

PHOTOCATALYTIC DECOMPOSITION OF RHODAMINE B DYE USING GO/PANI/CEO₂ NANOCOMPOSITE

Mahrugh Akram^{*1}, Maryam Irfan², Aqsa Anwar³, Ayesha Mehmood⁴, Ayesha Nazir⁵,

^{*1,2,3,4,5}Department of Chemistry, Faculty of Science, Government College University of Faisalabad, Pakistan.

¹alislahschool372@gmail.com, ²muryuumm@gmail.com, ³aqsaanwarshah@gmail.com,
⁴ayeshagrewal188@gmail.com, ⁵ayeshanazir690@gmail.com

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Corresponding Author: *

Mahrugh Akram

Abstract

The synthesis of efficient photocatalytic materials for the degradation of rhodamine B is important for the treatment of dye-contaminated water, as rhodamine B is a persistent synthetic dye. In this study, a GO/PANI/CeO₂ nanocomposite has been synthesized and characterized via the co-precipitation method, and its photocatalytic activity for the degradation of the Rhodamine B dye has been assessed under UV and visible-light illumination. The synthesis of the nanocomposite GO/PANI/CeO₂ was achieved by precipitation with NaOH and thermal treatment of graphene oxide, polyaniline, and cerium nitrate hexahydrate. The synthesized material was characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, and UV-visible spectroscopy. The photocatalytic activity was tested by using a solution of Rhodamine B under UV and visible light irradiation. The effect of the amount of catalyst and initial dye concentration was explored, and a pseudo-first-order model was used to determine the degradation kinetics. The crystallite size of the synthesized nanocomposite was estimated to be 13.75 nm, and exhibited characteristic structural features and functional properties of GO, PANI, and CeO₂. In comparison of the irradiation sources, in the process of the degradation of Rhodamine B under the condition of ultraviolet irradiation, the optimum dosage of the catalyst was 0.04 g/100 mL, and the degradation rate was about 81% after 60 min. Under the condition of visible-light, the optimum dosage of the catalyst was 0.03 g/100 mL, and the degradation rate was about 12.5% after 60 min. The degradation efficiency decreased with the progressive increase of the initial Rhodamine B concentration from 10 ppm to 30 ppm. The pseudo-first-order kinetic analysis gave an R² = 0.99 in both UV and visible-light conditions, with reported rate constants of $2.8 \times 10^{-3} \text{ min}^{-1}$ and $1.3 \times 10^{-3} \text{ min}^{-1}$, respectively. The GO/PANI / CeO₂ nanocomposite exhibited significant photocatalytic activity towards Rhodamine B, especially under UV irradiation, suggesting its application for lab-scale degradation of the dye.

INTRODUCTION

Synthetic dyes discharged from various industrial sectors such as textile, printing, leather, pharmaceutical and related industries are a persistent problem in water quality due to the fact that many dye molecules have complex aromatic structures, high chemical stability and biological resistance [1–3]. Coloured effluents may be responsible for reducing light penetration and disrupting the photosynthetic processes of aquatic organisms, and certain products resulting from dyes may be toxicologically problematic. There are several conventional treatment technologies such as adsorption, coagulation, membrane filtration and biological processes that can be used to remove dyes from wastewater; however, some of these technologies will not fully destroy the dye in the wastewater or create secondary waste products [2,4]. As a result, technologies that can convert organic dyes, rather than move them from one phase to the next have been receiving more and more attention.

Rhodamine B (RhB) is a cationic xanthene dye that has a long conjugated structure and high visible-light absorption. It is a stable pollutant that is also studied extensively as a model pollutant for advanced oxidation and photocatalytic processes [5,6]. Heterogeneous photocatalysis is the process of forming electron-hole pairs after being illuminated by a semiconductor material. These charge carriers participate in surface redox reaction and are able to attack and decompose organic dye molecule and form reactive species [7,8]. Rapid electron-hole recombination rate and low efficiency of visible light utilization, however, can limit the photocatalytic efficiency [8,9].

A strategy for obtaining a material that combines complementary properties is nanotechnology-based photocatalysts. Due to its two dimensional structure, oxygen-containing functional groups, and high accessible surface area, graphene oxide (GO) has garnered huge interest in photocatalytic composites [10,11]. GO can improve pollutant adsorption and aid in the migration of charge across the interfaces, which aids in the activity of photocatalysis [10-12]. In a hybrid photocatalyst, further promotion of the interfacial charge-

transfer process can be achieved by using a π -conjugated conducting polymer such as polyaniline (PANI) [13]. PANI/reduced graphene oxide composites have been shown to have a higher visible light degradation efficiency of RhB and other organic dyes which shows the significance of conducting polymers and carbon-based materials interactions [13,14].

Cerium oxide (CeO_2) is an important metal oxide with unique $\text{Ce}^{3+}/\text{Ce}^{4+}$ redox properties and oxygen storage capacity. The synergistic effect of CeO_2 and conducting polymers can be achieved by incorporating the latter to enhance the photocatalytic behavior by better charge separation and interfacial interactions. The degradation of RhB has already been proven to be effective using PANI/ CeO_2 systems, and dye removal has been proven to be better with the addition of GO in the photocatalyst due to the combined effect of adsorption and charge transfer mechanisms [11,14].

Despite advances in GO-, PANI-, and CeO_2 -based photocatalysts, comparatively limited attention has been given to ternary GO/PANI/ CeO_2 nanocomposites for RhB degradation under both UV and visible irradiation. The combined contribution of GO, PANI, and CeO_2 therefore requires further investigation, particularly regarding catalyst dosage, dye concentration, irradiation source, and degradation kinetics.

Research Objective

The objective of this study was to synthesize and characterize a GO/PANI/ CeO_2 nanocomposite by the co-precipitation method and evaluate its photocatalytic performance for the decomposition of Rhodamine B dye under UV and visible-light irradiation.

Materials and Methods**Chemicals and Reagents**

During the experimental work, the following chemicals were used: graphite, potassium permanganate (KMnO_4), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), hydrogen peroxide (H_2O_2), aniline, ammonium peroxydisulfate (APS), sodium hydroxide (NaOH), cerium nitrate

hexahydrate [$\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$], hydrochloric acid (HCl), and Rhodamine B (RhB). All the synthesis and photocatalytic experiments were conducted using deionized water. Chemicals and reagents were all analytical grade.

The synthesis of Graphene Oxide

Graphite powder was converted to graphene oxide (GO) by an improved Hummers method. The sulphuric acid (60 mL) and phosphoric acid (10 mL) were stirred together in an ice bath at approximately 5°C while graphite powder was gradually added. Slowly, 6 g of potassium permanganate was added, and the reaction temperature was kept below 20°C . The resultant suspension was then poured into an oil bath and stirred for 30 min at 40°C ; after that, 150 mL of deionized water was added, and the mixture was stirred for 30 min at 90°C till dark brown suspension was obtained. Water (350 mL) and 15 mL of 30% hydrogen peroxide were added dropwise to it. This was filtered and washed with 1:10 aqueous HCl solution. The resulting material was sonicated for 30 min and centrifuged at 4500 rpm to form a graphene oxide slurry which would be used for nanocomposite preparation.

Synthesis of Polyaniline

Chemical oxidative polymerisation was used for the synthesis of polyaniline (PANI). Deionized water was used to prepare aqueous solutions of aniline 0.05 M and hydrochloric acid 0.5 M. All the solution were mixed together in an ice bath with continuous stirring, keeping the reaction temperature below 5°C . It was stirred for 5 h continuously, and then ammonium peroxydisulfate was slowly added to the mixture in the form of an aqueous solution of 0.05 M. After the polymerization, a filtration procedure was performed and the product was washed with deionized water and dried in the electric oven at 80°C . The product was dried and then ground by hand with a mortar and pestle, and placed in a desiccator for later use.

Synthesis of GO/PANI/ CeO_2 Nanocomposite

The GO/PANI/ CeO_2 nanocomposite was prepared by the co-precipitation method with cerium nitrate hexahydrate as cerium precursor. The graphene oxide was first dispersed in 200 mL of deionized water, and the polyaniline was then dispersed in 200 mL of deionized water. Cerium nitrate hexahydrate (2.17 g) was dissolved in 250 mL of deionized water. The GO and PANI suspensions were sonicated for 1 hour and then mixed with the cerium salt solution. The mixture was sonicated for 30 min and then boiled under magnetic stirring for 70°C . 70°C solution of 1 M NaOH was added dropwise while stirring the mixture for about 5 h until the pH was about 11. The precipitate thus obtained was filtered, and the filtered precipitate was left to settle. The material collected was washed with deionized water and ethanol and dried at 80°C for 4 h. The dried material was then crushed and heated at ~ 500 – 600°C for 4 h to form GO/PANI/ CeO_2 nanocomposite and used for characterization and photocatalytic reactions.

Characterization of the Nanocomposite

However, X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, ultraviolet-visible (UV-Vis) spectroscopy, and scanning electron microscopy (SEM) were used to characterize the obtained GO/PANI/ CeO_2 nanocomposite. The crystalline structure of the synthesized material was analyzed by XRD, and the presence of functional groups in the nanocomposite was identified by FTIR analysis. The optical absorption properties of the material were studied using UV-Vis spectroscopy, and the surface morphology was analyzed using SEM.

UV-Vis Spectroscopic Analysis

UV-Vis spectroscopy was carried out between 200 and 800 nm wavelengths. A suspension was made in ethanol and sonicated for 15 minutes to disperse particles in ethanol prior to the optical characterization of the nanocomposite in ethanol by absorption spectrum. The optical band gap was calculated by using the Tauc method.

Photocatalytic Degradation of Rhodamine B

The photocatalytic activity of the synthesized GO/PANI/CeO₂ nanocomposite was tested for the degradation of Rhodamine B under UV and visible-light irradiation. De-ionized water was used to prepare Rhodamine B solutions and a fixed amount of the synthesized Rhodamine B nanocomposite was used as a photocatalyst. The suspension was shaken to make a uniform mixture and then placed under each light source. UV-Vis spectroscopic analysis was employed to track the changes of the concentration of Rhodamine B during the course of the irradiation. The influence of the catalyst dosage, initial dye concentration, irradiation time, and irradiation source on photocatalytic degradation was studied.

Effect of Photocatalyst Dosage

The degradation of Rhodamine B was studied under the effect of GO/PANI/CeO₂ dosage while irradiating with UV and visible light. The photocatalyst amounts used for different experiments were from 0.01 to 0.05 g of catalyst per 100 mL of dye solution with UV irradiation. Different catalyst amounts of 0.03, 0.04, and 0.05 g were used under visible light irradiation. Photocatalytic degradation was carried out, and the absorbance of dyes was measured by UV-Vis spectroscopy to see the changes in the dye's absorbance.

Effect of Initial Rhodamine B Concentration

The photocatalytic degradation was studied in the presence of UV, and the initial concentration of Rhodamine B was varied. For the preparation of dye solutions, the concentration of dye changed from 10 ppm to 20 ppm and 30 ppm, and the amount of photocatalyst changes in every experiment was maintained at 0.04 g. The treatment time was up to 60 minutes with UV-Vis spectroscopy measuring absorbance changes.

Effect of Irradiation Source

To assess the effect of the irradiation source, the amount of photocatalyst (0.04 g/100 mL of dye solution) was kept constant, while UV and visible light were used for irradiation. To compare the

two irradiation conditions, the amount of Rhodamine B and the photocatalyst dosage were fixed. UV-Vis spectroscopy was used to determine changes in dye absorbance upon irradiation.

Determination of Photocatalytic Degradation Efficiency

The photocatalytic degradation efficiency of Rhodamine B was calculated based on the difference in absorbance during irradiation. The initial absorbance (A_0) and the absorbance after a time of irradiation (A_t) were used to calculate the percentage degradation by the relationship

$$\text{Degradation (\%)} = [(A_0 - A_t) / A_0] \times 100$$

where A_0 represents the initial absorbance of the Rhodamine B solution and A_t represents the absorbance after irradiation for time t .

Photocatalytic Degradation Kinetics

The photocatalytic degradation kinetics of Rhodamine B under UV and visible-light irradiation were evaluated using a pseudo-first-order kinetic model. The relationship was expressed as $\ln(C_t/C_0) = \ln(A_t/A_0) = -kt$, where C_0 and C_t represent the initial and time-dependent dye concentrations, respectively; A_0 and A_t represent the corresponding absorbance values; t is the irradiation time in minutes; and k is the apparent reaction rate constant. The kinetic plots were obtained by plotting $\ln(A_t/A_0)$ against irradiation time, and the slope of the linear regression was used to determine the apparent rate constant.

Results

Figure 1 presents the X-ray diffraction (XRD) pattern of the synthesized GO/PANI/CeO₂ nanocomposite. The diffraction pattern confirms the crystalline nature and successful formation of the composite material. The major diffraction peaks observed at approximately 28.5° and 59.1° are assigned to the (111) and (222) planes of CeO₂, respectively, with the peak at 28.5° representing the predominant orientation of CeO₂. A diffraction peak around 33.1° is associated with the (200) plane of polyaniline,

whereas the peak near 47.5° is attributed to the (220) plane of graphene oxide. The average crystallite size of the synthesized nanocomposite was reported to be approximately 13.75 nm based

on the Debye-Scherrer equation. Overall, the XRD results provide structural evidence for the formation of the GO/PANI/CeO₂ nanocomposite.

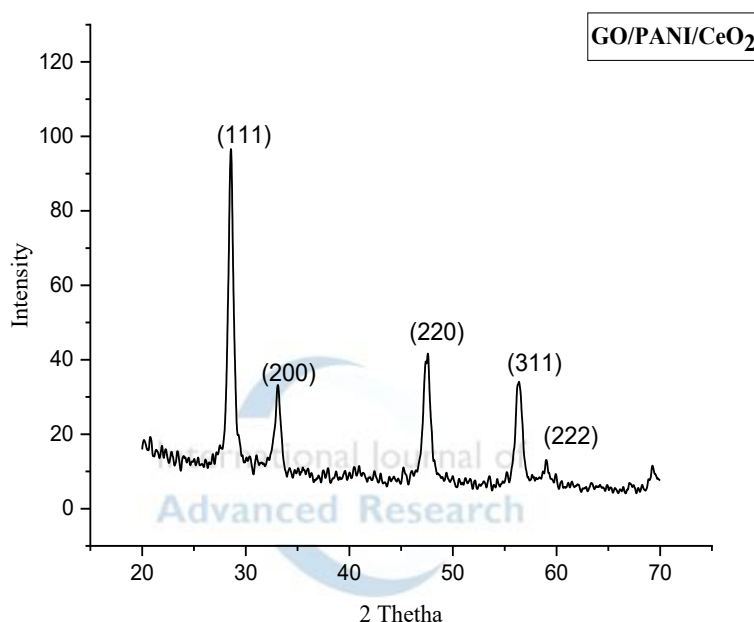


Figure 1: XRD spectra of GO/PANI/CeO₂ nanocomposite with phase labelling

Figure 2 shows the scanning electron microscopy (SEM) morphology of the synthesized GO/PANI/CeO₂ nanocomposite. The micrographs reveal the presence of graphene oxide sheets with cerium oxide particles distributed on their surfaces. The spherical morphology of CeO₂ nanoparticles can be observed together with the polyaniline network surrounding the graphene sheets. The surface appears rough, heterogeneous,

and highly agglomerated, with irregular surface features and interconnected regions. The observed morphology indicates the formation of a composite structure in which the different components are associated with one another. These morphological characteristics are relevant to photocatalytic applications because the rough and heterogeneous surface provides a suitable structure for interaction with dye molecules.

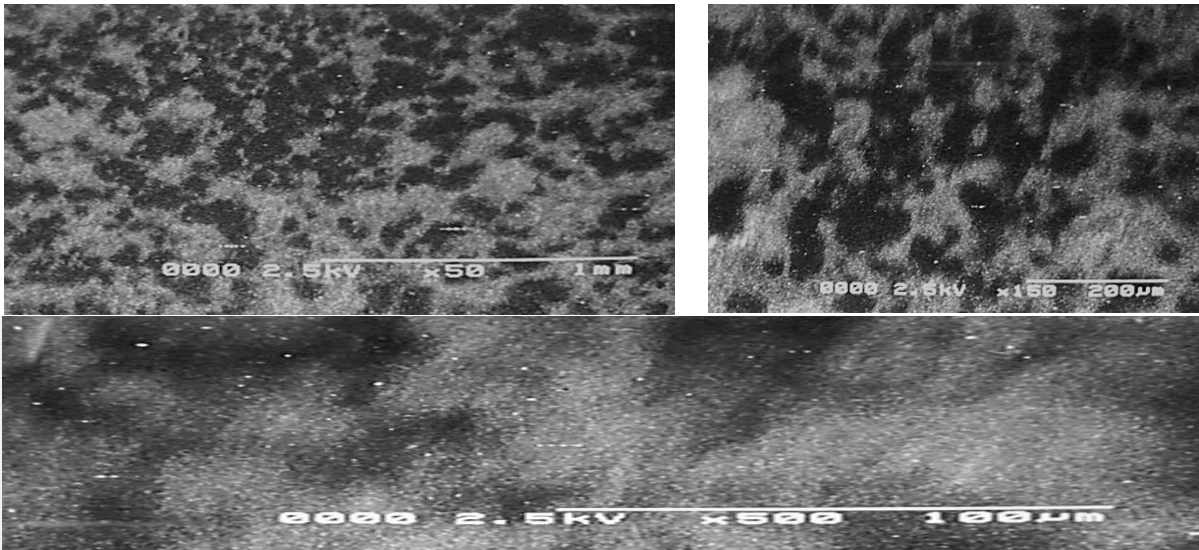


Figure 2. SEM Morphology of GO/PANI/CeO₂ Nanocomposite

Figure 3 illustrates the FTIR spectrum of the synthesized GO/PANI/CeO₂ nanocomposite and identifies the characteristic functional groups present in the material. The absorption bands around 3400 and 1056 cm⁻¹ are associated with functional groups related to graphene oxide, while the bands in the region around 1560–1585 cm⁻¹ and 1480–1490 cm⁻¹ correspond to the quinonoid and benzenoid structures of

polyaniline, respectively. The band around 1290–1300 cm⁻¹ is related to C–N bonding, whereas the bands around 1050–1080 and 800–820 cm⁻¹ correspond to C–O stretching and C–H bending vibrations. Characteristic Ce–O-related bands are observed below approximately 600 cm⁻¹. The presence of these characteristic absorption bands confirms the incorporation of GO, PANI, and CeO₂ in the synthesized nanocomposite.

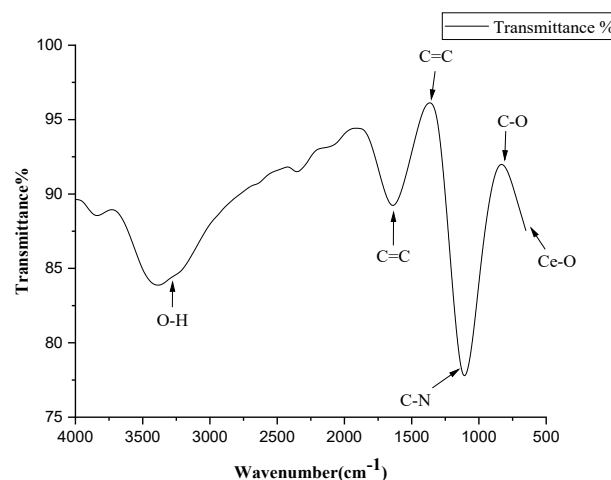


Figure 3. FTIR Spectrum of GO/PANI/CeO₂ Nanocomposite

Figure 4 presents the UV-visible absorption characteristics and optical band-gap behavior of the GO/PANI/CeO₂ nanocomposite. The absorption spectrum was recorded over the wavelength range of 200–800 nm to evaluate the optical response of the synthesized material. The nanocomposite exhibited an absorption feature corresponding to an energy of approximately 4.1 eV. An extended absorption tail was also observed

toward the visible region, indicating optical response beyond the ultraviolet region. The optical behavior is important for photocatalytic applications because light absorption determines the generation of photoinduced charge carriers. The band-gap analysis therefore provides important supporting evidence for evaluating the suitability of the synthesized GO/PANI/CeO₂ nanocomposite as a photocatalyst.

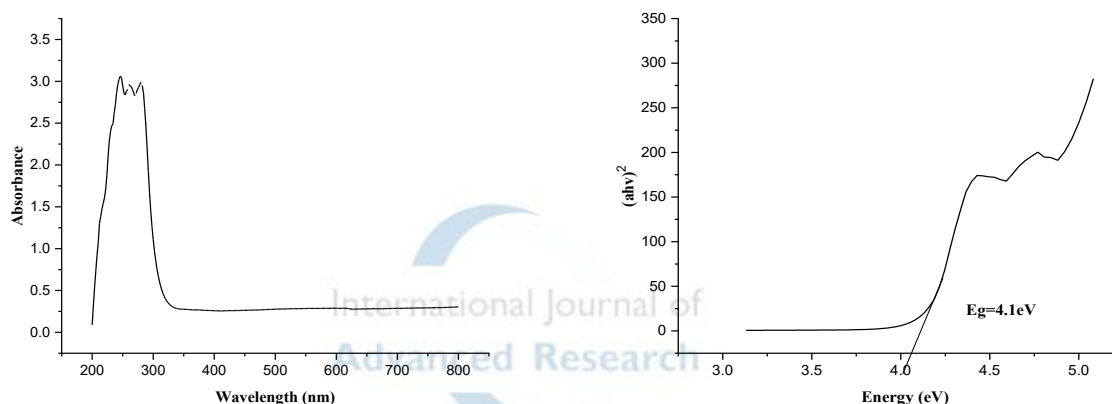


Figure 4. UV-Visible Absorption Spectrum and Optical Band Gap of GO/PANI/CeO₂

Figure 5 shows the UV-visible absorption spectra obtained during the photocatalytic degradation of Rhodamine B using the synthesized GO/PANI/CeO₂ nanocomposite. Rhodamine B exhibited a maximum absorption near 554 nm, which was used to monitor changes in dye concentration during irradiation. With increasing irradiation time, a progressive reduction in the characteristic absorption peak of Rhodamine B was observed. The decrease in absorbance

indicates the removal/decomposition of Rhodamine B from the solution during the photocatalytic process. The spectral changes therefore demonstrate the photocatalytic activity of the synthesized GO/PANI/CeO₂ nanocomposite toward Rhodamine B. This result directly supports the second major part of the study objective, namely evaluation of the nanocomposite for dye decomposition.

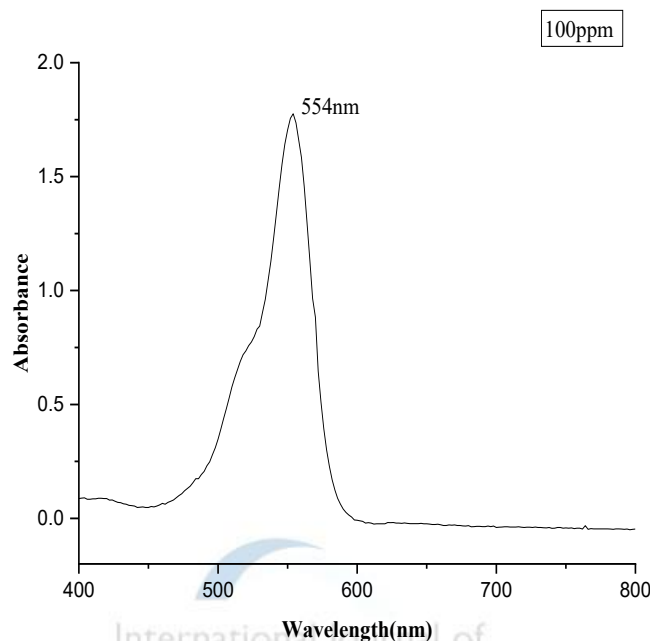


Figure 5. UV-Visible Spectra of Rhodamine B During Photocatalytic Degradation

Figure 6 demonstrates the effect of GO/PANI/CeO₂ photocatalyst dosage on the degradation of Rhodamine B under UV irradiation. Different amounts of photocatalyst were investigated to determine the influence of catalyst concentration on the degradation process. The thesis results show that increasing the catalyst amount initially enhanced the degradation efficiency, with the strongest response reported around 0.04 g in the investigated series. Beyond this concentration, the degradation efficiency

decreased, indicating that excessive catalyst loading did not further improve the photocatalytic process. The decrease at higher dosage was associated in the thesis with increased light absorption/scattering by the catalyst suspension. These results demonstrate that photocatalyst dosage is an important experimental parameter affecting Rhodamine B degradation.

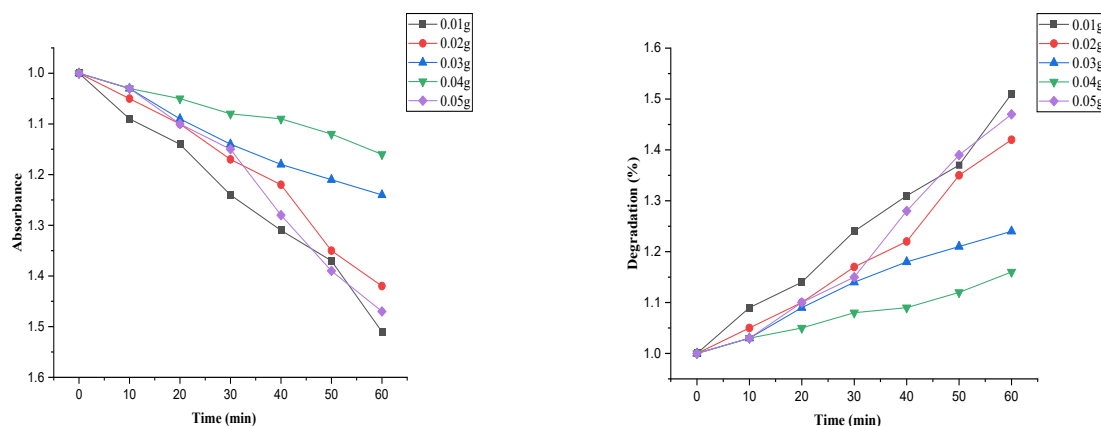


Figure 6. Effect of Photocatalyst Dosage on Rhodamine B Degradation Under UV Light

Figure 7 presents the influence of GO/PANI/CeO₂ dosage on Rhodamine B degradation under visible-light irradiation. Catalyst concentrations of 0.03, 0.04, and 0.05 g were investigated to determine the dosage producing the highest degradation response. The thesis results indicate that the 0.03 g catalyst dosage produced the highest degradation efficiency, reaching approximately 12.5% after 60

min of visible-light irradiation. The degradation efficiencies at 0.04 and 0.05 g were approximately 8.0% and 8.2%, respectively. The results therefore demonstrate that increasing catalyst dosage beyond the observed optimum did not increase the degradation efficiency under visible light. This figure provides evidence of the visible-light photocatalytic behavior of the synthesized nanocomposite.

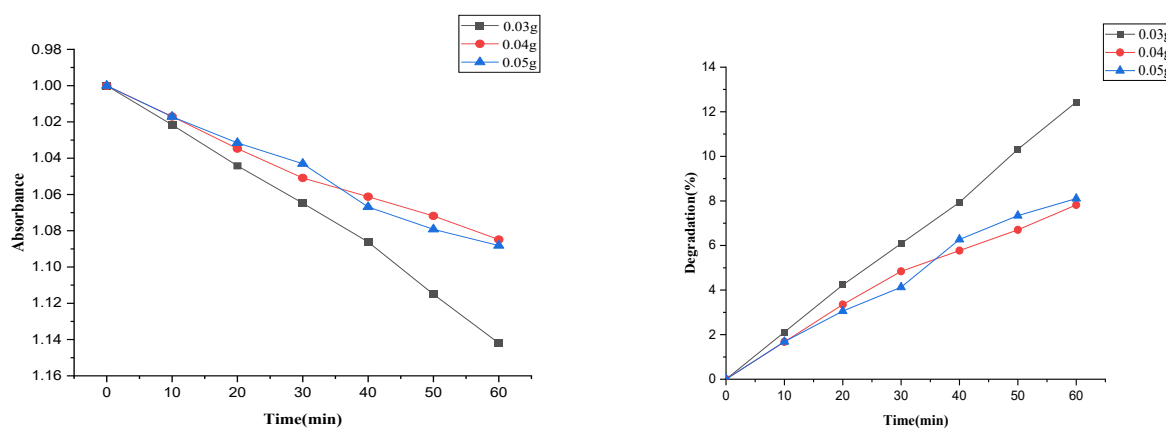


Figure 7. Effect of Photocatalyst Dosage on Rhodamine B Degradation Under Visible Light

Figure 8 shows the effect of initial Rhodamine B concentration on photocatalytic degradation under UV irradiation. Three initial dye concentrations, 10, 20, and 30 ppm, were

investigated while maintaining the photocatalyst dosage at 0.04 g. The results demonstrate a concentration-dependent change in the degradation behavior of Rhodamine B. The lower

dye concentration exhibited a greater change in absorbance during the irradiation period, whereas higher dye concentrations showed comparatively smaller changes. The thesis attributes this behavior to reduced light penetration and

increased screening effects at higher dye concentrations. These findings demonstrate that the initial concentration of Rhodamine B is an important factor influencing the photocatalytic performance of GO/PANI/CeO₂.

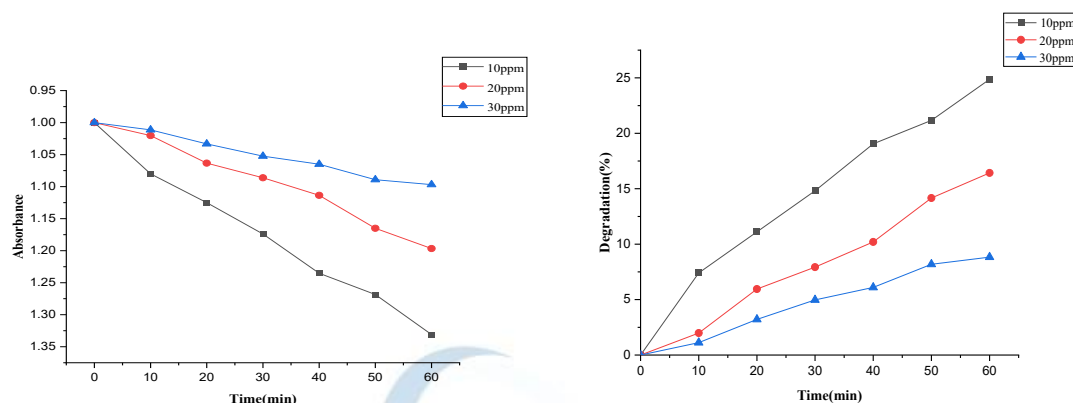


Figure 8. Effect of Initial Rhodamine B Concentration on Photocatalytic Degradation

Figure 9 compares the photocatalytic degradation performance of GO/PANI/CeO₂ under UV and visible-light irradiation. The catalyst dosage was maintained at 0.04 g per 100 mL of dye solution while the irradiation source was varied. A pronounced decrease in Rhodamine B absorbance was observed under UV irradiation, whereas only a relatively small change was observed under visible light. After 60 min, the thesis reports

approximately 81% degradation under UV irradiation compared with approximately 12.7% under visible-light irradiation. The substantially different degradation efficiencies demonstrate that the irradiation source strongly affected the photocatalytic response of the synthesized nanocomposite. This figure directly addresses the objective of evaluating GO/PANI/CeO₂ under both UV and visible-light conditions.

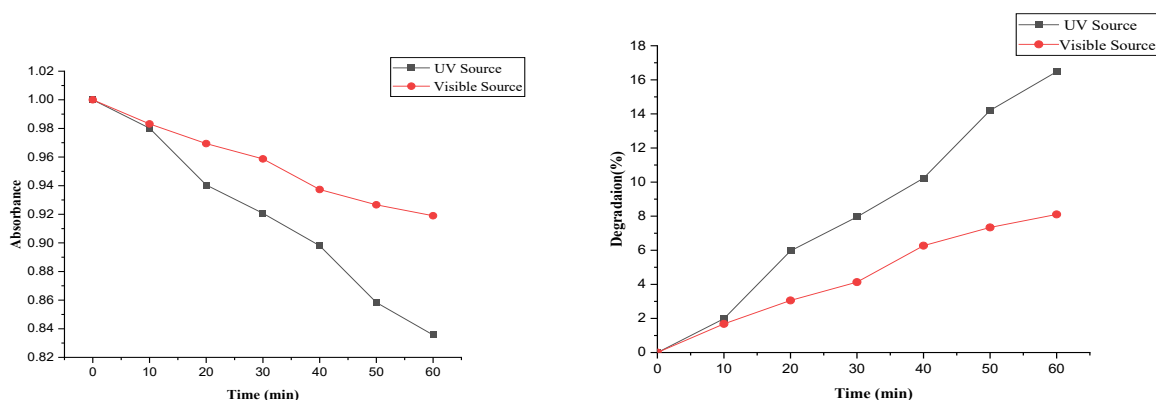


Figure 9. Comparison of Rhodamine B Degradation Under UV and Visible Light

Figure 10 presents the pseudo-first-order kinetic analysis of Rhodamine B degradation under UV and visible-light irradiation. The relationship between $\ln(A_t/A_0)$ and irradiation time was evaluated to determine the apparent degradation rate constant. The UV-light experiment produced a rate constant of approximately $2.8 \times 10^{-3} \text{ min}^{-1}$, with a correlation coefficient of $R^2 = 0.99$. Under

visible-light irradiation, the reported rate constant was approximately $1.3 \times 10^{-3} \text{ min}^{-1}$, also with $R^2 = 0.99$. The high R^2 values indicate a strong linear relationship between the experimental degradation data and the pseudo-first-order kinetic model. These kinetic results quantitatively support the photocatalytic degradation behavior of GO/PANI/CeO₂ under both irradiation conditions.

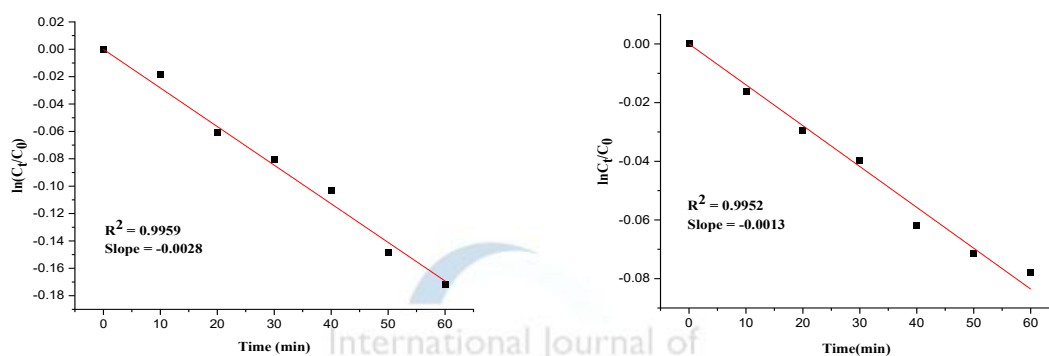


Figure 10. Pseudo-First-Order Kinetic Plot for Rhodamine B Degradation

Discussion

The structural characterisation revealed that the nanocomposite of GO/PANI/CeO₂ was successfully formed. The prominent reflections in the XRD, at ~ 28.5 , 33.1 , 47.5 and 59.1° were obtained, and a crystallite size of 13.75 nm was estimated. The reflections are similar to the fluorite structure of CeO₂, especially the characteristic CeO₂ reflections at 28.6° , 33.1° , 47.5° and 59.1° [15]. In the present work, a relatively large interfacial area for the interactions between the catalyst and Rhodamine B (RhB) is obtained because of the nanoscale crystallite size. In the same way, GO-metal-oxide nanocomposites have been reported to have better photocatalytic activity due to the easy adsorption of the pollutant and the charge transfer between the GO and the metal oxide [16].

The SEM images also confirmed the composite morphology, and revealed the presence of CeO₂ nanoparticles on the GO sheets in a rough and heterogeneous network of PANI. This close proximity of the components is important because GO can offer adsorption sites and electron

transfer pathway while PANI is able to take part in charge transport. The other bands were also observed in the FTIR spectrum at approximately 3400 and 1056 cm^{-1} (PANI bands), 1290 – 1300 cm^{-1} (C–N bands), and below 600 cm^{-1} (Ce–O related bands). These results agree with the earlier reports on PANI–CeO₂ hybrids that found that the interactions between the conducting polymer and semiconductor could enhance the photocatalytic activity of the hybrid [17].

The optical data revealed a feature in the absorption spectrum around 4.1 eV as well as a long tail of the absorption spectrum towards the visible region. This optical response shows that the ternary material is reacting to high energy UV and somewhat to visible radiation. The photocatalytic experiments exhibited this behaviour: for a catalyst dosage of $0.04 \text{ g}/100 \text{ mL}$, RhB degradation under UV achieved about 81% after 60 min while under visible light it achieved about 12.7% degradation after 60 min . The significant enhancement of the UV response is in accordance with the known limitation of CeO₂-based photocatalysts in relation to their wide optical band gap. However,

if conductive carbon and polymer material can be incorporated, charge separation and light response can be enhanced, as mentioned for GO-based semiconductor composites [18].

The amount of catalyst significantly affected the degradation of RhB. The degradation increased at first and reached maximum response around 0.04 g under UV irradiation, and the degradation was decreased by increasing the amount of catalyst. The highest degradation was only about 12.5% after 60 min, 8.0% after 60 min at 0.04 g, and 8.2% after 60 min at 0.05 g under UV irradiation. The drop in higher loadings is easily correlated with increased scattering and shielding in dense suspensions. Similar dependency on catalyst dosage has been documented in GO-based photocatalytic systems whereby too much catalyst can affect the penetration of light [16,18].

The photocatalytic performance was also influenced by the initial concentration of RhB. The degradation decreased with the increasing concentration of dyes and the solutions of 10 ppm, 20 ppm and 30 ppm had increasingly lower degradation at a constant catalyst dosage of 0.04g. All of this is consistent with the lower light penetration and higher screening of incident radiation with higher dye concentrations. Importantly, the present UV performance is good when compared with previous UV system based on PANI/CeO₂ reported by the study, which showed 91% degradation of RhB after 120 min [19] and another study reported about 35% degradation after 60 min with CeO₂-PANI [20]. This is about 81% within just 60 min, indicating that the combination of GO with PANI and CeO₂ could offer more adsorption and interfacial charge-transfer benefits. Furthermore, the kinetic analysis indicated pseudo-first-order behavior for both the irradiation conditions, with R² of 0.99. The reported apparent rate constants were $2.8 \times 10^{-3} \text{ min}^{-1}$ and $1.3 \times 10^{-3} \text{ min}^{-1}$ under the UV and visible light irradiation, respectively, which reflects faster apparent kinetics under the UV irradiation.

Strengths and Limitations

The systematic structural, morphological, functional, and optical characterization of the synthesized GO/PANI/CeO₂ nanocomposite using different techniques such as XRD, SEM, FTIR, and UV-Vis spectroscopy and application for the degradation of Rhodamine B under UV and visible-light illumination is a major strength of the present study. Additionally, the study analyzed key operational parameters such as the dosage of photocatalyst, initial dye concentration, the type of irradiation source, degradation efficiency, and pseudo-first-order kinetics, giving a comprehensive overview of the behavior of photocatalytic degradation. The nanocomposite showed the degradation of about 81% and 12.7% of the Rhodamine B dye after 60 min under UV and visible light, respectively, with kinetic analysis R² = 0.99 for both the conditions. But there are limitations of the study. The experiments were performed in the laboratory with only one model dye, and thus cannot be directly translated to complex industrial waste water. The observed decrease in absorbance was not confirmed using techniques such as TOC, HPLC or LC-MS which would give mineralization or degradation intermediates, and therefore should be interpreted as dye degradation, not complete mineralization. Besides, reusability of the catalyst, long-term stability and metal-ion leaching were not explored. Lastly, reported UV kinetic constant should be rechecked with the degradation data set prior to publication.

Conclusion

The successful synthesis and characterization of a GO/PANI/CeO₂ nanocomposite and its potential for photocatalytic degradation of Rhodamine B was demonstrated by using XRD, SEM, FTIR, and UV-Vis analyses, which were used together, and a crystallite size estimated at 13.75 nm. Photocatalytic experiments demonstrated that the performance of degradation was affected by the amount of catalyst and the initial concentration of Rhodamine B, but the irradiation source gave a significant difference in the activity. Using optimized UV conditions

(0.04 g of the catalyst per 100 mL), the degradation of Rhodamine B was nearly 81% complete after 60 min, while under conditions of visible light, the degradation efficiency was around 12.7% under the same catalyst dosage and irradiation time. The pseudo-first order plots revealed good linear kinetic relationship, with R^2 values of 0.99 for both the irradiation conditions. In conclusion, it is established that GO/PANI/CeO₂ exhibits good photocatalytic properties, especially when exposed to UV light, and could be considered as a candidate for laboratory-scale dye-contaminated water treatment. More research is needed to determine its practical use, including the use of real wastewater, recycling of the catalysts, mineralization analysis, degradation intermediates and long-term stability.

REFERENCES

- Robinson T, McMullan G, Marchant R, Nigam P. Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative. *Bioresource Technology*. 2001;77(3):247–255. doi:10.1016/S0960-8524(00)00080-8.
- Forgacs E, Cserháti T, Oros G. Removal of synthetic dyes from wastewaters: A review. *Environment International*. 2004;30(7):953–971. doi:10.1016/j.envint.2004.02.001.
- Crini G. Non-conventional low-cost adsorbents for dye removal: A review. *Bioresource Technology*. 2006;97(9):1061–1085. doi:10.1016/j.biortech.2005.05.001.
- Saratale RG, Saratale GD, Chang JS, Govindwar SP. Bacterial decolorization and degradation of azo dyes: A review. *Journal of the Taiwan Institute of Chemical Engineers*. 2011;42(1):138–157. doi:10.1016/j.jtice.2010.06.006.
- Gupta VK, Suhas. Application of low-cost adsorbents for dye removal—A review. *Journal of Environmental Management*. 2009;90(8):2313–2342. doi:10.1016/j.jenvman.2008.11.017.
- Konstantinou IK, Albanis TA. TiO₂-assisted photocatalytic degradation of azo dyes in aqueous solution: Kinetic and mechanistic investigations. *Applied Catalysis B: Environmental*. 2004;49(1):1–14. doi:10.1016/j.apcatb.2003.11.010.
- Chong MN, Jin B, Chow CWK, Saint C. Recent developments in photocatalytic water treatment technology: A review. *Water Research*. 2010;44(10):2997–3027. doi:10.1016/j.watres.2010.02.039.
- Schneider J, Matsuoka M, Takeuchi M, Zhang J, Horiuchi Y, Anpo M, Bahnemann DW. Understanding TiO₂ photocatalysis: Mechanisms and materials. *Chemical Reviews*. 2014;114(19):9919–9986. doi:10.1021/cr5001892.
- Rauf MA, Ashraf SS. Fundamental principles and application of heterogeneous photocatalytic degradation of dyes in solution. *Chemical Engineering Journal*. 2009;151(1–3):10–18. doi:10.1016/j.cej.2009.02.026.
- Khan F, Khan MS, Kamal S, Arshad M, Ahmad SI, Nami SAA. Recent advances in graphene oxide and reduced graphene oxide based nanocomposites for the photodegradation of dyes. *Journal of Materials Chemistry C*. 2020;8:15940–15955. doi:10.1039/D0TC03684F.
- Al Kausor M, Chakraborty D. Graphene oxide based semiconductor photocatalysts for degradation of organic dye in waste water: A review on fabrication, performance enhancement and challenges. *Inorganic Chemistry Communications*. 2021;129:108630. doi:10.1016/j.inoche.2021.108630.
- Yaqoob AA, Mohd Noor NH, Serrà A, et al. Advances and challenges in developing efficient graphene oxide-based ZnO photocatalysts for dye photo-oxidation. *Nanomaterials*. 2020;10(5):932. doi:10.3390/nano10050932.

- Mitra A, Chandra S, Das P. Polyaniline/Reduced Graphene Oxide Composite-Enhanced Visible-Light-Driven Photocatalytic Activity for the Degradation of Organic Dyes. *ACS Omega*. 2019;4:3267–3276. doi:10.1021/acsomega.8b02941. The study specifically reported RhB degradation by PANI/RGO under visible light.
- Samai B, Bhattacharya SC. Conducting polymer supported cerium oxide nanoparticle: Enhanced photocatalytic activity for waste water treatment. *Materials Chemistry and Physics*. 2018;220:171–181. doi:10.1016/j.matchemphys.2018.08.050. This is particularly relevant to your work because it directly investigated PANI/CeO₂ for Rhodamine B degradation and reported enhanced photocatalytic performance compared with the individual components.
- Samai, B., & Bhattacharya, S. C. (2018). Conducting polymer supported cerium oxide nanoparticle: Enhanced photocatalytic activity for waste water treatment. *Materials Chemistry and Physics*, 220, 171–181. <https://doi.org/10.1016/j.matchemphys.2018.08.050>
- El-Shafai, N. M., El-Khouly, M. E., El-Kemary, M., Ramadan, M. S., & Masoud, M. S. (2018). Graphene oxide-metal oxide nanocomposites: Fabrication, characterization and removal of cationic rhodamine B dye. *RSC Advances*, 8, 13323–13332. <https://doi.org/10.1039/C8RA00977E>
- Shah, A.-u.-H. A., Akhlaq, S., Sayed, M., Bilal, S., & Ahmad, N. (2018). Synthesis and characterization of polyaniline-zirconium dioxide and polyaniline-cerium dioxide composites with enhanced photocatalytic degradation of rhodamine B dye. *Chemical Papers*, 72, 1927–1938. <https://doi.org/10.1007/s11696-018-0494-7>
- Khan, F., Khan, M. S., Kamal, S., Arshad, M., Ahmad, S. I., & Nami, S. A. A. (2020). Recent advances in graphene oxide and reduced graphene oxide based nanocomposites for the photodegradation of dyes. *Journal of Materials Chemistry C*, 8, 15940–15955. <https://doi.org/10.1039/D0TC03684F>
- Muthukumar, K., et al. (2019). Application of nanostructured graphene oxide/titanium dioxide composites for photocatalytic degradation of rhodamine B and acid green 25 dyes. *Journal of Materials Research and Technology*, 8, 5610–5622. <https://doi.org/10.1016/j.jmrt.2019.09.029>
- Bassi, A., Gusain, M., Singh, L., Tannarana, M., et al. (2026). Advances in graphene oxide based multifunctional photocatalysts for the degradation of synthetic dyes: A review. *Discover Chemical Engineering*. <https://doi.org/10.1007/s43938-026-00132-0>.