst

The evaluation of photocatalytic performance was conducted on both pure and doped cadmium oxide nanoparticles, utilizing sunlight exposure and an aqueous solution containing dye. To prepare the dye solution, double distilled water was employed to create a 5ppm concentration solution. In the study, a 50 ml volume of the dye solution was mixed with 50 mg of the sample. To establish adsorption and desorption equilibrium, this mixture was stirred in darkness for 30 minutes before being subjected to sunlight radiation. Subsequently, with continuous stirring, the solution was exposed to natural sunlight, and samples (aliquots) were extracted at specific time intervals. Analysis of these aliquots was performed using a UV-Vis spectrophotometer to determine the residual amount of dye remaining after irradiation.The percentage degradation of the dye was calculated using the following formula, allowing for an assessment of the photocatalytic efficacy:

$$\% \text{ Degradation} = \frac{(A_0 - A_t)}{A_0} \text{ x } 100 \quad \textbf{(1)}$$

In this context, A_0 signifies the initial absorbance of dye before being subjected to sunlight, while A_t represents the absorbance measured at any subsequent time after exposure.This can be understandable by the figure.1

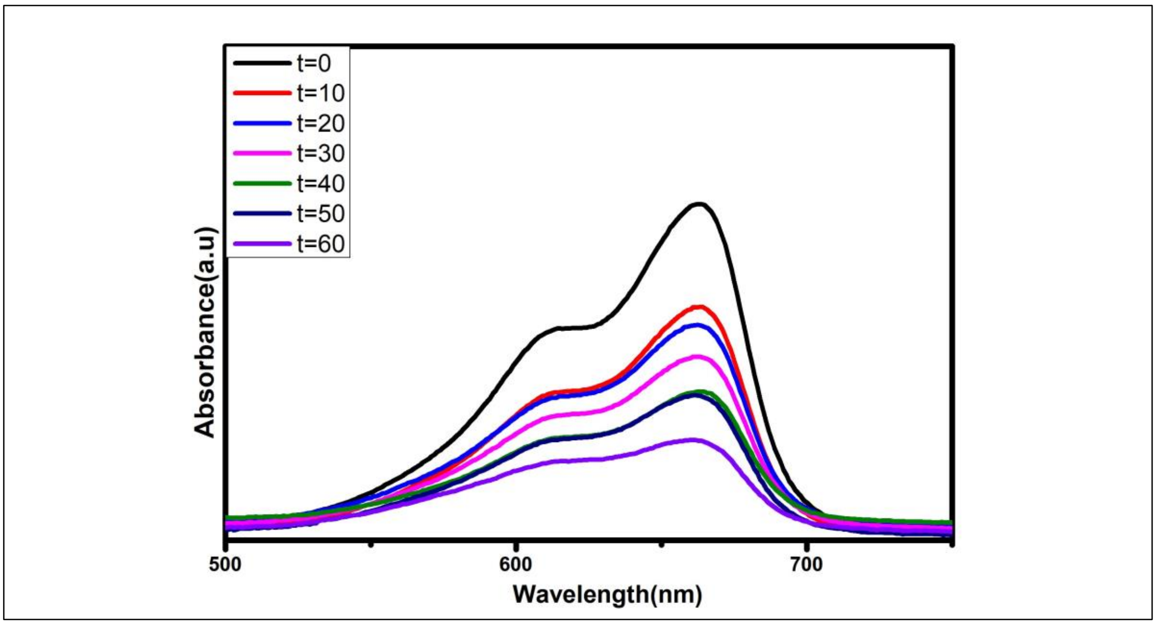

Figure 1. Dye degradation mechanism

Conclusion

In conclusion, the comprehensive investigation into cadmium oxide (CdO) nanoparticles as photocatalysts for the degradation of dyes has yielded valuable insights into their exceptional potential in environmental remediation and sustainable technology applications. The compilation of data, as demonstrated in Table 1 below, clearly illustrates the remarkable photocatalytic efficiency of CdO nanoparticles across various dye degradation experiments.

Table 1

Sr. No.	**Dye**	**Degradation Efficiency (%)**	**References**
1	Methylene Blue	80	**[7]**
2	Methyl orange	50	**[6]**
3	Malachite Green	78	**[10]**
4	Crystal Violet	98	**[8]**
5	Rhodamine B	96	**[11]**

References

1. A. Khodabakshi, M.M. Amin, Determination of malachite green in trout tissue and effluent water from fish farms, Int. J. Environ. Health Eng. 1 (2012) 10.
2. V.K. Gupta, Suhas, application of low-cost adsorbents for dye removal – a review, J. Environ. Manag. 90 (8) (2009) 2313–2342.
3. P. Senthil Kumar, M. Selvakumar, Purabi Bhagabati, B. Bharathi, S. Karuthapandian, S. Balakumar, CdO/ZnO nano hybrids: facile synthesis and morphologically enhanced photocatalytic performance, RSC Adv. 4 (2014) 32977–32986.
4. C. Ren, B. Yang, M. Wu, J. Xu, Z. Fu, Y. Lv, T. Guo, Y. Zhao, C. Zhu, Synthesis of Ag/ZnO nanorods array with enhanced photocatalytic performance, J. Hazard. Mater. 182 (2010) 123–129.
5. R. Aydina, B. S¸ ahinb, Comprehensive research on physical properties of Zn and M (M: Li, Na, K) double doped cadmium oxide (CdO) nanostructures using SILAR method, Ceram. Int. 43 (2017) 9285–9290.
6. S Khan et. al., Photocatalytic degradation of methyl orange by cadmium oxide nanoparticles synthesized by the sol-gel method, Optik 251 (2022) 168401.
7. S Kumar et. al., Cadmium oxide nanoparticles grown in situ on reduced graphene oxide for enhanced photocatalytic degradation of methylene blue dye under ultraviolet irradiation, Journal of Photochemistry & Photobiology, B: Biology 159 (2016) 111–119.
8. D. Singhwal et al., Effect of codoping of Zn and Ag on the spatial, optical and photocatalytic properties of cadmium oxide nanoparticles, Optik, Volume 274,2023,170562.
9. S Kumar et. al., Facile synthesis of CdO nanorods and exploiting its properties towards supercapacitor electrode materials and low power UV irradiation driven photocatalysis against methylene blue dye, Materials Research Bulletin,Volume 90,2017,Pages 224-231.
10. R.K. Mandal et. al., Silver modified cadmium oxide – A novel material for enhanced photodegradation of malachite green, Optik, Volume 180,2019, Pages 174-182.
11. T D Munusamy et. al.,Construction of hybrid g-C3N4/CdO nanocomposite with improved photodegradation activity of RhB dye under visible light irradiation,Advanced Powder Technology,Volume 31, Issue 7,2020,Pages 2921-2931.