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Synthesis of ZnO and BiOCl nanoparticles for the photodegradation of rhodamine b xanthene dye

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ABSTRACT

The study aimed to prepare heterojunction structures for the photocatalytic degradation of RhB, a persistent organic pollutant (POP) that is both carcinogenic and mutagenic. There photocatalyst was prepared in two steps, first the single components, ZnO and BiOCl, followed by the heterojunction. ZnO was prepared using microwave-assisted hydrothermal synthesis at two different temperatures and was subsequently calcined at two different temperatures. The heterojunction was then prepared by depositing BiOCl on the surface of ZnO using hydrothermal synthesis in an autoclave. XRD analysis was used to study the crystallographic structures of the single-component catalysts, which were further indexed according to the literature. The photocatalytic performance of the heterojunction showed improvement compared with that of pure ZnO and BiOCl. ZnO and BiOCl were able to degrade 50% and 82% of the dye, respectively, within 90 minutes. The heterojunctions achieved degradation efficiencies of 94%, 80%, and 99% for ZnO/BiOCl (1:1), ZnO/BiOCl (1:2.5), and ZnO/BiOCl (2.3:1), respectively. Overall, the heterojunctions demonstrated enhanced photocatalytic activity and showed strong potential for POP treatment applications.

INTRODUCTION

Water is vital for human survival; however, its quality has deteriorated due to contamination from pollutants originating in chemical, pharmaceutical, pesticide, herbicide, and textile industries, whose effluents are often discharged into natural water bodies [1]. Among these pollutants, organic dyes such as rhodamine B (RhB), a water-soluble xanthene dye widely used in textiles, printing, leather, paper, and plastics, are of major concern. RhB is highly stable, resistant to biodegradation, and contributes to increased chemical oxygen demand (COD), posing serious environmental and health hazards. It has been identified as mutagenic and carcinogenic, causing developmental and neurotoxic effects in animals and humans [2]. Semiconductor-based photocatalysts have recently gained attention as sustainable materials for degrading such persistent organic pollutants [3]. Photocatalysis is considered environmentally friendly because it converts toxic dyes into harmless products like carbon dioxide and water under light irradiation without additional chemicals. Zinc oxide (ZnO) and bismuth oxychloride (BiOCl) are widely used due to their low cost and stability [4]. However, their wide band gaps (3.4 eV and 3.3 eV) limit visible-light activity, which can be improved through ZnO/BiOCl heterojunction formation to enhance charge separation and photocatalytic efficiency.

AIMS AND OBJECTIVES

Main aim:

To prepare microwave-assisted sol-gel synthesis of ZnO, which was decorated with BiOCl for photocatalytic degradation of rhodamine B xanthene dye.

The primary objectives:

- Synthesis of ZnO, BiOCl, and ZnO/BiOCl,
- To study the crystallographic properties using XRD analysis.
- To evaluate the photocatalytic performance of the synthesised materials under UV conditions in a photocatalytic reactor against methylene blue and rhodamine B.

MATERIAL SYNTHESIS

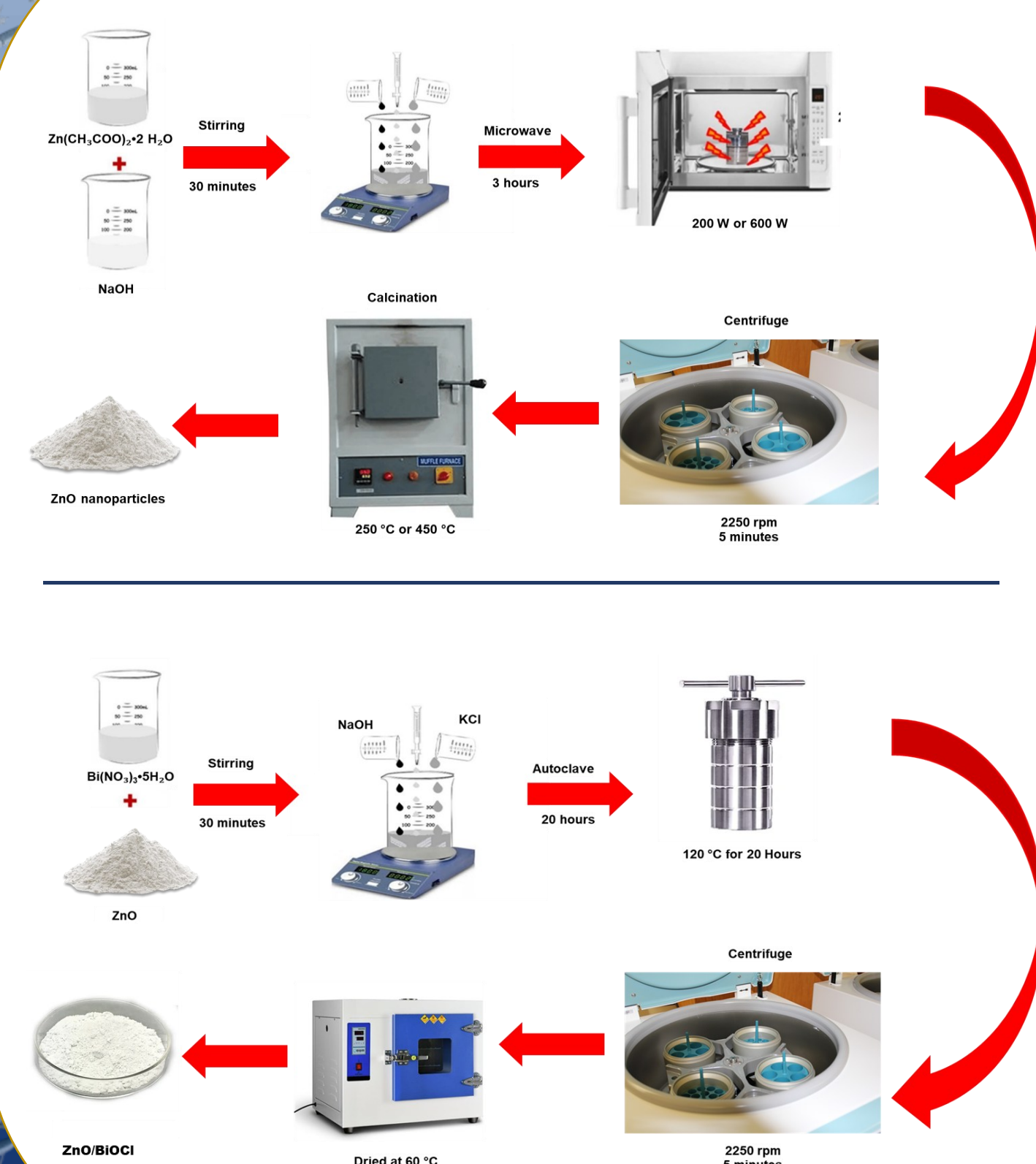


Figure 1: The stepwise synthesis of microwave assisted and calcined ZnO oxide.

Figure 2: The stepwise synthesis of hydrothermal synthesis of BiOCl and ZnO/BiOCl.

Results

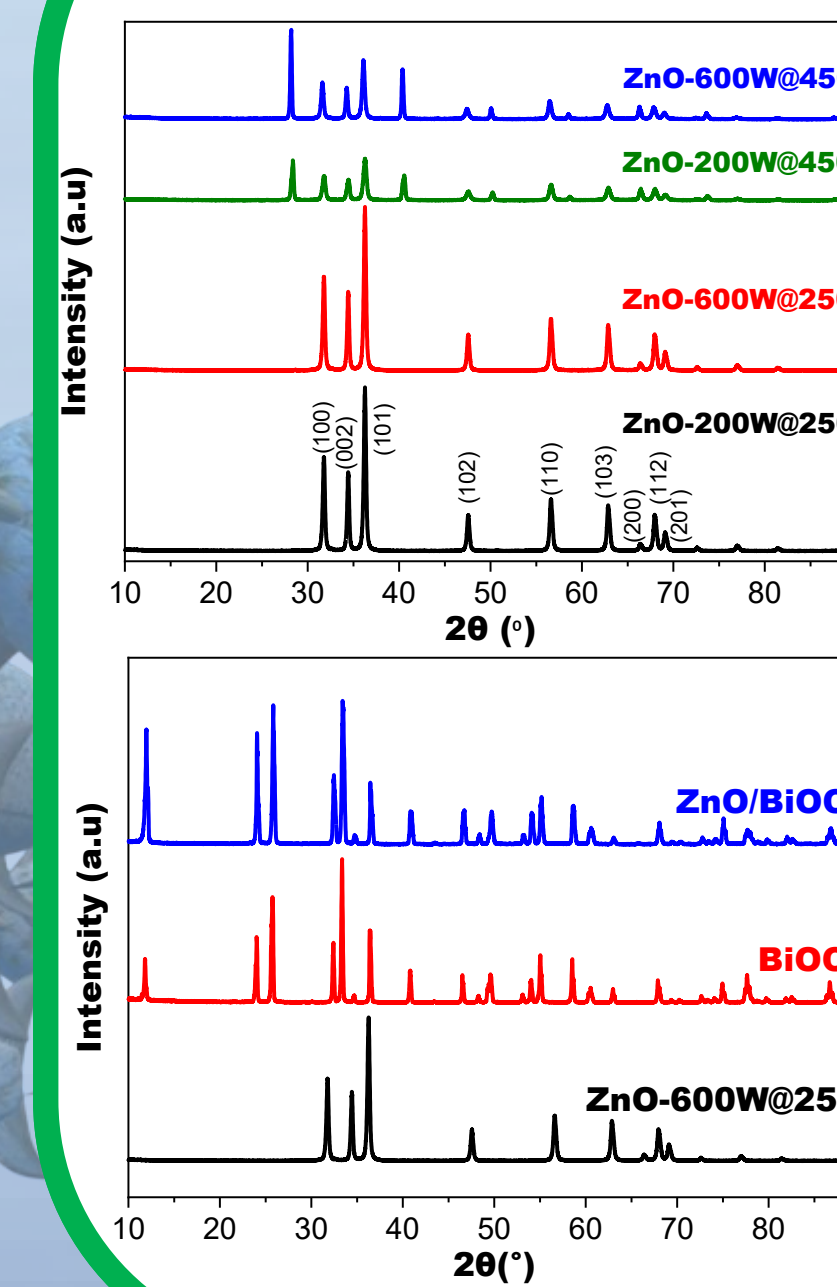


Figure 3: The XRD patterns of ZnO-200W@250, ZnO-200W@450, ZnO-600W@250, and ZnO-600W@450.

XRD diffractogram interpretation

- The observation of pronounced peaks in the XRD patterns in **figure 3** provides evidence for the formation of a pure ZnO phase, which is identified as having a hexagonal wurtzite structure. The major diffraction peaks in ZnO spectra in the range of 10 and 90° at 2θ = 31°, 34°, 36°, 47°, 56°, 62°, 66°, 68°, and 69°, which were indices (100), (002), (101), (102), (100), (103), (200), (112) and (201) which was matched with JCPDS no. 36-1451.
- The diffraction pattern of **figure 4** confirms that the synthesised BiOCl nanoparticles are of pure phase. The diffraction peaks were observed at 2θ = 24°, 25°, 32°, 33°, 34°, 36°, 40°, 46°, 48°, 49°, 53°, 54°, 55°, 58°, 60°, and 68° corresponds to the planes (002), (101), (110), (102), (111), (003), (112), (200), (201), (113), (202), (211), (104), (212), (114), (220), respectively were related to pure phase of BiOCl and matched well with JCPDS no. 06-0249.

Figure 4: The XRD patterns of ZnO, BiOCl, and ZnO/BiOCl.

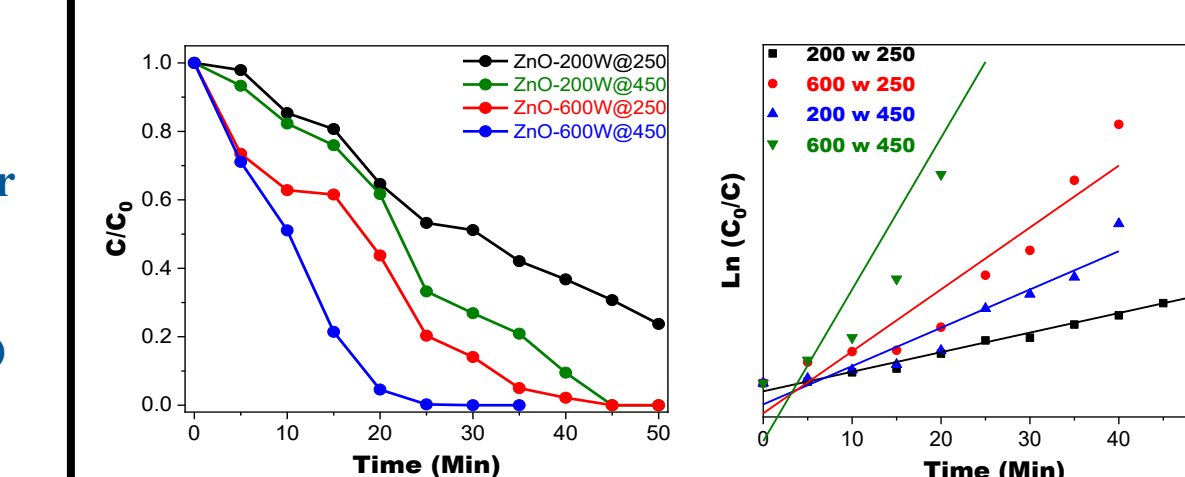


Figure 5: The photocatalytic degradation of MB on ZnO-200W@250, ZnO-200W@450, ZnO-600W@250, and ZnO-600W@450 under UV light at pH=7. b) The pseudo-first-order kinetic fitting curves ZnO-200W@250, ZnO-200W@450, ZnO-600W@250, and ZnO-600W@450 under UV light pH=7.

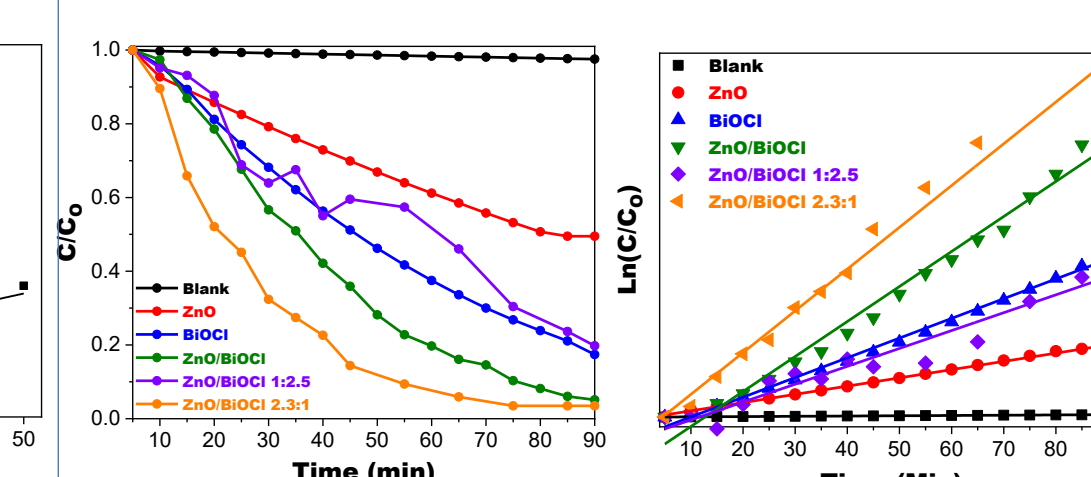


Figure 6: a) The photocatalytic degradation of RhB using BiOCl and ZnO/BiOCl in pH=3 (HNO₃). b) The pseudo-first-order kinetic fitting curves of BiOCl and ZnO/BiOCl in pH=3 (HNO₃).

- **MB degradation**
- The photocatalysts display good performance at a pH of 7
- All were able to completely degrade the methylene blue with the exception of ZnO synthesised at 200 W and calcined at 250 °C.
- The ZnO prepared at 600 W and calcined at 450 °C displayed the best performance with completely degrading the dye within 25 minutes
- The general trend shows that the material prepared at higher power outputs and calcined at higher temperatures has a better performance.

- **RhB degradation**
- The photocatalysts display good performance at a pH of 3
- The UV lamp was only able to degrade 5% of the dye in a span of 90 minutes
- This indicates that the photocatalysts do the actual degradation. The heterojunction structure displays better performance, which could be attributed to the countering of electron-hole pair recombination, which leads to more electrons being available for redox reactions.
- The heterojunctions were able to degrade over 94.89%, 80.22%, and 99.82% in a span of 90 minutes for ZnO/BiOCl (1:1), ZnO/BiOCl (1:2.5), and ZnO/BiOCl (2.3:1), respectively.

Conclusion

- Synthesis of ZnO, BiOCl, and ZnO/BiOCl was completed using microwave-assisted synthesis for ZnO and hydrothermal method for BiOCl and the heterojunction structure.
- The XRD spectrum confirms that the ZnO synthesised is the wurtzite (JCPDS, no. 36-1451) structure and the tetragonal phase of BiOCl (JCPDS, no. 06-0249),
- The photocatalysts display good photocatalytic performance, particularly the BiOCl and the heterojunction against rhodamine B.
- The results from the rhodamine b displayed an improved in performance of BiOCl when coupled with ZnO. BiOCl was able to degrade 82.60%, while ZnO only degraded 50.50%.
- The ZnO/BiOCl heterojunctions were prepared at various mass ratios, the 1:1 mass ratio was able to degraded 94.89%, while the 1:2.5 mass ratio degraded 80.22% of the dye in 90 minutes. The best performing on is the 2.3:1 mass ratio, which degraded 99.82% in a time span of 90 minutes.

Reference

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