INSIGHTS-JOURNAL OF
LIFE AND SOCIAL SCIENCES

INSIGHTS-JLSS
Insights-Journal of Life and Social Sciences

# COMPARATIVE ANALYSIS MgO AND TiO2 NANOCATALYST IN DEGRADATION OF REACTIVE BLUE 13 DYE

*Original Article*

**Shaher Bano[1]*, Ali Raza[1], Ayesha Safdar[2], Mahnoor Tariq[3], Muhammad Ajmal[4], Muniba Riaz[5], Azka Masood[6], Dawood Ali[7]**

[1]MPhil, Riphah International University, Faisalabad, Pakistan.
[2]BS Chemistry, The Islamia University of Bahawalpur, Pakistan.
[3]BS Biotechnology, University of Okara, Pakistan.
[4]MS Chemistry, Khawaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan.
[5]Master's in Chemistry, University of the Punjab, Pakistan.
[6]BS Chemistry, Bahauddin Zakariya University (BZU) , Pakistan.
[7]MPhil Chemistry, Department of Chemistry, Forman Christian College University, Pakistan.

**Corresponding Author:** Shaher Bano, MPhil, Riphah International University, Faisalabad, Pakistan, ali.raza5415411@gmail.com

Conflict of Interest: None

Grant Support & Financial Support: None

Acknowledgment: The authors acknowledge the valuable support provided by the Riphah International University, Faisalabad, and fellow researchers in the field of environmental nanotechnology.

## ABSTRACT

**Background:** Synthetic dyes, especially azo-based compounds like Reactive Blue 13, are widely used in the textile industry and pose significant environmental hazards due to their stability and resistance to biodegradation. Photocatalysis using metal oxide nanoparticles offers a sustainable approach for degrading such dyes in wastewater. Titanium dioxide ($TiO_2$) and magnesium oxide (MgO) nanoparticles have demonstrated high catalytic activity under UV irradiation, yet their comparative efficiency under varying operational parameters remains underexplored.

**Objective:** To evaluate and compare the photocatalytic degradation efficiency of Reactive Blue 13 dye using $TiO_2$ (anatase) and MgO nanoparticles under UV light by optimizing pH, catalyst dosage, and dye concentration.

**Methods:** Reactive Blue 13 stock solutions (1000 ppm) were prepared and diluted for experimental use. Photocatalytic degradation was carried out in a controlled photoreactor under UV light, with pH adjusted using 0.1 M HCl and NaOH. Catalyst dosages ranged from 0.01 g to 0.15 g, and dye concentrations varied from 10 ppm to 40 ppm. UV-Vis spectrophotometry was employed to monitor absorbance at $\lambda max$ = 574 nm. Degradation efficiency was calculated as a percentage reduction in dye concentration over time.

**Results:** $TiO_2$ showed maximum degradation efficiency (98%) at 10 ppm dye concentration, pH 10, and 0.1 g catalyst dose. MgO achieved 97% efficiency at the same dye concentration with a pH of 11 and 0.05 g catalyst dose. Efficiency declined at higher dye concentrations due to light penetration limits and active site saturation.

**Conclusion:** Both $TiO_2$ and MgO are effective photocatalysts for degrading Reactive Blue 13 dye, with MgO demonstrating broader pH tolerance and $TiO_2$ showing peak efficiency under alkaline conditions. These findings underscore the importance of parameter optimization for real-world wastewater remediation applications.

**Keywords:** Azo dyes, Environmental remediation, Magnesium oxide, Nanoparticles, Photocatalysis, Titanium dioxide, UV spectroscopy.

## INTRODUCTION

The history of dye usage is deeply rooted in human civilization, tracing back to ancient cultures that utilized naturally sourced pigments from plants, minerals, and animals to express identity, status, and creativity through textiles and art. Civilizations such as the Egyptians, Greeks, and Romans developed dyeing techniques that were both symbolic and practical. Over centuries, technological advances, trade expansion, and industrialization contributed to significant shifts in dye sources and processing. The Industrial Revolution marked a pivotal moment, introducing synthetic dyes that revolutionized the textile industry by enabling large-scale production, improved colorfastness, and a wider spectrum of shades (1,2). However, the rapid rise of synthetic dyes also brought environmental concerns to the forefront, particularly due to the toxic effluents released during textile dyeing processes. As a result, the 21st century has witnessed a paradigm shift toward sustainable dyeing practices, with increasing focus on biodegradable dyes, eco-friendly technologies, and novel catalytic materials that can mitigate the environmental burden caused by dye pollutants (3,4). Among synthetic dyes, reactive dyes are widely employed for coloring cellulose-based fibers due to their ability to form covalent bonds with textile substrates, resulting in excellent wash and light fastness. Despite these advantages, the release of unreacted dye residues in wastewater poses a significant environmental hazard, affecting aquatic ecosystems, impairing water quality, and presenting challenges in wastewater treatment (5,6). With heightened environmental awareness, researchers are actively investigating advanced treatment methods that are both efficient and sustainable. In this context, nanocatalysts have emerged as promising candidates for environmental remediation owing to their high surface area, reactivity, and ability to facilitate degradation of recalcitrant pollutants. Magnesium oxide (MgO) nanoparticles, in particular, have shown considerable potential due to their physicochemical stability, affordability, and catalytic activity in degrading harmful dyes and other organic contaminants (7,8).

MgO nanoparticles, with their high surface-area-to-volume ratio and environmentally benign nature, offer significant advantages in dye degradation applications. Their ability to generate reactive oxygen species under specific conditions allows for the efficient breakdown of dye molecules, converting toxic compounds into harmless by-products. Several studies have reported the successful application of MgO in degrading various classes of dyes, including azo and reactive dyes, either alone or in combination with other photocatalysts such as titanium dioxide ($TiO_2$) (9,10). Comparative analyses have revealed notable differences in degradation efficiencies depending on nanoparticle size, surface characteristics, and reaction parameters such as pH, light exposure, and catalyst concentration. These findings underscore the importance of optimizing nanocatalyst properties to maximize environmental benefits while minimizing secondary pollution risks. Furthermore, research on MgO nanocatalysts has extended into green synthesis methods using biological extracts, making the production process more sustainable and reducing the use of hazardous chemicals. Their application in dye degradation not only enhances the effectiveness of wastewater treatment systems but also aligns with global sustainability goals by reducing dependency on energy-intensive and chemically aggressive methods (11,12). $TiO_2$, another extensively studied nanocatalyst, offers a benchmark for assessing the performance of alternative materials such as MgO. Therefore, direct comparisons of $TiO_2$ and MgO under controlled conditions can provide critical insights into their relative efficiencies and practical applicability. Given the pressing need to address dye pollution and promote eco-conscious industrial practices, the current study aims to synthesize and characterize magnesium oxide nanoparticles and evaluate their catalytic performance in degrading Reactive Blue 13 dye under UV irradiation. The degradation efficiency of MgO will be compared with that of $TiO_2$ nanoparticles, providing a rational basis for selecting sustainable nanocatalysts in textile wastewater treatment. This research endeavors to contribute to environmentally responsible dyeing practices by offering viable, low-cost, and scalable solutions for dye degradation.

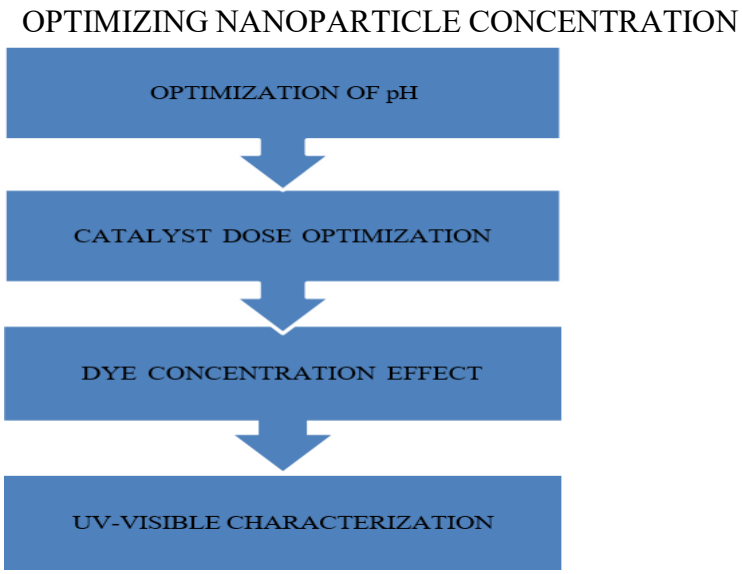
## METHODS

The present experimental study was conducted at the laboratories of Riphah International University, Faisalabad, with the objective of investigating the photocatalytic degradation efficiency of magnesium oxide (MgO) nanoparticles on Reactive Blue 13 dye under ultraviolet (UV) irradiation. The study design involved a controlled laboratory setup in which a comparative evaluation was also made between MgO and titanium dioxide ($TiO_2$) nanocatalysts. Although no human or animal participants were involved, ethical approval for the use of university resources and chemicals was obtained from the institutional research committee, ensuring all safety and ethical considerations were met. The experiment utilized analytical-grade reagents, including Reactive Blue 13 dye, MgO nanoparticles, $TiO_2$ anatase powder, deionized water, hydrochloric acid (HCl), and sodium hydroxide (NaOH) for pH adjustments. Laboratory glassware such as beakers, Erlenmeyer flasks, volumetric flasks, pipettes, burettes, and test tubes were employed for solution preparation and handling. Analytical equipment included a UV-visible spectrophotometer (Perkin Elmer), centrifuge, digital pH meter, hot plate/stirrer

with magnetic mixing capabilities, and an ultrasonic bath for catalyst dispersion. The UV-Vis spectrophotometer played a key role in tracking the dye's degradation by measuring absorbance changes at the dye's λmax (maximum absorbance wavelength), enabling quantification of decolorization efficiency in treated solutions (13-15).

A stock solution of Reactive Blue 13 was prepared at a concentration of 1000 ppm by dissolving 0.1 g of dye in 100 ml of distilled water, which was subsequently diluted to obtain working concentrations. Standard solutions of 0.1 M HCl and 0.1 M NaOH were prepared for pH adjustment by dissolving 8.3 g of HCl and 4.0 g of NaOH in distilled water, respectively, to final volumes of 1 liter in volumetric flasks. The prepared solutions were stored under sterile conditions and labeled appropriately. Photocatalytic experiments were carried out in a custom photoreactor chamber equipped with a UV lamp, where distance between the UV source and reaction vessel was standardized. For each trial, 1000 ml of dye solution adjusted to a specific pH was added to the reactor, followed by a known amount of MgO or $TiO_2$ catalyst. The suspension was stirred magnetically to maintain uniform distribution of the catalyst, while UV light exposure initiated the photodegradation process. Samples of 5 ml were withdrawn at predetermined time intervals and immediately centrifuged to remove particulate matter. The supernatant was analyzed spectrophotometrically to determine the residual dye concentration, and percentage decolorization was calculated using the formula: **Decolorization (%) = $[(C_0 - C_t)/C_0] \times 100$**, where $C_o$ is the initial dye concentration and $C_t$ is the concentration at time $t$ (15,16). Optimization of experimental variables was carried out to determine the most effective conditions for dye degradation. Parameters including catalyst concentration (MgO and $TiO_2$), initial dye concentration, and solution pH were varied one at a time while keeping the others constant to identify optimal performance conditions. The influence of each parameter on degradation efficiency was assessed to provide insights into the catalytic behavior of MgO compared to $TiO_2$ (17). Characterization of degradation was further supported by UV-Vis spectroscopy, which evaluated absorbance at λmax over time to assess the breakdown of the dye's chromophoric structure. The absorbance data was translated into transmittance and further processed using Beer-Lambert Law to establish a correlation between dye concentration and absorbance values: **$A = \varepsilon.c.d$**, where $A$ is absorbance, $\varepsilon$ is molar extinction coefficient, $c$ is concentration, and $d$ is path length (18,19).




***Process of flow methodology***

## RESULTS

Spectrophotometric analysis revealed the maximum absorbance wavelength (λmax) for Reactive Blue 13 dye was observed at 574 nm. Using this wavelength, the degradation performance of two photocatalysts—$TiO_2$ (anatase) and MgO nanoparticles—was assessed across various experimental parameters, including pH, dye concentration, and catalyst dosage. Under optimized conditions, $TiO_2$ demonstrated its highest degradation efficiency at pH 10, where the dye removal percentage reached 98% for a 10 ppm solution after

120 minutes of UV exposure. At dye concentrations of 20 ppm, 30 ppm, and 40 ppm, the degradation efficiency progressively declined to 75%, 51%, and 36% respectively. The degradation effectiveness was found to decrease significantly beyond 0.1 g of $TiO_2$, where increased catalyst load led to particle agglomeration and reduced UV penetration. The highest photocatalytic activity of $TiO_2$ was observed at a concentration of 0.1 g and pH 10, while further increases up to 0.15 g did not improve dye removal. Regarding pH sensitivity, $TiO_2$-mediated degradation was less efficient in acidic environments, with moderate to low removal at pH 3 and 4. At pH 11, degradation efficiency also dropped slightly compared to pH 10, likely due to excessive hydroxyl ion competition limiting radical formation. $TiO_2$ showed no significant degradation effect at low catalyst concentrations (0.05 g) or at excessively high dye concentrations (≥40 ppm), confirming the necessity of optimized catalyst-to-dye ratios for effective performance.

MgO nanoparticles, in contrast, demonstrated efficient dye degradation over a broader pH range. Significant degradation was observed at both acidic (pH 3: 90%) and alkaline (pH 10: 85%) conditions, with moderate degradation recorded at pH 4 (65%) and pH 11 (70%). The degradation process was strongly influenced by the MgO concentration. Increasing the catalyst dose from 0.01 g to 0.05 g improved dye removal from 30% to 97%, after which efficiency plateaued, reflecting a saturation point. In terms of dye concentration, MgO also followed a similar trend to $TiO_2$. The highest degradation rate (97%) was recorded at 10 ppm dye concentration with 0.05 g MgO and pH 11 after 120 minutes. At higher dye concentrations, degradation rates declined, attributed to increased light absorption by dye molecules, which restricted UV penetration and ROS formation. Additionally, excessive dye coverage on the MgO surface inhibited active site availability, reducing radical generation and subsequent degradation efficiency. A comparative assessment between $TiO_2$ and MgO highlighted that while both catalysts effectively degraded Reactive Blue 13, MgO provided broader applicability across varied pH levels. $TiO_2$ showed its peak performance strictly in alkaline conditions, especially pH 10, but was limited in acidic environments. MgO, conversely, maintained high degradation efficiency in both acidic and alkaline conditions, indicating greater adaptability and less stringent pH dependency. Both catalysts exhibited a similar trend in relation to increasing dye concentration, where degradation efficiency decreased beyond 20 ppm. Notably, degradation efficiency was found to be influenced not only by catalyst and dye concentrations but also by interaction between dye molecules and generated hydroxyl radicals. The optimized catalyst concentrations were 0.1 g for $TiO_2$ and 0.05 g for MgO, with 10 ppm being the most suitable dye concentration for maximal degradation in both cases.

**Table 1: Characteristics of MgO photocatalyst**

| **Characteristic** | **Description** |
|---|---|
| Adsorption | Molecules to MgO nanoparticles' surface, aiding subsequent reactions. |
| Electron-Hole Pairs | MgO creates electron-hole pairs upon UV light exposure, crucial for degradation. |
| Redox Reactions | Electrons and holes react with breaking it down chemically. |
| Hydroxyl Radical Formation | MgO generates hydroxyl radicals, highly reactive in degrading. |
| Efficiency | Degradation effectiveness depends on MgO properties and reaction conditions. |
| Mineralization | Breaks down into harmless byproducts like CO2 and water. |
| Optimization | Ongoing research aims to improve MgO efficiency in degrading. |
| **Applications** | **MgO photocatalysis shows promise in treating textile dye wastewater.** |

**Table 2: General characteristics of Reactive Blue 13**

| **Sr. No.** | **Property** | **Information** |
|---|---|---|
| 1 | Item | Reactive Blue 13 |
| 2 | Appearance | Brilliant blue powder |
| 3 | Molecular formula | C29H16ClN7Na4O14S4 |
| 4 | Soluble in water | At 150 g/L of concentration, the solubility scale scores a 20; at 160 g/L of concentration |
| 5 | pH | Neutral |
| **6** | **Molecular Weight** | **942.15** |

**Table 3: Comparatively analysis of Reactive Blue 13 by optimization parameters**

| Sr. No. | Dye concentration (ppm) | TiO2 concentration (g) | pH Level | Effect of dye degradation |
|---|---|---|---|---|
| 1 | 10 | 0.1 | 3 | Moderate |
| 2 | 10 | 0.1 | 4 | Moderate |
| 3 | 10 | 0.1 | 10 | Clear |
| 4 | 10 | 0.1 | 11 | Less Moderate |
| 5 | 20 | 0.1 | 3 | Moderate |
| 6 | 20 | 0.1 | 4 | Moderate |
| 7 | 20 | 0.1 | 10 | Clear |
| 8 | 20 | 0.1 | 11 | Less Moderate |
| 9 | 30 | 0.1 | 3 | Moderate |
| 10 | 30 | 0.1 | 4 | Moderate |
| 11 | 30 | 0.1 | 10 | Clear |
| 12 | 30 | 0.1 | 11 | Less Moderate |
| 13 | 40 | 0.1 | 3 | Moderate |
| 14 | 40 | 0.1 | 4 | Moderate |
| 15 | 40 | 0.1 | 10 | Clear |
| 16 | 40 | 0.1 | 11 | Less Moderate |
| 17 | 30 | 0.05 | 10 | No Effect |
| **18** | **30** | **0.15** | **10** | **No Effect** |

**Table 4: Degradation percentages of Reactive Blue 13 dye using TiO2 and MgO catalysts**

| Catalyst | pH Level | Degradation Effect |
|---|---|---|
| TiO2 | 3 | Moderate |
| TiO2 | 4 | Less Efficient |
| TiO2 | 10 | Clear |
| TiO2 | 11 | Less Moderate |
| MgO | 3 | Significant |
| MgO | 4 | Moderate |
| MgO | 10 | Significant |
| **MgO** | **11** | **Moderate** |

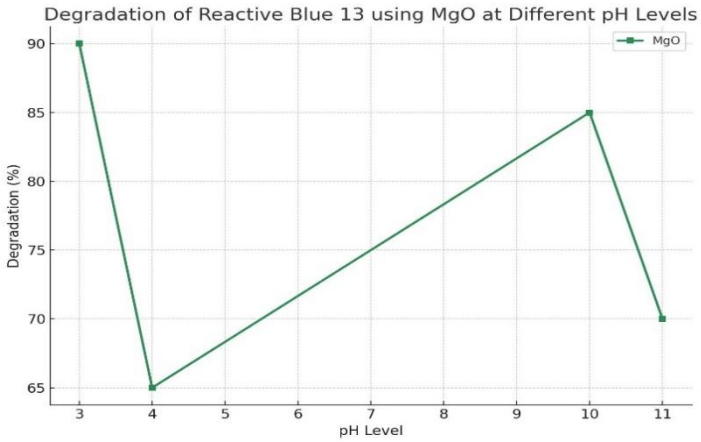



*Figure 1 Degradation of Reactive Blue 13 using MgO at Different pH Levels*

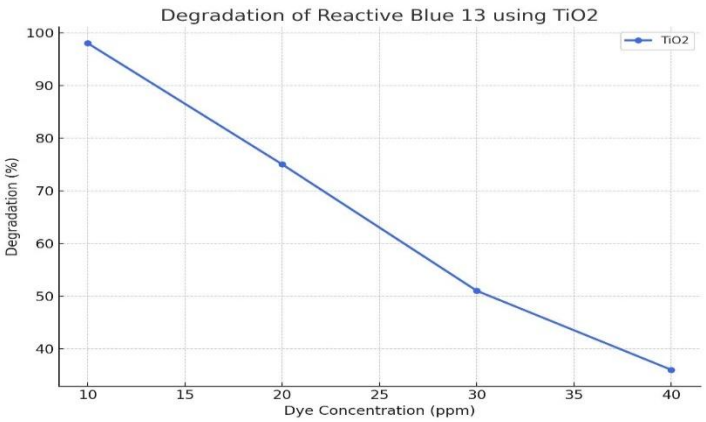



*Figure 2 Degradation of Reactive Blue 13 Using TiO2*

## DISCUSSION

The current study systematically evaluated the photocatalytic degradation potential of titanium dioxide ($TiO_2$, anatase) and magnesium oxide (MgO) nanoparticles for the treatment of Reactive Blue 13 dye, a widely used azo dye in textile industries. The findings highlighted the comparative efficiency of both catalysts under varying physicochemical conditions, such as pH, catalyst concentration, and dye loading. The degradation process, driven by the generation of reactive oxygen species (ROS), was optimized to assess each catalyst's performance under UV light exposure. $TiO_2$ demonstrated superior degradation activity in alkaline conditions, with pH 10 yielding the highest degradation efficiency. This was consistent with previous literature reporting enhanced ROS formation and charge separation in alkaline media that promote photocatalytic activity of $TiO_2$. However, the efficiency decreased marginally at pH 11 and was notably less in acidic environments, indicating a narrow pH-operational range (20,21). Although $TiO_2$ is a well-established photocatalyst with strong oxidative capabilities, its performance was sensitive to environmental factors, which may complicate large-scale industrial application unless precise pH control is maintained. Furthermore, increasing $TiO_2$ concentration initially enhanced degradation efficiency, likely due to the greater number of active sites available for dye adsorption and ROS interaction. Yet, at concentrations beyond 0.1 g, the efficiency plateaued, possibly due to catalyst agglomeration and light scattering, which reduced UV penetration and hindered photocatalytic efficiency. These observations echoed established findings that overly dense suspensions can limit active surface area and light absorption (22,23).

MgO nanoparticles, in contrast, exhibited efficient dye degradation across both acidic and alkaline pH ranges, highlighting their broader pH tolerance. Maximum degradation occurred at pH 11, although substantial decolorization was also observed at pH 3 and 4. This flexibility suggests that MgO may be more suitable for treating wastewater with fluctuating or unregulated pH, a common scenario in industrial effluents. The catalyst dosage of MgO also influenced dye degradation significantly, with the optimal performance noted at 0.05 g. Similar to $TiO_2$, an excess of MgO beyond this threshold did not proportionally enhance degradation due to possible particle aggregation and opacity of the medium, which interfered with photon penetration and reactive species generation (24,25). The study also confirmed that MgO nanoparticles could sustain their photocatalytic activity even at higher dye concentrations, although with slightly diminished efficiency due to UV shielding effects and competitive adsorption by dye molecules. Comparative analysis revealed that although both catalysts effectively facilitated the degradation of Reactive Blue 13, MgO demonstrated more stable performance over a wider range of pH conditions and dye concentrations. This greater operational flexibility is crucial for real-world wastewater treatment settings where environmental variables are less controllable. Furthermore, MgO appeared to be less prone to performance inhibition by dye saturation or particle overloading, making it a cost-effective and environmentally resilient option (26,27). Notably, the ability of MgO to generate hydroxyl and superoxide radicals efficiently was a key contributor to its superior performance, as supported by observed degradation rates and corroborative spectral analyses.

One of the strengths of this study lies in its systematic parameter optimization and direct comparative design, which allowed for a nuanced understanding of photocatalyst behavior under realistic conditions. The use of UV-Vis spectrophotometry enabled precise quantification of dye degradation and provided insight into reaction kinetics and catalytic efficiency. Additionally, the controlled use of nanoparticle doses and environmental conditions strengthened the reproducibility and reliability of the findings. Nevertheless, certain limitations must be acknowledged. The study was conducted under laboratory-scale conditions with constant UV irradiation and temperature, which may not fully replicate the complexities of industrial wastewater treatment environments. Furthermore, only one type of dye was used, limiting the generalizability of the findings across different dye structures and pollutant classes. The long-term stability, recyclability, and potential leaching behavior of the nanoparticles were not assessed, which are essential considerations for environmental safety and economic feasibility in real-world applications. Future research should focus on pilot-scale studies incorporating varying dye classes, continuous flow reactors, and natural light sources to validate the photocatalytic potential of these nanomaterials under practical settings (28). Additionally, exploring synergistic effects of $TiO_2$ and MgO composites or doping these catalysts with transition metals could enhance their optical absorption and catalytic properties. Assessing nanoparticle recovery and reusability, as well as their potential ecotoxicological impacts, will also be critical for their integration into sustainable wastewater management strategies. In conclusion, this study provided valuable comparative insights into the photocatalytic capabilities of $TiO_2$ and MgO nanocatalysts. While $TiO_2$ proved effective under optimal alkaline conditions, MgO emerged as a more versatile and environmentally adaptive alternative, capable of maintaining high degradation efficiency across a broader pH spectrum. These findings hold promise for the advancement of photocatalytic dye removal technologies and contribute to the growing body of evidence supporting nanomaterial-based solutions for industrial wastewater remediation.

## CONCLUSION

This study concluded that both titanium dioxide ($TiO_2$) and magnesium oxide (MgO) nanoparticles effectively facilitated the photocatalytic degradation of Reactive Blue 13 dye under UV irradiation, with performance influenced by catalyst concentration, pH, and dye loading. The research highlighted the importance of optimizing these parameters to achieve maximum efficiency, noting that while increasing catalyst concentration initially enhanced degradation, excessive amounts led to reduced performance due to saturation effects. MgO demonstrated greater adaptability across varied pH levels, reinforcing its potential as a versatile and cost-effective catalyst for real-world wastewater treatment. By identifying the interplay between catalyst type, dosage, and environmental conditions, the study provided a valuable framework for designing sustainable dye removal strategies. These findings contribute significantly to advancing eco-friendly wastewater management practices and underscore the importance of continued exploration into scalable and economically viable photocatalytic solutions for industrial pollution control.

### AUTHOR CONTRIBUTION

| Author | Contribution |
|---|---|
| Shaher Bano* | Substantial Contribution to study design, analysis, acquisition of Data<br>Manuscript Writing<br>Has given Final Approval of the version to be published |
| Ali Raza | Substantial Contribution to study design, acquisition and interpretation of Data<br>Critical Review and Manuscript Writing<br>Has given Final Approval of the version to be published |
| Ayesha Safdar | Substantial Contribution to acquisition and interpretation of Data<br>Has given Final Approval of the version to be published |
| Mahnoor Tariq | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Muhammad Ajmal | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Muniba Riaz | Substantial Contribution to study design and Data Analysis<br>Has given Final Approval of the version to be published |
| Azka Masood | Contributed to study concept and Data collection<br>Has given Final Approval of the version to be published |
| Dawood Ali | Writing - Review & Editing, Assistance with Data Curation |

## REFERENCES

1. Abinaya, S., Kavitha, H. P., Prakash, M., & Muthukrishnaraj, A. (2021). Green synthesis of magnesium oxide nanoparticles and its applications.Sustainable Chemistry and Pharmacy, 19, 100-368.
2. Akbari, S., Moussavi, G., & Giannakis, S. (2021). Efficient photocatalytic degradation of ciprofloxacin under UVA-LED, using S, N-doped MgO nanoparticles: Synthesis, parametrization and mechanistic interpretation. Journal of Molecular Liquids, 324, 114-831.
3. Alaizeri, Z. M., Alhadlaq, H. A., Aldawood, S., Akhtar, M. J., Amer, M. S., & Ahamed, M. (2021). Facile synthesis, characterization, photocatalytic activity, and cytotoxicity of ag-doped mgo nanoparticles. Nanomaterials, 11(11), 29-15.
4. Ardila-Leal, L. D., Poutou-Piñales, R. A., Pedroza-Rodríguez, A. M., & Quevedo-Hidalgo,
B. E. (2021). A brief history of colour, the environmental impact of synthetic dyes and removal by using laccases. Molecules, 26(13), 31-83.
5. Balakrishnan, G., Velavan, R., Batoo, K. M., & Raslan, E. H. (2020). Microstructure, optical and photocatalytic properties of MgO nanoparticles. Results in Physics, 16, 103-313.
6. Benisha, R., Amalanathan, M., Aravind, M., Mary, M. S. M., Ahmad, A., Tabassum, S., Ahmad, I. (2022). Catharanthus roseus leaf extract mediated Ag-MgO nanocatalyst for photocatalytic degradation of Congo red dye and their antibacterial activity. Journal of Molecular Structure, 1262, 133-235.

7. Cabezuelo, O., Diego-Lopez, A., Atienzar, P., Marin, M. L., & Bosca, F. (2023). Optimizing the use of light in supported TiO2 photocatalysts: Relevance of the shell thickness. Journal of Photochemistry and Photobiology Chemistry, 444, 114-917.
8. David, E., & Niculescu, V.-C. (2021). Volatile organic compounds (VOCs) as environmental pollutants: Occurrence and mitigation using nanomaterials. International Journal of Environmental Research and Public Health, 18(24), 13-47.
9. El-Khawaga, A. M., Ayman, M., Hafez, O., & Shalaby, R. E. (2024). Photocatalytic, antimicrobial and antibiofilm activities of MgFe2O4 magnetic nanoparticles. Scientific Reports, 14(1), 12877.
10. Ikram, M., Inayat, T., Haider, A., Ul-Hamid, A., Haider, J., Nabgan, W., .Ul-Ain, K. (2021). Graphene oxide-doped MgO nanostructures for highly efficient dye degradation and bactericidal action. Nanoscale research letters, 16, 1-11.
11. Karaca, H., Kısaoğlan, B., Koparal, A. T., & Kıvanç, M. (2022). Decolorization of reactive blue 13 by Sporotrichum sp. and cytotoxicity of biotreated dye solution. Water Environment Research, 94(2), 16-86.
12. Karuppusamy, I., Samuel, M. S., Selvarajan, E., Shanmugam, S., Kumar, P. S. M., Brindhadevi, K., Science, I. (2021). Ultrasound-assisted synthesis of mixed calcium magnesium oxide (CaMgO2) nanoflakes for photocatalytic degradation of methylene blue. Environment Research, 584, 770-778.
13. Khalid, H., Haq, A. u., Fawad Zahoor, A., Irfan, A., & Zaki, M. E. (2024). An investigation of Ca-doped MgO nanoparticles for the improved catalytic degradation of thiamethoxam pesticide subjected to visible light irradiation. Scientific Reports, 14(1), 1-126.
14. Khan, S., Naushad, M., Iqbal, J., Bathula, C., & Ala'a, H. (2022). Challenges and perspectives on innovative technologies for biofuel production and sustainable environmental management. Fuel, 325, 124845.
15. Kiran, S., Albargi, H. B., Afzal, G., Aimun, U., Anjum, M. N., Qadir, M. B., Abdullah, M. (2023). A zadirachta indica-assisted green synthesis of magnesium oxide nanoparticles for degradation of Reactive Red 195 dye: a sustainable environmental remedial approach. Applied Water Science, 13(10), 193.
16. Koyuncu, I. (2002). Reactive dye removal in dye/salt mixtures by nanofiltration membranes containing vinylsulphone dyes: effects of feed concentration and cross flow velocity. Desalination, 143(3), 243-253.
17. Kumar, S. A., Jarvin, M., Sharma, S., Umar, A., Inbanathan, S., & Lalla, N. (2021). Facile and green synthesis of MgO nanoparticles for the degradation of victoria blue dye under UV irradiation and their antibacterial activity. Food & Agroforestry, 5, 14-19.
18. Kumar, S. G., & Devi, L. G. (2011). Review on modified TiO2 photocatalysis under UV/visible light: selected results and related mechanisms on interfacial charge carrier transfer dynamics. The Journal of physical chemistry, 115(46), 13211-13241.
19. Kurade, M. B., Waghmode, T. R., Kagalkar, A. N., & Govindwar, S. P. (2012). Decolorization of textile industry effluent containing disperse dye Scarlet RR by a newly developed bacterial-yeast consortium BL-GG. Chemical Engineering Journal, 184, 33-41.
20. Lanjwani, M. F., Tuzen, M., Khuhawar, M. Y., & Saleh, T. A. (2024). Trends in photocatalytic degradation of organic dye pollutants using nanoparticles: a review. Inorganic Chemistry Communications, 159, 111-613.
21. Lin, S.-H., & Juang, R.-S. (2002). Heavy metal removal from water by sorption using surfactant-modified montmorillonite. Journal of hazardous materials, 92(3), 315-326.
22. Liu, L., Chen, Z., Zhang, J., Shan, D., Wu, Y., Bai, L., & Wang, B. (2021). Treatment of industrial dye wastewater and pharmaceutical residue wastewater by advanced
23. oxidation processes and its combination with nanocatalysts: A review. Journal of Water Process Engineering, 42, 102-122.
24. Liu, W.-J., Jiang, H., & Yu, H.-Q. (2015). Development of biochar-based functional materials: toward a sustainable platform carbon material. Chemical reviews, 115(22), 12251-12285.
25. Mantilaka, M. P. G., De Silva, R. T., Ratnayake, S. P., Amaratunga, G., & De Silva, K. N. (2018). Photocatalytic activity of electrospun MgO nanofibres: Synthesis, characterization and applications. Materials Research Bulletin, 99, 204-210.
26. Matyjas, E., & Rybicki, E. (2003). Novel reactive red dyes. Environment Research Journal, 3(2), 90-95.
27. Mbarek, W. B., Escoda, L., Saurina, J., Pineda, E., Alminderej, F. M., Khitouni, M., & Suñol, J.-J. (2022). Nanomaterials as a sustainable choice for treating wastewater: a review. Environment Research Materials, 15(23), 8576.
28. Moazzam, A., Jamil, N., Nadeem, F., Qadir, A., Ahsan, N., & Zameer, M. (2017). Reactive Dye Removal by a Novel Biochar/MgO Nanocomposite. Journal of the Chemical Society of Pakistan, 39(1), 120-136.