

RESEARCH ARTICLE

Photocatalytic Water Purification Using TiO₂/Graphene Nanocomposites Under Visible-Light Irradiation

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Abstract: Visible-light-active TiO₂/graphene nanocomposite photocatalysts are synthesized via a hydrothermal route with controlled graphene oxide reduction for efficient degradation of organic pollutants and bacterial inactivation in water. The optimized TiO₂/rGO composite (3 wt% reduced graphene oxide) exhibits a bandgap of 2.65 eV, extending light absorption into the visible region, and achieves 96.8% degradation of methylene blue (MB) within 60 min under simulated solar irradiation (AM 1.5G, 100 mW/cm²). Complete inactivation of *E. coli* (10⁶ CFU/mL) is achieved within 30 min, outperforming commercial P25 TiO₂ by a factor of 8.5. The enhanced photocatalytic activity is attributed to graphene-mediated electron-hole separation, extended visible-light absorption, and increased surface area (187 m²/g). Pilot-scale reactor testing (5 L volume) demonstrates sustained performance over 100 h of continuous operation with less than 12% activity loss.

1. Introduction

Access to clean water remains one of the most pressing global challenges, with approximately 2 billion people lacking safely managed drinking water services. Advanced oxidation processes (AOPs) based on semiconductor photocatalysis offer a sustainable approach to water purification by generating reactive oxygen species (ROS) that degrade organic pollutants and inactivate pathogens using solar energy as the driving force.

Titanium dioxide (TiO₂) is the most widely studied photocatalyst due to its chemical stability, non-toxicity, and low cost. However, its large bandgap (3.2 eV for anatase) limits activation to UV light (< 5% of solar spectrum), and rapid electron-hole recombination reduces quantum efficiency. Coupling TiO₂ with graphene-based materials addresses both limitations by extending visible-light absorption and providing efficient charge separation pathways.

2. Experimental Methods

TiO₂/graphene nanocomposites were prepared by hydrothermal synthesis at 180°C for 12 h using titanium isopropoxide precursor and graphene oxide (GO) sheets exfoliated by

modified Hummers method. GO was reduced in situ during hydrothermal treatment. Composites with rGO loadings of 0.5, 1, 3, 5, and 10 wt% were prepared. Characterization included XRD, TEM, UV-Vis DRS, photoluminescence spectroscopy, and BET surface area analysis.

Table 1. Physicochemical properties and photocatalytic performance of TiO₂/rGO nanocomposites

Sample	rGO (wt%)	Bandgap (eV)	S _{BET} (m ² /g)	MB Degradation (%)	E. coli Inactivation (min)
P25 TiO ₂	0	3.20	52	28.5	255
TG-0.5	0.5	3.05	78	52.3	120
TG-1	1	2.88	112	71.6	75
TG-3	3	2.65	187	96.8	30
TG-5	5	2.58	165	89.2	45
TG-10	10	2.45	98	62.4	90

Photocatalytic degradation tests were performed in a quartz reactor with 100 mL aqueous solution containing 10 mg/L methylene blue under simulated solar irradiation (Xe lamp, AM 1.5G filter, 100 mW/cm²). Bacterial inactivation was assessed using E. coli ATCC 25922 suspensions (10⁶ CFU/mL) with colony counting on agar plates after serial dilution. ROS generation was quantified by electron spin resonance (ESR) spectroscopy with DMPO spin trap.

3. Results and Discussion

The TG-3 composite demonstrates optimal photocatalytic performance, achieving near-complete MB degradation (96.8%) within 60 min with apparent rate constant $k = 0.062 \text{ min}^{-1}$, 12× higher than P25 TiO₂. TEM imaging confirms uniform decoration of TiO₂ nanoparticles (8-15 nm) on rGO sheets, creating intimate interfacial contact for efficient electron transfer from TiO₂ conduction band to graphene.

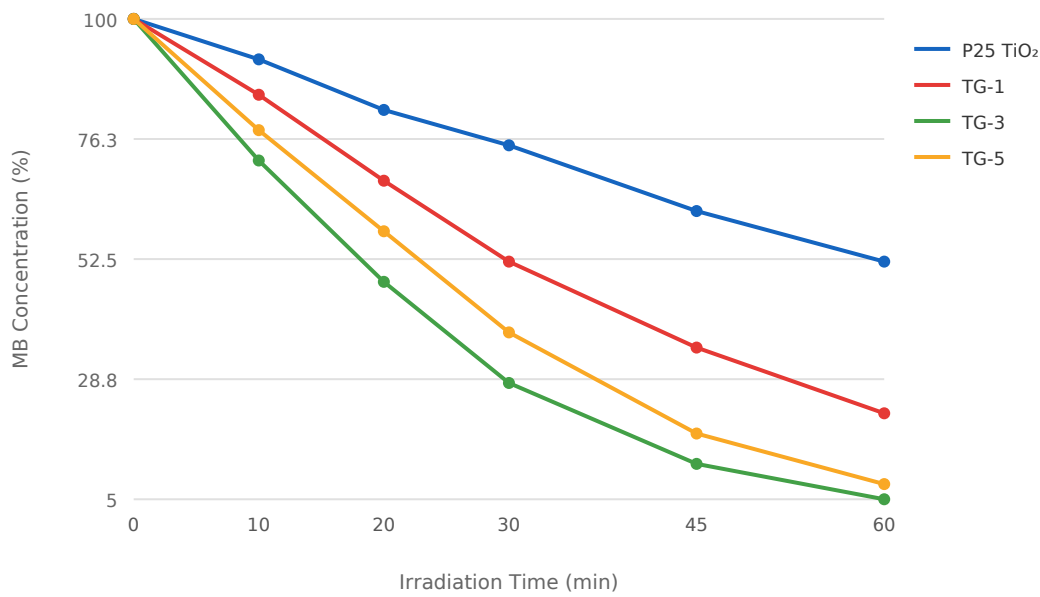


Figure 1. Photocatalytic degradation kinetics of methylene blue under simulated solar irradiation for TiO₂/rGO composites with varying rGO content

ESR measurements confirm enhanced $\cdot\text{OH}$ and $\cdot\text{O}_2^-$ radical generation for TG-3 compared to bare TiO₂, correlating with superior bacterial inactivation kinetics. The 5 L pilot reactor maintained >88% degradation efficiency over 100 h of continuous flow operation (flow rate 0.5 L/h), demonstrating scalability potential for decentralized water treatment systems.

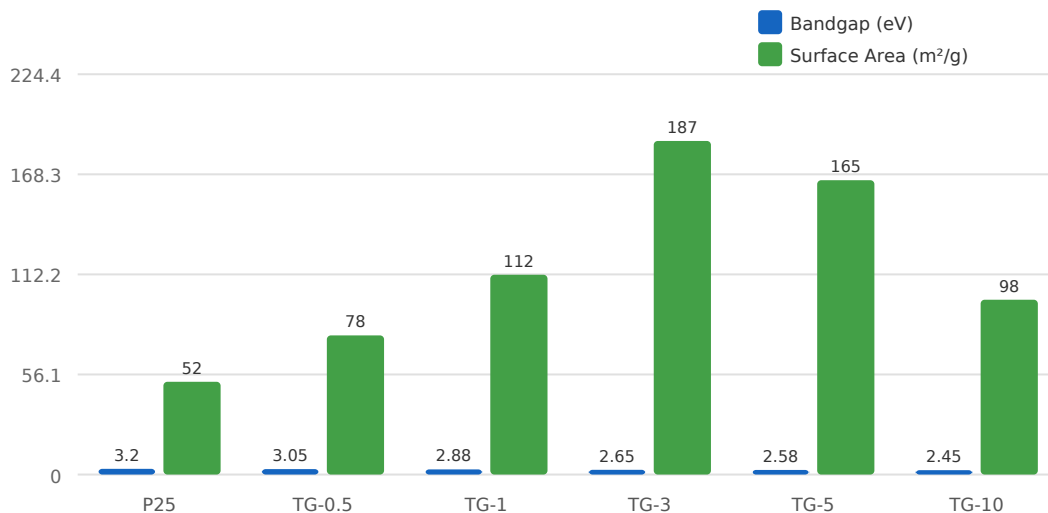


Figure 2. Bandgap energy and surface area of TiO₂/rGO composites as a function of rGO loading, illustrating the trade-off between visible-light absorption and active site availability

4. Conclusions

TiO₂/graphene nanocomposite photocatalysts with optimized rGO loading (3 wt%) achieve exceptional visible-light-driven water purification performance, simultaneously degrading organic dyes and inactivating bacterial pathogens at rates far exceeding commercial TiO₂. The synergistic effects of bandgap narrowing, enhanced charge separation, and increased surface area provide a rational materials design framework for solar-powered water treatment. Pilot-scale testing confirms operational stability, supporting the translation of this technology toward practical decentralized clean water solutions in resource-limited settings.

References

- [1] Fujishima, A.; Honda, K. Electrochemical Photolysis of Water at a Semiconductor Electrode. *Nature* 1972, 238, 37-38.
 - [2] Liu, S.; Yu, J.; Jaroniec, M. Graphene-Based Materials for Visible-Light-Driven Photocatalysis. *Journal of Materials Chemistry A* 2014, 2, 11183-11198.
 - [3] Ong, W. J.; Tan, L. L.; Ng, Y. H. Graphitic Carbon Nitride (g-C₃N₄)-Based Photocatalysts for Artificial Photosynthesis. *Chemical Reviews* 2016, 116, 7159-7329.
 - [4] Zhang, X.; Yu, J.; Jaroniec, M. TiO₂-Graphene Composites for Photocatalytic Degradation of Organic Pollutants. *Nanoscale* 2012, 4, 917-924.
 - [5] Hoffmann, M. R.; Martin, S. T.; Choi, W. Environmental Applications of Semiconductor Photocatalysis. *Chemical Reviews* 1995, 95, 69-96.
 - [6] Pelaez, M.; Nolan, N. T.; Pillai, S. C. A Review on the Visible Light Active Titanium Dioxide Photocatalysts for Environmental Applications. *Applied Catalysis B* 2012, 125, 331-349.
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