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Carbon Nitride Nanosheet-based Titanium Dioxide Hybrid Photocatalyst for Organic Effluent Degradation

Ayesha Ashfaq,[1] Muhammad Tallal,[1] Amna Liaqat,[1, a)] Nadia Khan,[1] Nouman Waheed,[1] and Muhammad Amin[1]

Department of Chemistry, The University of Lahore, Sargodha Campus, Sargodha, Pakistan

ABSTRACT: This research has synthesized and characterized a hybrid nanocomposite of carbon nitride ($g-C_3\ N_4$) nanosheets and titanium dioxide (TiO_2) for photocatalytic wastewater purification. The nanocomposite, designed with hydrothermal synthesis, was evaluated using UV-Vis spectroscopy, SEM, XRD, and FT-IR to identify its structural and optical properties. Photocatalytic activity was assessed using Congo red dye degradation, with efficiency tailored by altering temperature, time frame, and catalyst concentration. The results indicated successful hybridization, consistent shape, and improved degrading capability, indicating that the nanocomposite has the potential to treat wastewater sustainably.

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I. INTRODUCTION

The intense urbanization and industrialization of the past few decades contributed significantly to the dumping of organic pollutants into water bodies, creating serious environmental and health risks. Dyes, medicines, and other organic effluents tend to be nonbiodegradable, rendering traditional wastewater treatment treatments ineffective. In this context, sophisticated oxidation technologies, particularly photocatalysis, have developed as effective ways to convert such contaminants into more benign substance[1]. Titanium dioxide (TiO_2) is a popular photocatalytic material due to its great stability, non-toxicity, and strong oxidative properties under UV radiation. TiO_2's wide bandgap and quick recombination of photo-generated electron-hole pairs limit its practical utilization and lower photocatalytic performance. To address these constraints, hybridization with other materials has been investigated[2]. Carbon nitride ($g-C_3\ N_4$), a twodimensional polymeric semiconductor with a low bandgap, shows high potential as a cocatalyst for TiO_2. Its strong visible-light absorption, chemical stability, and capacity to improve charge separation make it a good choice for hybrid photocatalyst development[3].

This investigation concentrates on synthesizing and characterizing a g-C3 N_4 nanosheet-based TiO_2 hybrid photocatalyst for the degradation of organic effluents in wastewater. By integrating the properties of $g-C_3\ N_4$ and TiO_2, the strive is to attain a synergistic effect that boosts photocatalytic efficiency. The hybrid nanocomposite is assessed for its structural, optical, and photocatalytic properties employing modern characterization techniques, with Congo red dye used as a model pollutant. The ability it has to absorb more light, effectively separation charges carriers, and generates reactive oxygen species that decompose pollutants which give $g-C_3\ N_4/TiO_2$ it enhanced photocatalytic activity. This work aims to contribute to the development of efficient, sustainable, and scalable solutions for wastewater treatment by means of photocatalysis[4]. hydrothermal method because its allows for homogeneous, well-structured material with an establish connection between titanium oxide and carbon nitride nanosheets.by using this method pressure and temperature can be easily controlled[5] By mixing titanium oxide and carbon nitride nanosheets, this study aims to create a novel hybrid photocatalyst that may enhance the degradation of organic pollutants in waste water. To be able to evaluate the hybrid material's structural, optical and photocatalytic qualities the study focuses mainly on its manufacturing characterization[6]. The aim of the present research to discover a novel and more efficient material that breaks down hazardous pollutants in waste water

[a)]Electronic mail: amna.liaqat@chem.uol.edu.pk

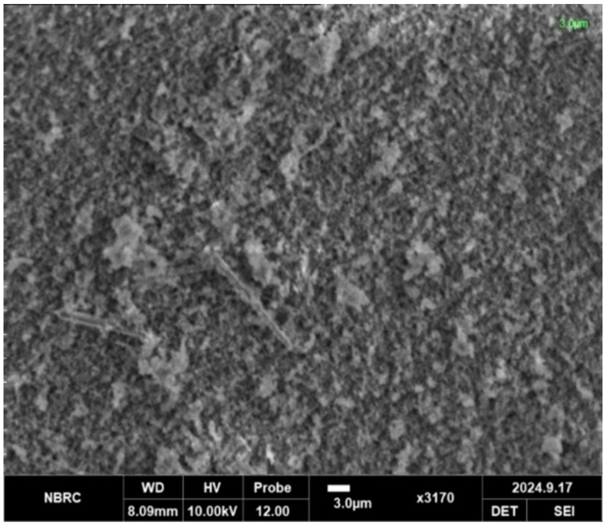

FIG. 1: Scanning electron micrograph of g-C3N4 nanosheet-based TiO2 hybrid photocatalyst at 3.0 micrometer.

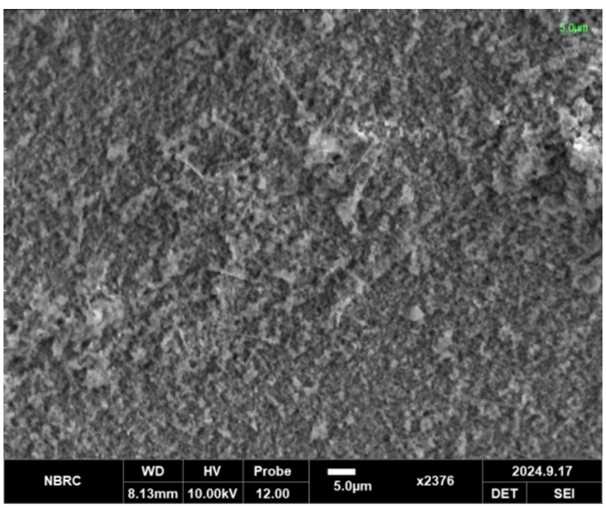

FIG. 2: Scanning electron micrograph of g-C3N4 nanosheet-based TiO2 hybrid photocatalyst at 5.0 micrometer..

through the use of light. Through the utilization of titanium oxide and carbon nitride nanosheets, the research seeks to increase the utility, speed and environmental friendliness of industrial waste.

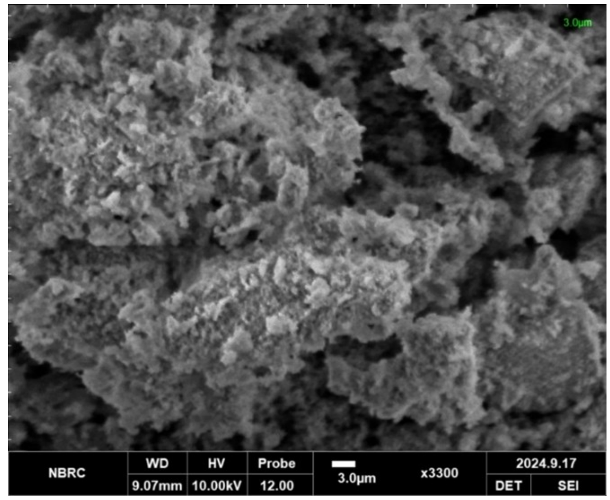

FIG. 3: Scanning electron micrograph of TiO2 and ZnO nanocomposite in the absence of g-C3N4 at 3.0 micrometer.

II. METHODOLOGY

A. Synthesis of Hybrid Photocatalyst

TiO_2/ZnO hybrid photocatalyst were synthesized via a hydrothermal method because its allows for homogeneous, well structured material with an establish connection between titanium oxide and carbon nitride nanosheets.by using this method pressure and temperature can be easily controlled. while C_3 N_4 nanosheets were prepared by thermal polymerization of melamine. After being dissolved in 50 milliliters of distilled water, 1.5 grams of zinc oxide (ZnO) and titanium dioxide (TiO_2) were subjected to a 45 -minute ultrasonic cleaning treatment[7]. The ZnO solution was made acidic (pH 4) with HCl, while the pH of the TiO_2 solution was brought to 10 with NaOH. On a heated plate set at 40°C, the solutions were swirled for 60 minutes. After that, the ZnO solution was progressively added to the TiO_2 solution, and stirring continued for another half hour. Using UV-Vis spectroscopy to investigate the degradation of Congo Red and Methyl Orange dyes, the photocatalytic activity of the resultant TiO 2 - ZnO nanocomposite was assessed[8].

III. RESULT AND DISCUSSION

A. Scanning Electron Microscopy (SEM) Analysis

The rough, uneven surface of graphitic carbon nitride nanosheet-based TiO_2 composites, as seen in electron micrographs Figs. 1-4, is perfect for photocatalytic

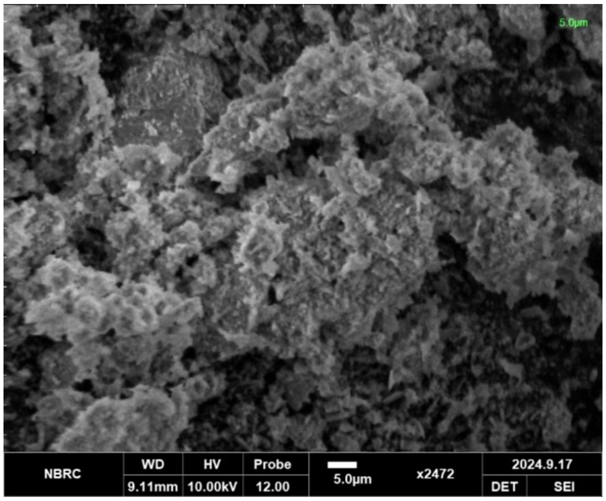

FIG. 4: Scanning electron micrograph of TiO2 and ZnO nanocomposite in the absence of g-C3N4 at 5.0 micrometer.

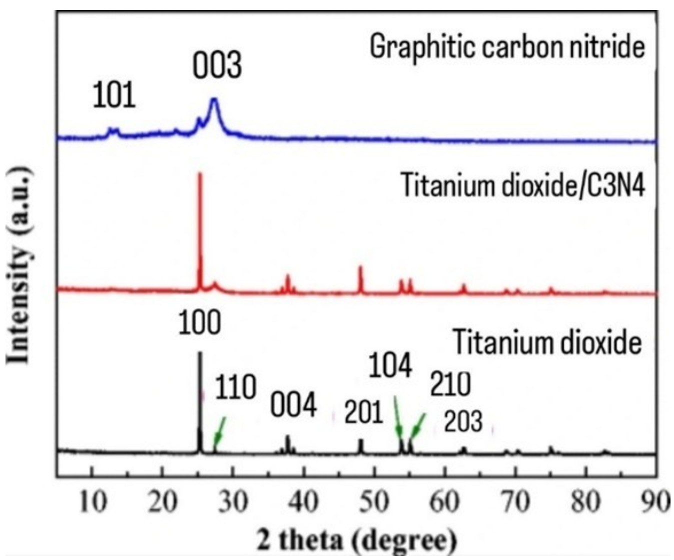

FIG. 5: PXRD spectrum of g-C3N4 nanosheet-based TiO2 nanocomposite.

activities because of its large surface area. Additionally, these images imply that ZnO and TiO_2 nanoparticles are uniformly dispersed throughout the surface, which improves their performance[9]. The structure of the ZnO and TiO_2 nanoparticles is small and granular, with infrequent clumping or aggregates in particular areas. The image's perforated areas imply active locations that are necessary for organic dye degradation[10].

Without a carbon nitride nanosheet, the TiO_2 and ZnO nanocomposite's surface appeared more granular, with bigger clusters and reduced porosity, according to scanning electron micrographs. In comparison to the composite with the nanosheet, the nanoparticles had a smaller surface area and were less uniformly dispersed. The efficiency of this structure in photocatalytic applications is lower[11].

TABLE I: PXRD crystal plane values for g-C3N4 based TiO2 hybrid photocatalyst7.

Sr. No	2θ value	Crystalline phase
1.	25.3°	101
2.	27.4°	003
3.	37.8°	004
4.	55.0°	211

TABLE II: Functional group values of g-C3N4 based TiO2 hybrid photocatalyst.

Sr. No.	Functional group assigned	FT-IR peaks (cm^{-1})
1.	N-H	3440 cm^{-1}
2.	$C=O$	1736 cm^{-1}
3.	$C-N$	1125 cm^{-1}
4.	Ti-O	693 cm^{-1}

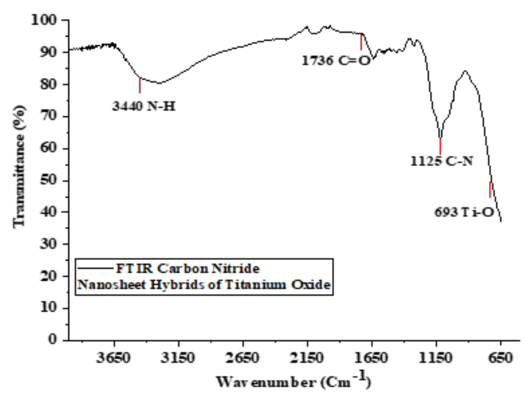

FIG. 6: FTIR spectrum of g-C3N4 nanosheet-based TiO2 nanocomposite.

B. POWDER X-RAY DIFFRACTION ANALYSIS

Diffraction patterns for graphitic carbon nitride (C_3 N_4) and TiO_2 are shown in Fig. 5. With characteristics at planes 101 and 003 , the blue line verifies the existence of

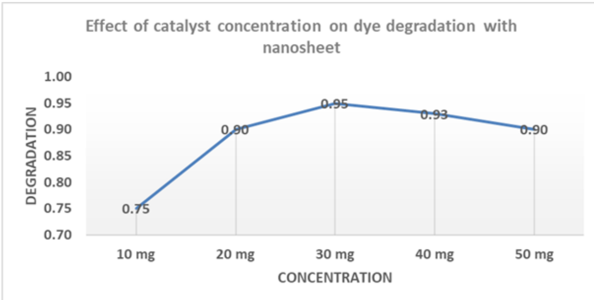

FIG. 7: Effect of catalyst concentration on dye degradation with C3N4 nanosheet.

C_3 N_4. The black lines at 004,200 , and 210 on the red figure represent changes in diffraction intensity relative to pure TiO_2, highlighting the TiO_2-C_3 N_4 composite. These variations in intensity point to a robust interaction between TiO_2 and C_3 N_4. The composite's photocatalytic qualities are improved by this interaction, increasing its applicability[12].

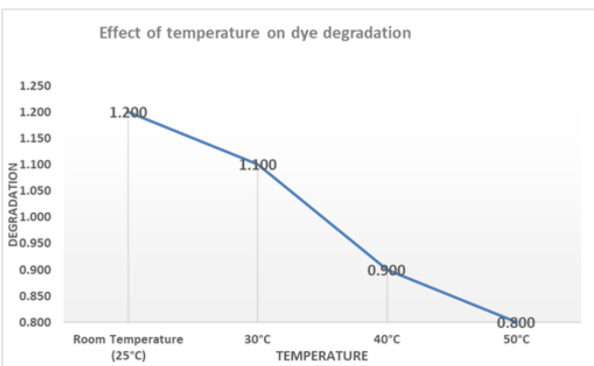

FIG. 8: Effect of temperature on dye degradation.

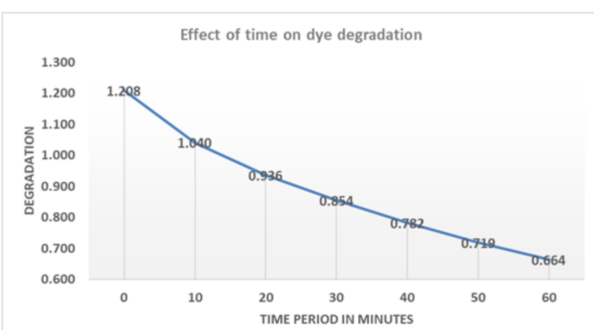

FIG. 9: Effect of Time on Dye Degradation.

C. FT-IR SPECTROSCOPY ANALYSIS

The hydrophilic aspect of the material is highlighted by a peak at 1736 cm^{-1} that suggests carbonyl groups, whereas $N-H$ vibrations at 3440 cm^{-1} in Fig. 6 indicate amine groups from carbon nitride. Photocatalytic efficacy is increased when amine, imine, carbonyl, and Si-O groups are present. When compared to materials lacking carbon nitride nanosheets, the addition enhances functional group variety, charge separation, and degrading efficiency. Additionally, this lowers the TiO_2 photocatalyst's band gap[13].

D. UV-VISIBLE SPECTROSCOPY ANALYSIS

EFFECT OF G-C3N4 NANOSHEET BASED TIO2 PHOTOCATALYST CONCENTRATION ON ABSORBANCE photocatalytic activity of carbon nitride nanosheet, the hybrid composite was investigated. Degradation increases marginally with catalyst concentration, peaking at 0.95 at 30 mg , as Fig. 7 illustrates. But after this, the rate of deterioration slows down as the concentration rises higher. This implies that the best performance may be achieved at a specific catalyst concentration and after that the further increase in concentration decrease the rate of degradation[14].

E. Effect of Temperature on Dye Degradation

The degradation values peak at 1.200 at ambient temperature and 1.100 at 30°C, as seen in Fig.8. The degradation values start to decrease as the temperature rises. Given that higher temperatures cause catalyst deactivation, this pattern implies that lower temperatures offer more effective deterioration. Furthermore, higher temperatures encourage electron-hole pair recombination, which lowers degradation efficiency even more. As a result, the catalyst's photocatalytic activity is limited at higher temperatures[15].

F. EFFECT OF TIME ON DYE DEGRADATION

Because there are active sites on the catalyst surface, the dye degrades quickly at first. The dye molecules rapidly break down when they come into contact with the photocatalyst. But as the response goes on, the rate of degradation slows down and eventually levels out. The reason for this decrease is that the majority of dye molecules undergo early degradation, leaving behind molecules that either occupy the active sites or become resistant to photocatalytic degradation. This tendency is depicted in Fig. 9 which shows a slow decline after the initial maximum degradation. After 60 minutes, the response finally stabilizes[16]. The hydrothermal technique usually provides material with better crystalline structure and less imperfections than the solgel method. Although very popular and basic solgel technique frequently yield less crystallinity and may necessitates additional heat treatment to enhance the materials quality[17].

IV. CONCLUSION

The study emphasizes how crucial it is to adjust a number of variables in order to maximize dye degradation while employing titanium dioxide (TiO_2) as a photocatalyst. The inclusion of carbon nitride nanosheets greatly enhances catalytic performance, with maximal degradation seen at 30 mg of catalyst concentration, whereas TiO_2 speeds up the rate of deterioration. Particle aggregation brought on by higher concentrations lowers the effectiveness of breakdown. Since higher temperatures cause catalyst deactivation, lower temperatures are proven to be more effective. The photocatalytic reaction proceeds quickly in the first phase and exhibits first-order kinetics. All things considered, the results provide insightful information for enhancing photocatalytic processes in environmental applications.

DECLARATION OF COMPETING INTEREST

The authors have no conflicts to disclose.

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