

EFFECT OF GRAPHENE OXIDE LOADING ON THE STRUCTURAL AND PHOTOCATALYTIC PROPERTIES OF CuO/GO COMPOSITES FOR BASIC FUCHSIN DEGRADATION

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ABSTRACT

A series of CuO/GO composites with GO loadings of 0.2, 0.4, and 0.6 g were prepared by a wet chemical precipitation route and tested for their ability to photocatalytically degrade Basic Fuchsin (BF) dye under visible light irradiation. XRD, FTIR, SEM, and UV-Vis spectroscopy were employed to probe the structure, morphology, and optical behaviour of the resulting materials. XRD confirmed the monoclinic phase of CuO in all samples, with crystallite size decreasing progressively from 16.2 nm (pristine CuO) to 9.7 nm (CuO/GO-0.6) with increasing GO content, suggesting that GO sheets inhibit CuO crystal growth. SEM revealed improved particle dispersion in CuO/GO-0.4, providing more accessible active sites for photocatalysis. Of all the composites tested, CuO/GO-0.4 gave the best performance, degrading 97% of the BF dye with a rate constant of 0.0480 min^{-1} , roughly 40-fold higher than that recorded for photolysis alone. Radical scavenging experiments established that hydroxyl radicals ($\bullet\text{OH}$) and superoxide radicals ($\text{O}_2^{\bullet-}$) are the dominant reactive species, with holes (h^+) playing a negligible role. The catalyst also demonstrated good stability, retaining over 88% degradation efficiency after four reuse cycles.

Keywords: Basic Fuchsin, Copper oxide, Graphene oxide, Photocatalytic degradation, Visible light

INTRODUCTION

Aquatic ecosystems are under increasing pressure from environmental pollution, especially the continuous discharge of untreated industrial effluents. A major concern is the release of wastewater containing synthetic dyes into water bodies (Lin *et al.*, 2018). Their complex molecular structures and high chemical stability make these dyes resistant to natural degradation, creating serious risks to both the environment and human health. Many of them are toxic and even carcinogenic, endangering aquatic life and human health through contamination of the food chain (Banu *et al.*, 2019).

Among these pollutants, Basic Fuchsin (BF), a widely used triphenylmethane dye in the textile, leather, and printing industries, is of particular concern (Wang *et al.*, 2021). Its persistence in wastewater reduces light penetration in water, which disrupts photosynthesis in aquatic systems (Al-tohamy *et al.*, 2022). Moreover, BF has mutagenic and toxic effects that can endanger both aquatic and terrestrial organisms (Wang *et al.*, 2021). Taken together, these issues highlight a pressing need for reliable, sustainable strategies to remove BF from industrial effluent. Conventional approaches to dye-contaminated wastewater, including biological treatment, physical filtration, and chemical

coagulation, have long been used to address this problem (Jiang and Zhao). However, these approaches are often limited by low removal rates, high operating costs, and the additional sludge they produce (Yaseen *et al.*, 2022). Consequently, heterogeneous photocatalysis has gained increasing attention as an environmentally friendly alternative. Owing to the unique optical and electronic properties of semiconductor materials, photocatalysis effectively mineralizes persistent organic pollutants into harmless byproducts, including carbon dioxide and water, making it a promising approach for sustainable water treatment (Wang *et al.*, 2020).

As a p-type semiconductor that combines a narrow band gap, strong optical absorption and favorable electrical conductivity, copper oxide (CuO) stands out as an attractive candidate for photocatalytic applications (Rafiq *et al.*, 2022). However, the rapid recombination of photogenerated electron-hole (e^-/h^+) pairs in pristine CuO significantly limits its photocatalytic efficiency (Sagadevan *et al.*, 2021). To overcome this limitation, graphene oxide (GO) has been incorporated into CuO due to its excellent electrical conductivity and large surface area, which can promote charge separation and improve photocatalytic performance (Benito *et al.*, 2019; Zomorodian *et al.*, 2024).

While CuO/GO composite synthesis has been explored in prior work, relatively few studies have examined how the amount of GO loaded affects the resulting structural, optical, and photocatalytic behavior, especially in the context of BF dye degradation. Since the amount of GO incorporated can significantly affect charge separation, surface interactions, and light absorption behavior, optimizing GO content is essential for improving photocatalytic efficiency. This study therefore sets out to synthesize CuO/GO-x% photocatalysts at three GO concentrations ($x = 0.2, 0.4$, and 0.6) and to assess how their structural characteristics relate to their performance in degrading BF dye.

MATERIALS AND METHODS

Materials

Copper sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), basic fuchsin, graphene oxide, glacial acetic acid (CH_3COOH), ascorbic acid (AA), ethylenediaminetetraacetic acid (EDTA), ethanol, and isopropanol (IPA) were used without further purification.

Synthesis of copper oxide (CuO)

Copper oxide (CuO) was synthesized using the wet chemical precipitation method as reported by (Anjum *et al.*, 2023), with some modifications. A $0.3 \text{ M CuSO}_4 \cdot 5\text{H}_2\text{O}$ solution was prepared by dissolving $7.5 \text{ g CuSO}_4 \cdot 5\text{H}_2\text{O}$ in 40 mL of distilled water (DW) with continuous stirring until completely dissolved. This solution

was quantitatively transferred into a 100 mL volumetric flask and made up to volume with distilled water. The solution was then transferred into a 250 mL beaker, followed by the addition of 1.5 mL glacial acetic acid. The mixture was heated at 95 °C for 1 h with constant stirring. Subsequently, a 0.3 M NaOH solution was added dropwise to the heated solution until a pH of 11 was reached, and a colour change from green to black was observed. The obtained precipitate was then centrifuged at 4000 rpm for 10 min and washed with DW five times to remove the impurities. The black powder obtained was then dried at 60 °C overnight and calcined at 400 °C for 2 h to obtain pristine CuO.

Synthesis of Copper Oxide/Graphene Oxide (CuO/GO) Composites

Copper oxide/graphene oxide (CuO/GO) composites were synthesized following the method reported by Biswas *et al.* (2021), with some modifications. Initially, 1.0 g of the synthesized CuO was dispersed in 30 mL of DW under magnetic stirring. Separately, 0.2 g of GO was dispersed in 50 mL of DW and stirred continuously to obtain a homogeneous suspension, and was then added to the CuO dispersion under continuous stirring. The resulting mixture was heated at 90 °C and stirred continuously for 3 h to ensure uniform dispersion. Once the mixture had cooled to room temperature, it was filtered and rinsed multiple times with distilled water to eliminate impurities. The obtained sample was dried at room temperature for 24 h and annealed at 150 °C for 2 h to obtain CuO/GO composites, as confirmed by XRD and FTIR analyses. The same procedure was repeated using 0.4 g and 0.6 g of GO while keeping all the other experimental conditions constant, resulting in the formation of CuO/GO composites with varying GO loading (0.2, 0.4 and 0.6 g). The as-prepared composites were then labelled as CuO/GO-0.2, CuO/GO-0.4, and CuO/GO-0.6, respectively.

Characterizations

The FTIR spectra of the CuO and CuO/GO composites were obtained using an Agilent Cary 630 FTIR spectrophotometer (Agilent Technologies, Malaysia) in the range of 4000-400 cm⁻¹ at a resolution of 16 cm⁻¹ and 64 scans. The crystalline structure was examined using a Philips X'Pert diffractometer (Model: PW3040/60 X'Pert PRO MPD, Netherlands), with Cu-K α radiation (λ = 0.15478 nm), over a 2θ range of 10-70°. The surface morphology was studied using scanning electron microscopy (SEM) with a Phenom ProX Scanning Electron Microscope (Model: 800-07334, Phenom World, Netherlands). The UV-Vis absorption spectra of the synthesized materials were recorded using a Cary 60 UV-Vis spectrophotometer (Agilent Technologies, USA) over the wavelength range of 200-800 nm.

Photocatalytic test

The photocatalytic test of the synthesized CuO/GO composites was evaluated using BF dye as a model pollutant under fluorescence light irradiation. To carry out the degradation experiments, 0.05 g of the composite was dispersed in 100 mL of a 10 mg/L BF solution, and the suspension was stirred in the dark for 30 min to reach adsorption-desorption equilibrium. Thereafter, the reaction mixture was exposed to light. During the irradiation process, degradation was carried out for 1 h, with samples collected every 20 min, centrifuged and analyzed using a UV-Vis spectrophotometer (Biobase LLC, 3231 Osgood Common, Fremont, CA 94539, USA) at a wavelength of 544 nm.

The photocatalytic degradation efficiency (R %) was calculated using Equation (1), while the reaction kinetics were analyzed using the modified Langmuir-Hinshelwood model (Equation (2)) (Benito *et al.*, 2019; Sagadevan *et al.*, 2021)

$$R(\%) = \frac{C_0 - C_t}{C_t} \times 100 \quad (1)$$

$$\ln\left(\frac{C_0}{C_t}\right) = kt \quad (2)$$

Where: C_0 is the initial concentration, C_t is the concentration at irradiation time, k is the degradation rate constant, and t is the time.

RESULTS AND DISCUSSION

XRD study

The XRD patterns of pristine CuO and the CuO/GO composites are presented in Figure 1. The diffractogram of pristine CuO (Figure 2a) displays characteristic diffraction peaks corresponding to the (110), (111), (202), (020), (202), (113), (311), and (220) reflection planes, consistent with the monoclinic phase of CuO (JCPDS card no. 00-044-0706) (Anjum *et al.*, 2023). All composite samples retained the characteristic CuO diffraction peaks, confirming the preservation of the CuO crystal structure upon GO incorporation. A progressive reduction in peak intensity with increasing GO content is attributed to the interference of GO sheets with the long-range periodic ordering of CuO crystallites. Notably, a weak diffraction peak at approximately $2\theta = 26^\circ$, corresponding to the (002) reflection of graphitic carbon, emerges in the patterns of CuO/GO-0.4 (Figure 1c) and CuO/GO-0.6 (Figure 1d), confirming the presence of GO in the composites (Banu, 2026). Its absence in CuO/GO-0.2 (Figure 1b) suggests that at lower GO loading, the sheets are sufficiently dispersed within the CuO matrix to preclude the formation of ordered stacking domains detectable by XRD, reflecting effective interfacial interaction between CuO and GO at this loading level (Moura *et al.*, 2021)

The average crystallite sizes of the synthesized composites were estimated using the Scherrer equation (Equation 3).

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (3)$$

Where D is the average crystallite size, K is the shape factor (0.89), λ is the X-ray wavelength (0.15406 nm), β is the full width at half maximum (FWHM) in radians, and θ is the Bragg diffraction angle. The calculated crystallite sizes for pristine CuO, CuO/GO-0.2, CuO/GO-0.4, and CuO/GO-0.6 were 16.2, 12.6, 11.0, and 9.7 nm, respectively. The decrease in crystallite size with increasing GO content suggests that GO sheets act as a physical barrier, inhibiting CuO crystal growth during synthesis (Majumder & Gangopadhyay, 2022).

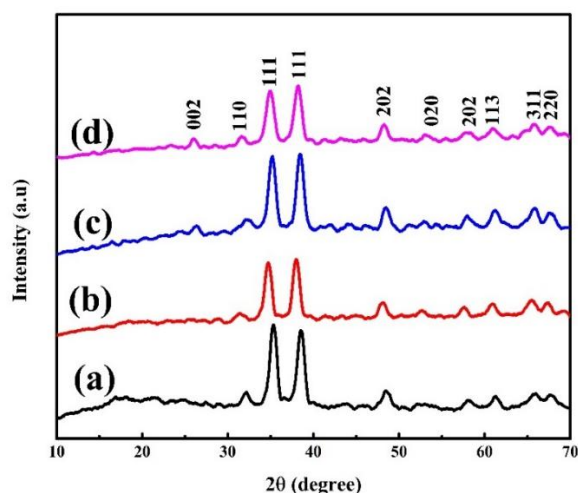


Figure 1. XRD spectra of (a) pristine CuO, (b) CuO/GO-0.2, (c) CuO/GO-0.4, (d) CuO/GO-0.6

FTIR analysis

The FTIR spectra of pristine CuO and the CuO/GO composites are presented in Figure 2(a–d). The spectrum of pristine CuO (Figure 2a) shows two characteristic absorption bands in the low wavenumber region at approximately 530 and 600 cm^{-1} assignable to Cu–O stretching vibrations of monoclinic CuO (Sone *et al.*, 2020). The absence of significant bands in the spectrum confirms the phase purity of the synthesized CuO. In the composite spectra (Fig. 2b–d), the Cu–O stretching bands are retained, confirming the preservation of the CuO structure upon GO incorporation. Additional bands characteristic of GO appear as GO content increases, confirming its successful integration into the composites. A broad band centered around 3200–3500 cm^{-1} attributed to O–H stretching vibrations of hydroxyl groups on the GO surface and adsorbed moisture (Anjum *et al.*, 2023). Bands at approximately 890 cm^{-1} and 1110 cm^{-1} are assignable to C=C skeletal stretching of the graphitic sp^2 carbon network and C=O stretching of carboxyl (–COOH) groups, respectively. The concurrent presence of CuO vibrational signatures and GO-related functional group bands, with systematic evolution in band intensities across the composite series, collectively confirms the successful formation of CuO/GO composites and suggests interfacial interaction between CuO nanoparticles and the GO sheets.

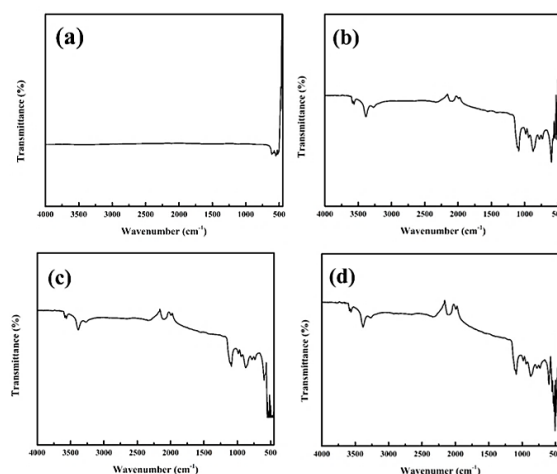


Figure 2: FTIR spectra of (a) pristine CuO (b) CuO/GO-0.2 (c) CuO/GO-0.4 (d) CuO/GO-0.6

Morphology Study

The surface morphology of the synthesized photocatalysts was examined by scanning electron microscopy (SEM), as shown in Figure 3(a–d). In the pristine CuO sample (Figure 3a), particles appear heavily clumped together, with irregular shapes and indistinct boundaries, indicating limited surface accessibility. Upon incorporation of GO at 0.2 g (Figure 3b), the agglomeration is partially disrupted, and a slightly more open particle arrangement is observed, though considerable clustering persists. For the CuO/GO-0.4 composite (Figure 3c), CuO particles are distributed more evenly throughout the GO matrix, with less clumping and better dispersion overall, indicating stronger interaction between the CuO and GO phases at this loading level. This well-dispersed morphology provides more accessible active sites and enhanced light harvesting. In contrast, CuO/GO-0.6 (Figure 3d) shows a return to increased agglomeration, likely due to restacking and overcrowding of GO sheets at higher loadings, which reduces the effective surface area (Krishna *et al.*, 2023).

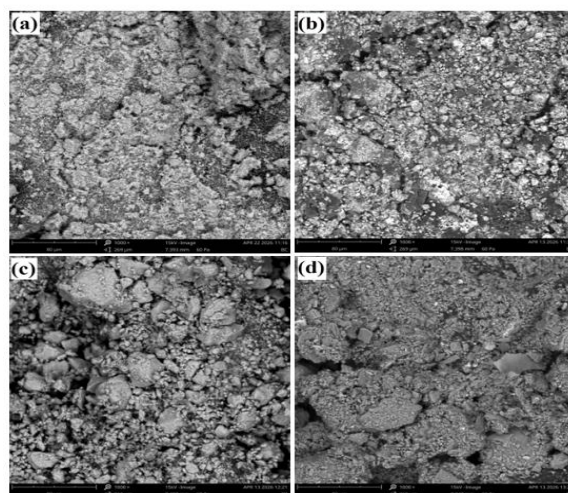


Figure 3: SEM images of (a) pristine CuO, (b) CuO/GO-0.2, (c) CuO/GO-0.4, (d) CuO/GO-0.6

Optical Absorption Properties

The band gap energies of the synthesized materials were obtained from Tauc's plot and were calculated using equation (4) (Mallik & Rath, 2022).

$$(\alpha h\nu)^{1/2} = A(h\nu - E_g) \quad (4)$$

Where: α = absorption coefficient, h = Planck's constant, ν = frequency, $n = \frac{1}{2}$ or 2 for direct and indirect transitions, A = constant, and E_g = band gap energy.

The band gap energies obtained from the Tauc plot are 1.98 eV, 1.92 eV, 1.90 eV, and 1.95 eV for pristine CuO, CuO/GO-0.2, CuO/GO-0.4, and CuO/GO-0.6 composites, respectively. The band gap energy is noticeably reduced from pristine CuO to CuO/GO-0.4 composites and slightly increases at higher GO loading (Figure 4 (d)). The reduction in the band gap energy indicates that loading an appropriate amount of GO may effectively modify the electronic structure of CuO up to a certain optimum loading (NourEldien & Nassar, 2026). All synthesized samples exhibited band gap energies that remained within the visible-light range, confirming their potential for photocatalytic activity under visible-light irradiation.

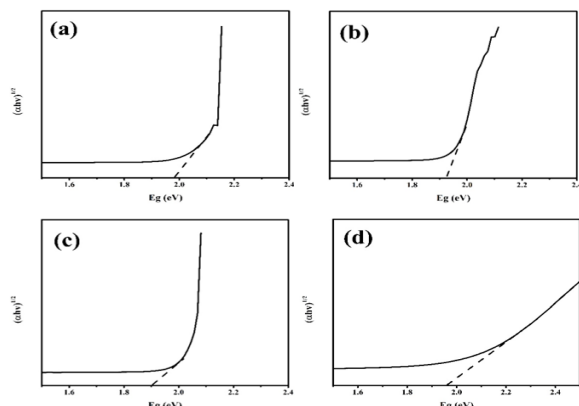


Figure 4: Tauc's plot of (a) pristine CuO (b) CuO/GO-0.2 (c) CuO/GO-0.4 (d) CuO/GO-0.6

Photocatalytic Efficiency Test

To assess how well the synthesized catalysts performed, their ability to degrade BF dye under visible light was tested, with the results shown in Figure 5a. Control runs carried out without a catalyst (photolysis) and without light (dark adsorption) achieved only 6.7% and 16.3% removal, respectively, confirming that the degradation seen elsewhere is driven mainly by the photocatalytic process itself. The figure shows pristine CuO achieving 48% removal, whereas the CuO/GO composites performed progressively better as the GO content rose, up to an optimal level. A dramatic enhancement was observed for CuO/GO-0.4, which achieved the highest removal efficiency of 97%, demonstrating the synergistic effect of GO incorporation at this loading level. However, a further increase in GO content to 0.6 g instead caused the removal efficiency to drop to 81.7%, likely because excess GO sheets restack at higher loadings, reducing the number of active sites and blocking light from reaching the CuO surface.

The photocatalytic reaction kinetics were analyzed using the modified Langmuir–Hinshelwood model, and the results are presented in Figure 5b. All degradation processes exhibited good linearity with R^2 values close to unity. The rate constants followed

the order: CuO/GO-0.4 (0.0480 min^{-1}) > CuO/GO-0.6 (0.0245 min^{-1}) > CuO/GO-0.2 (0.0136 min^{-1}) > pristine CuO (0.0110 min^{-1}) > dark (0.0032 min^{-1}) > photolysis (0.0012 min^{-1}), consistent with the trend observed in the removal efficiency. The rate constant of CuO-GO-0.4 is approximately 40 times greater than that of photolysis alone, confirming that the photocatalyst plays a decisive role in driving the degradation process. The decrease in rate constant from CuO/GO-0.4 to CuO/GO-0.6 further corroborates the detrimental effect of excess GO loading on photocatalytic activity.

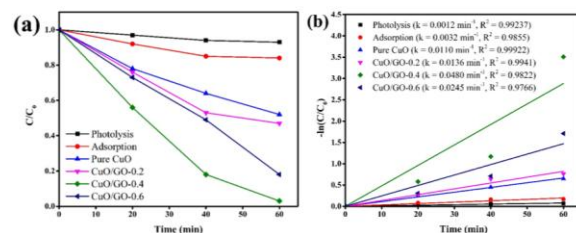


Figure 5: (a) Photocatalytic degradation of BF using CuO/GO composites photocatalysts (b) kinetic curve evaluating the rate constants.

Radical scavenging experiments

To identify the reactive species responsible for the photocatalytic degradation of BF, radical scavenging experiments were conducted using isopropanol (IPA), ethylenediaminetetraacetic acid (EDTA), and ascorbic acid (AA) as scavengers for hydroxyl radicals ($\bullet\text{OH}$), holes (h^+), and superoxide radicals ($\text{O}_2^{\bullet-}$), respectively, and the results are presented in Figure 6a. Without any scavenger, the catalyst achieved 97% dye removal, serving as the baseline for comparison. The addition of EDTA caused negligible suppression of degradation efficiency, with removal remaining at 95%, indicating that holes play a minimal role in the degradation process. In contrast, the introduction of IPA and AA significantly reduced the degradation efficiency to 14% and 11%, respectively, confirming that hydroxyl radicals ($\bullet\text{OH}$) and superoxide radicals ($\text{O}_2^{\bullet-}$) are the dominant reactive species driving the photocatalytic degradation.

The reusability of the CuO/GO-0.4 photocatalyst was evaluated over four consecutive degradation cycles. After each cycle, the catalyst was washed, dried, and reused using the same experimental conditions. As shown in Figure 6b, the catalyst maintained good photocatalytic activity, exhibiting only about a 9% decrease in degradation efficiency after four cycles. This slight decline is likely due to the accumulation of degradation intermediates on the catalyst surface and minor catalyst loss during recovery. The results indicate good stability and reusability of the CuO/GO-0.4 composite, suggesting its potential for practical applications.

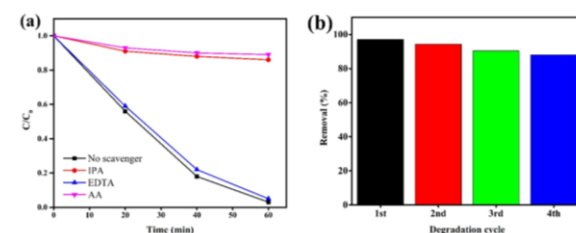


Figure 6: (a) Scavenging experiment (b) reusability study

Proposed photocatalytic degradation mechanism

When exposed to visible light, CuO absorbs photons with energy equal to or greater than its bandgap, generating electron-hole (e^-/h^+) pairs. The photogenerated electrons are rapidly transferred from the conduction band (CB) of CuO to the GO sheets, which act as efficient electron acceptors owing to their high electrical conductivity and extended π -conjugated structure (Thambiliyagodage *et al.*, 2024). This interfacial charge transfer effectively suppresses electron-hole recombination, thereby enhancing the photocatalytic efficiency of the composite. The accumulated electrons on GO reduce dissolved oxygen to produce superoxide radicals ($O_2^{\bullet-}$), while the holes remaining in the valence band (VB) of CuO react with surface hydroxyl groups or adsorbed water to generate highly reactive hydroxyl radicals ($\bullet OH$). These reactive oxygen species are primarily responsible for the oxidative degradation and eventual mineralization of BF into CO_2 and H_2O . The proposed reactions are summarized in Equations (5) – (9), and the corresponding schematic mechanism is presented in Figure 7.

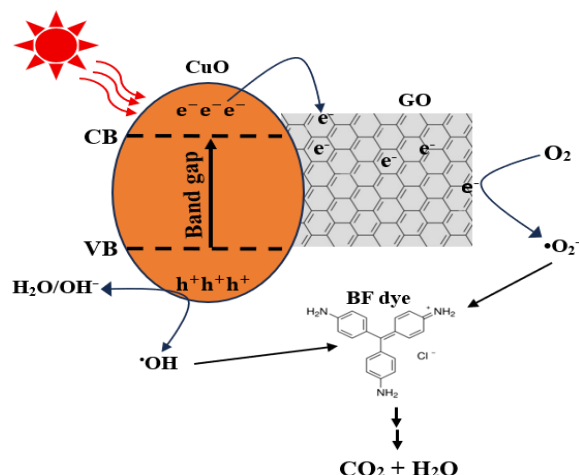
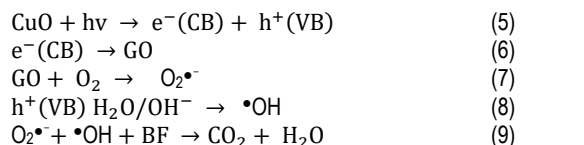


Figure 7. Schematic mechanism for the photocatalytic degradation of BF dye over CuO/GO-0.4 composite photocatalyst under visible light irradiation.

Conclusion

In this study, CuO/GO composite photocatalysts with varying GO loadings were successfully synthesized and applied for the visible-light-driven degradation of BF dye. The incorporation of GO significantly enhanced the photocatalytic performance of CuO by promoting charge separation and improving surface accessibility. CuO/GO-0.4 emerged as the best-performing composite, achieving 97% BF removal, attributable to its well-dispersed morphology and effective interfacial interaction between CuO and GO at this loading. Beyond this loading, excess GO restacking reduced photocatalytic activity, as evidenced by the lower efficiency of CuO/GO-0.6. The dominance of $\bullet OH$ and $O_2^{\bullet-}$ as reactive species confirms that degradation proceeds primarily via oxidative pathways facilitated by the GO-mediated charge-transfer

mechanism. The good reusability of CuO/GO-0.4 further supports its potential for practical wastewater treatment applications. Overall, this work demonstrates that controlled GO incorporation is an effective approach for enhancing CuO photocatalytic activity.

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REFERENCE

- Al-Tohamy, R., Ali, S. S., Li, F., Okasha, K. M., Mahmoud, Y. A. G., Elsamahy, T., & Sun, J. (2022). A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. *Ecotoxicology and Environmental Safety*, 231, 113160. <https://doi.org/10.1016/j.ecoenv.2021.113160>
- Anjum, F., Shaban, M., Ismail, M., Gul, S., Bakhsh, E. M., Khan, M. A., & Khan, M. I. (2023). Novel synthesis of CuO/GO nanocomposites and their photocatalytic potential in the degradation of hazardous industrial effluents. *ACS Omega*, 8 (20), 17667–17681. <https://doi.org/10.1021/acsomega.3c00129>
- Banu, K. B. (2026). Integrated experimental and DFT study of a GO–CuO nanocomposite with improved antifungal efficacy and photocatalytic behavior. *Discover Chemistry*, 3, 140. <https://doi.org/10.1007/s44371-026-00595-8>
- Banu, R., Salvi, N., Ameta, C., Ameta, R., & Punjabi, P. B. (2019). Visible light-driven photocatalytic degradation of brilliant green dye using graphene oxide/copper oxide binary composite. *Indian Journal of Chemistry, Section B*, 58 (2), 157 – 166. <https://api.semanticscholar.org/CorpusID:139445588>
- Biswas, K., Mohanta, Y.K., Mishra, A.K., Al-Sehemi, A.G., Pannipara, M., Sett, A., Bratovic, A., De, D., Prasad Panda, B., Kumar Avula, S. & Mohanta, T.K. (2021). Wet chemical development of CuO/GO nanocomposites: their augmented antimicrobial, antioxidant, and anticancer activity. *Journal of Materials Science: Materials in Medicine*, 32(12), 151. <https://doi.org/10.1007/s10856-021-06612-9>
- Dasineh Khiavi, N., Katal, R., Kholghi Eshkalak, S., Masudy-Panah, S., Ramakrishna, S., & Jiangyong, H. (2019). Visible light-driven heterojunction photocatalyst of CuO–Cu₂O thin films for photocatalytic degradation of organic pollutants. *Nanomaterials*, 9(7), 1011. <https://doi.org/10.3390/nano9071011>
- Esfahani, M. Z., Soroush, E., Mohammadnejad, S., Helli, M., Khachatourian, A. M., Toprak, M. S., & Varma, R. S. (2024). Copper oxide/graphene-based composites: Synthesis methods, applications and recent advancements. *FlatChem*, 47, 100716. <https://doi.org/10.1016/j.flatc.2024.100716>

- Jiang, Y., & Zhao, J. (2022). A new photocatalytic reactor for hexachlorobenzene removal in water. *Desalination and Water Treatment*, 253, 231–238. <https://doi.org/10.5004/dwt.2022.28306>
- Krishna, Ambati Mounika Sai, Brindha Ramasubramanian, Sheik Haseena, Priyanka Bamola, Himani Sharma, Chandreswar Mahata, Alexander Chroneos et al. "C., Chroneos, A., Krishnamurthy, S., Ravva, M.K., Chandu, B. and Lim, Y.F., (2023). Functionalized graphene-incorporated cupric oxide charge-transport layer for enhanced photoelectrochemical performance and hydrogen evolution. *Catalysts* 13, no. 4 (2023) 785. <https://doi.org/10.3390/catal13040785>
- Lin, W., Yu, X., Zhu, Y., & Zhang, Y. (2018). Graphene Oxide/BiOCl Nanocomposite Films as Efficient Visible Light Photocatalysts. *Frontiers in Chemistry*, 6, 274. <http://doi.org/10.3389/fchem.2018.00274>
- Majumder, P., & Gangopadhyay, R. (2022). Evolution of graphene oxide (GO)-based nanohybrid materials with diverse compositions: An overview. *RSC Advances*, 12, 1293 – 1323. <http://doi.org/10.1039/D1RA06731A>
- Mallik, G., & Rath, S. (2022). Electrical properties of CuO nanoflakes/Au heterojunction under photoexcitation. *Materials Today: Proceedings*, 62, 5997 – 6000. <https://doi.org/10.1016/j.matpr.2022.04.978>
- Moura, D. B., Alan, I., Sousa, T. G., Lima, A. M., Silva, W. O., & Brandao, L. P. (2021). Synthesis and Characterization of Graphene-Oxide Reinforced Copper Matrix Composite. *Materials Proceedings*, 4, 72. <https://doi.org/10.3390/IOCN2020-08000>
- NourEldien, M. S., & Nassar, M. Y. (2026). Ascorbic acid-mediated solid-state synthesis of cavity-engineered CuO–Cu₂O–Cu heterostructures: structural transformation mechanism and photocatalytic detoxification of Cr (vi). *RSC Advances*, 16(7), 6377 – 6393. <https://doi.org/10.1039/d5ra09131d>
- Rafiq, S., RaZa, Z.A., Aslam, M., & Bakhtiyar, M. J. (2022). Graphene Nanosheets Decorated with Copper Oxide Nanoparticles for the Photodegradation of Methylene Blue. *Chemical Research in Chinese Universities*, 38(6), 1518 – 1525. <https://doi.org/10.1007/s40242-022-2109-7>
- Sagadevan, S., Lett, J. A., Weldegebräel, G. K., Garg, S., Oh, W. C., Hamizi, N. A., & Johan, M. R. (2021). Enhanced photocatalytic activity of rGO-CuO nanocomposites for the degradation of organic pollutants. *Catalysts*, 11(8), 1008. <https://doi.org/10.3390/catal11081008>
- Sone, B. T., Diallo, A., Fuku, X. G., Gurib-Fakim, A., & Maaza, M. (2020). Biosynthesized CuO nano-platelets: Physical properties & enhanced thermal conductivity nanofluidics. *Arabian Journal of Chemistry*, 13(1), 160–170. <https://doi.org/10.1016/j.arabjc.2017.03.004>
- Thambiliyagodage, C., Liyanaarachchi, H., Jayanetti, M., Ekanayake, G., Mendis, A., Samarakoon, U., & Vigneswaran, S. (2024). Persulfate-assisted photocatalytic and antibacterial activity of TiO₂–CuO coupled with graphene oxide and reduced graphene oxide. *Scientific Reports*, 14(1), 12505. <https://doi.org/10.1038/s41598-024-63452-7>
- Víctor-Román, S., García-Bordejé, E., Hernández-Ferrer, J., González-Domínguez, J. M., Ansón-Casaos, A., Silva, A. M., ... & Benito, A. M. (2020). Controlling the surface chemistry of graphene oxide: Key towards efficient ZnO-GO photocatalysts. *Catalysis Today*, 357, 350–360. <https://doi.org/10.1016/j.cattod.2019.01.020>
- Wang, L., Wang, J., Pana, H., Zhao, M., & Chena, J. (2021). Kinetics and removal pathway of basic fuchsin by electrochemical oxidation. *Journal of Electroanalytical Chemistry*, 880, 114792. <https://dx.doi.org/10.1016/j.jelechem.2020.114792>
- Wang, N., Zhang, F., Mei, Q., Wu, R., & Wang, W. (2020). Photocatalytic TiO₂/rGO/CuO Composite for Wastewater Treatment of Cr (VI) Under Visible Light. *Water, Air & Soil Pollution*, 231(5). <https://doi.org/10.1007/s11270-020-04609-8>
- Yaseen, M., Farooq, S., Khan, A., Shah, N., Shah, L. A., Bibi, S., Khan, I. U., & Ahmad, S. (2022). CuO-SiO₂-based nanocomposites: Synthesis, characterization, photocatalytic, antileishmanial, and antioxidant studies. *Journal of the Chinese Chemical Society*, 69(8), 1637 – 1653. <https://doi.org/10.1002/jccs.202200182>