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BIOMASS-DERIVED REDUCED GRAPHENE OXIDE FOR EFFICIENT PHOTOCATALYTIC DEGRADATION OF THIAZOLE YELLOW G DYE

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Abstract

This study presents a sustainable approach for the removal of azo dye pollutants, specifically Thiazole Yellow G dye, using biomass-derived reduced graphene oxide (rGO). The rGO is synthesized via a green reduction method employing plant or agricultural waste extracts as eco-friendly reducing agents. Characterization using XRD and Raman spectroscopy confirms its structural properties. The photocatalytic activity of rGO is evaluated through the degradation of Thiazole Yellow G dye under light irradiation, with key parameters such as catalyst dosage, dye concentration, pH, and irradiation time optimized. Enhanced performance is attributed to high surface area and reduced electron–hole recombination. The study demonstrates that biomass-derived rGO is an efficient, low-cost, and environmentally friendly photocatalyst capable of converting dye pollutants into harmless products like CO_2 and H_2O.

Keywords: Biomass-derived, Reduced Graphene Oxide (rGO), Photocatalytic Degradation, Thiazole Yellow G Dye

1. Introduction

Rapid industrialization and urbanization have significantly increased the discharge of synthetic dyes into water bodies, leading to serious environmental and health concerns. Thiazole Yellow G (TYG), a commonly used dye in textile and paper industries, is highly stable and resistant to degradation due to its complex aromatic structure [1-2]. This persistence results in long-term contamination of aquatic ecosystems. Conventional treatment methods like adsorption, coagulation, and membrane filtration are often inefficient, costly, and generate secondary waste such as sludge [3-5]. Therefore, there is a growing need for sustainable and effective technologies for dye removal.

Photocatalysis has emerged as a promising advanced oxidation process capable of degrading organic pollutants into harmless substances like carbon dioxide and water under light irradiation. Semiconductor materials such as TiO_2 and ZnO have been widely studied due to their stability and strong oxidative properties [6-8]. However, their performance is limited by rapid electron–hole recombination and poor visible light absorption. To address these issues, carbon-based materials like graphene have gained attention for enhancing photocatalytic efficiency.

Reduced graphene oxide (rGO) offers high electrical conductivity, large surface area, and strong adsorption capacity, making it an excellent support material. It improves charge separation and extends light absorption into the visible region [9-11]. However, traditional synthesis methods for graphene involve expensive and hazardous chemicals. As a result, biomass-derived carbon materials have emerged as eco-friendly and cost-effective alternatives.

Agricultural waste and plant-based biomass can be converted into graphene-like materials through processes such as carbonization and reduction. This approach not only utilizes renewable resources but also supports green chemistry principles. Biomass-derived rGO enhances photocatalytic performance by promoting electron transfer and increasing active sites for dye degradation. [12-15]

Characterization techniques like XRD, Raman spectroscopy, are used to study the structural and optical properties of the synthesized materials. These analyses confirm successful synthesis and help

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optimize performance. Overall, biomass-derived rGO-based photocatalysts provide a sustainable, efficient, and environmentally friendly solution for the degradation of hazardous dyes like Thiazole Yellow G in wastewater treatment. [16-18]

1.1 Objectives of the Study

- To synthesize biomass-derived reduced graphene oxide (rGO) using an eco-friendly and cost-effective method from agricultural waste materials.
- To prepare rGO-based photocatalytic composites by integrating biomass-derived rGO with suitable semiconductor materials for enhanced photocatalytic performance.
- To characterize the synthesized materials using analytical techniques (such as XRD, Raman etc.) to evaluate structural, morphological, and optical properties.
- To evaluate the photocatalytic efficiency of the developed composite for the degradation of thiazole yellow G dye under light irradiation.
- To investigate degradation kinetics and mechanism, including the role of reactive oxygen species and charge transfer processes.
- To assess reusability and stability of the photocatalyst for potential practical application in wastewater treatment.

1.2 Methodology

The research methodology involves the synthesis, characterization, and photocatalytic evaluation of biomass-derived reduced graphene oxide (rGO) for degradation of thiazole yellow G dye. Suitable biomass such as rice husk, sugarcane bagasse, or coconut shell is collected, washed, dried, and powdered. [19-21] The biomass is carbonized at 400–600°C under limited oxygen to produce biochar. The biochar is then oxidized using a modified Hummers' method to obtain graphene oxide (GO)[22-25]. The synthesized materials are characterized using XRD, and Raman Spectroscopy techniques. Photocatalytic activity is tested by degrading thiazole yellow G dye under UV or visible light irradiation. Dye concentration changes are monitored using a UV–Vis spectrophotometer to calculate degradation efficiency and kinetics. Recyclability and stability studies are conducted to evaluate the practical applicability of the photocatalyst.

1.3 Photocatalytic activity test

The photocatalytic activity of biomass-derived rGO composites will be evaluated using thiazole yellow G dye degradation under controlled conditions. A stock dye solution will be prepared and diluted to a working concentration of 10–50 mg/L. A fixed amount of photocatalyst (0.5–1.0 g/L) will be added to the dye solution in a reactor. The suspension will be stirred in the dark for 30 minutes to achieve adsorption–desorption equilibrium. The reaction will then be exposed to UV or visible light under continuous stirring. At regular time intervals, samples will be collected and centrifuged to remove catalyst particles. The dye concentration will be analyzed using a UV–Visible spectrophotometer at its maximum absorption wavelength. Degradation efficiency and kinetics will be calculated using standard equations. Reactive oxygen species generated during the process will contribute to dye breakdown. Recyclability studies will be conducted to evaluate catalyst stability and reusability.

1.4 Expected Outcome

The study is expected to achieve successful synthesis of biomass-derived reduced graphene oxide (rGO) using an eco-friendly and cost-effective approach from agricultural waste. The synthesized rGO is anticipated to exhibit good structural integrity and enhanced electrical conductivity. The synthesized rGO is likely to show high photocatalytic degradation efficiency (around 85–95%) for thiazole yellow G dye. The degradation process is expected to follow pseudo-first-order kinetics with an improved rate constant. Enhanced charge separation due to rGO will reduce electron–hole recombination. Increased generation of reactive oxygen species such as hydroxyl and superoxide radicals will promote effective dye degradation. The photocatalyst is anticipated to demonstrate good stability during repeated use. Reusability over multiple cycles is expected without significant loss in efficiency. Overall, the study will contribute to sustainable, low-cost, and efficient wastewater treatment technology.

2. Materials and methods

2.1 Materials

A suitable biomass source Soyabean Husk was used as a natural reducing agent due to its rich phytochemical content (polyphenols, flavonoids, and sugars), enabling eco-friendly reduction of graphene oxide (GO) to reduced graphene oxide (rGO). Graphite powder served as the precursor for GO synthesis.

Analytical grade chemicals including sulfuric acid (H_2SO_4), potassium permanganate ($KMnO_4$), and hydrogen peroxide (H_2O_2) were used in the modified Hummers' method. Distilled/deionized water was used for all preparations and washing steps.

Thiazole Yellow G Dye was selected as a model pollutant for photocatalytic degradation studies. The synthesized biomass-derived rGO acted as the photocatalyst due to its high surface area, electrical conductivity, and adsorption capacity.

Ethanol/acetone was used for washing purposes. Standard laboratory glassware and filter paper were used for experimental procedures. A UV/visible light source was employed to initiate photocatalytic reactions.

2.2 Synthesis method and Characterization Techniques of Nanomaterials

2.2.1 Synthesis

As per the literature study chemical and physical methods have been used for the synthesis of nanoparticles (NPs). The Thermal decomposition method is used to synthesize rGO from Soyabean Husk.

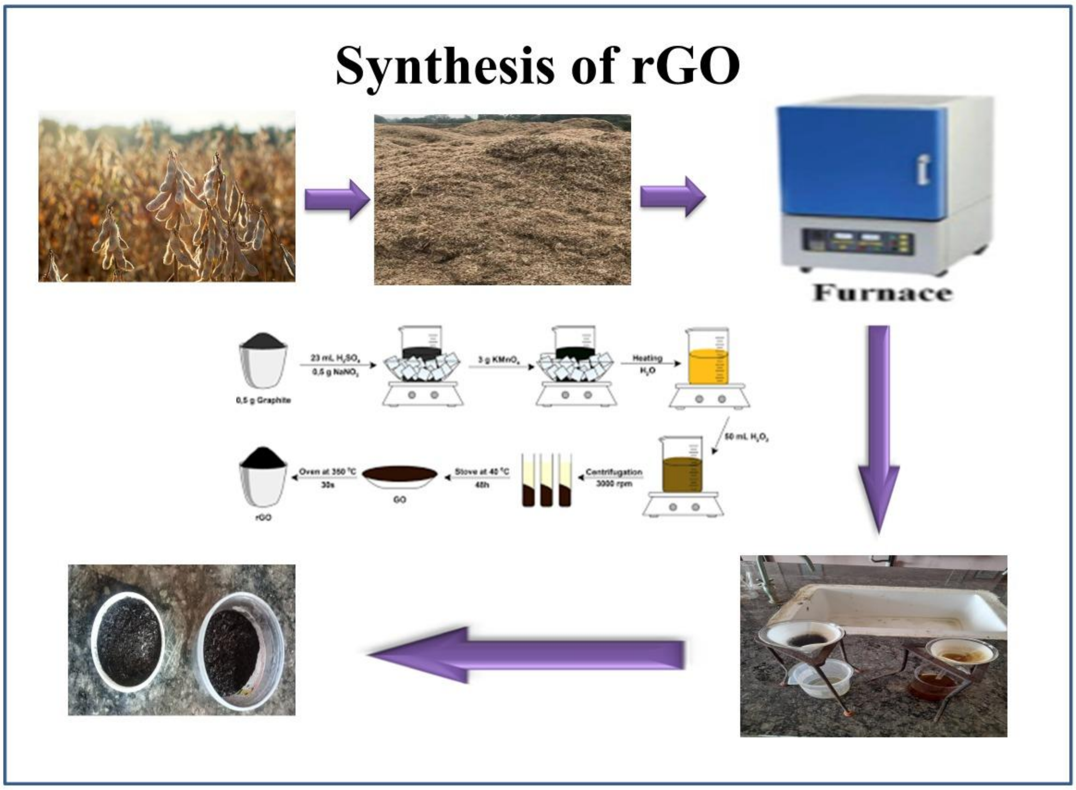


Figure 2.1 Schematicre presentation of synthesis of nanoparticles.

2.2.2Characterization Techniques

Characterization of nanomaterials is essential to understand their structural, morphological, and chemical properties. Various analytical tools are used to study these properties, which are important for determining their performance in applications such as photocatalysis.

X-ray Diffraction (XRD) Analysis

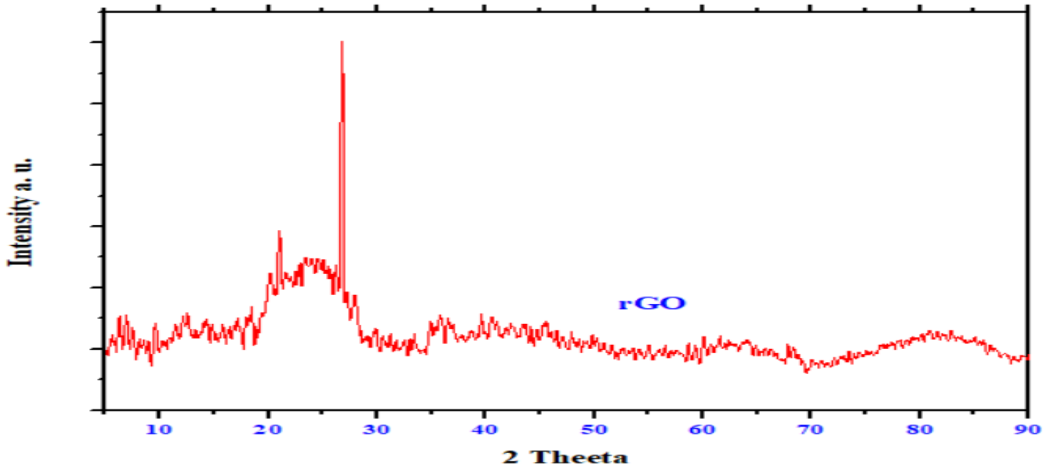
XRD is a powerful technique used to determine the crystal structure, phase composition, and interplanar spacing of materials. It works based on the diffraction of X-rays when they interact with atomic planes in a crystal. The diffraction pattern provides information about the crystallinity and structure of the material. The interplanar spacing is calculated using Bragg's law, which relates the wavelength of X-rays to the diffraction angle.

Raman Spectroscopy

Raman spectroscopy is used to study molecular vibrations and structural properties of materials. It is based on the Raman effect, where light scattering causes a shift in energy due to molecular interactions. This technique is especially useful for analyzing carbon-based materials such as graphene and reduced graphene oxide. It provides information about defects, disorder, and graphitic structure. Raman spectroscopy is a non-destructive method and requires minimal sample preparation.

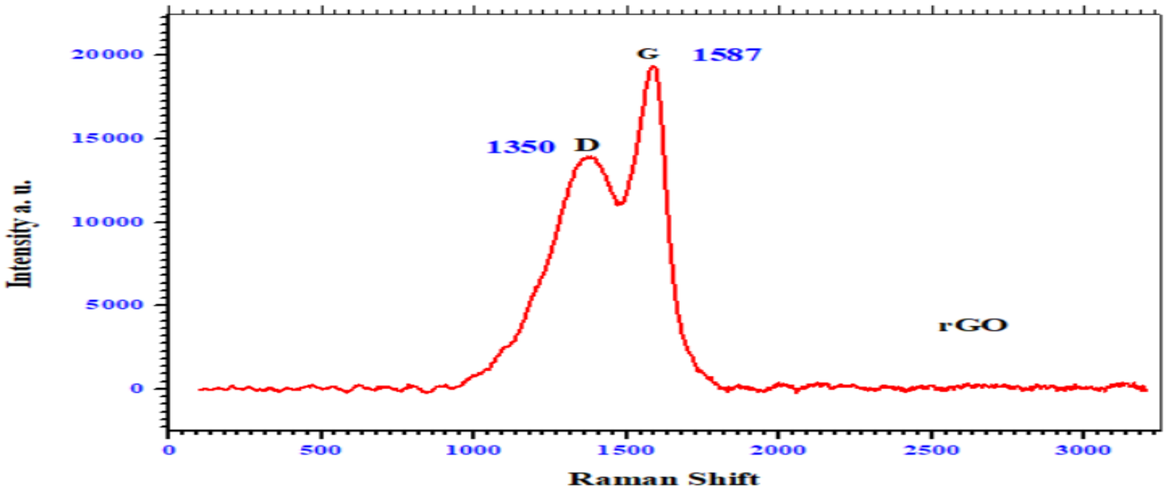
3. Result and Discussion

3.1 XRD Analysis of rGO



The XRD pattern of reduced graphene oxide (rGO) shows a broad peak at $2\theta \approx 24–26°$, indicating the restoration of graphitic structure after reduction. Compared to graphene oxide (GO), which shows a peak at 10–12°, the shift confirms the removal of oxygen-containing groups and reduced interlayer spacing. The broad and low-intensity peak suggests poor crystallinity and a disordered structure. Overall, the XRD results confirm the successful conversion of GO into rGO.

3.2 Raman Spectroscopy of rGO



The Raman spectrum of rGO shows two main peaks: the D band (~1350 cm^{-1}) and G band (~1587 cm^{-1}). The G band indicates graphitic structure, while the D band represents defects and disorder. A higher D/G intensity ratio suggests more structural defects. The presence of both bands confirms the successful reduction of GO to rGO with a partially restored structure. This defective but conductive structure makes rGO suitable for photocatalytic applications

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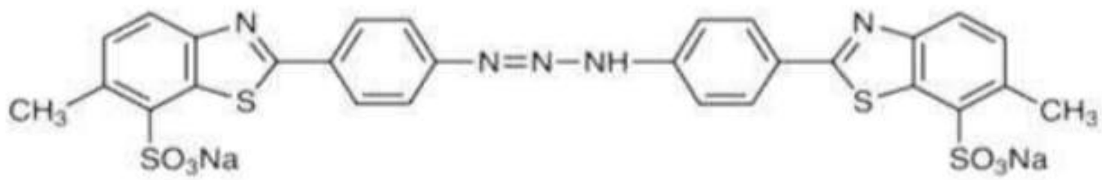
3.3 Application for the decomposition of toxic Thiazole Yellow G dye

The leather and textile industries widely use synthetic dyes to meet the growing demand for coloured products. These dyes are mainly produced from chemicals such as aromatic hydrocarbons like benzene, toluene, and naphthalene, along with heterocyclic compounds [26-28]. Many of these substances are volatile and highly harmful to the environment. When released into water, soil, or air, they cause serious pollution and pose risks to all forms of life. The dyeing process in industries is water-intensive and not completely efficient. Around 5–10% of dyes are lost in wastewater during processing [29-31]. This contaminated wastewater is often discharged into rivers, lakes, and seas, affecting aquatic ecosystems.

A large proportion of dyes used are azo dyes, which can release toxic aromatic amines upon decomposition. These compounds are carcinogenic and can accumulate in organs like the liver, kidney, and bladder, leading to severe health issues [32-33]. Wastewater from industries such as textile, leather, paper, and printing contributes significantly to environmental pollution. Various treatment methods like sedimentation, filtration, coagulation, and oxidation have been applied to remove dyes. However, these methods often convert pollutants into other forms, leading to secondary pollution. Some chemical treatments may remove colour but fail to completely break down harmful compounds.

Dyes can be classified based on their source, structure, and application, including basic, acidic, and azo dyes. Their release into the environment leads to toxicity, mutagenicity, and water contamination. Therefore, proper treatment of dye-containing wastewater is essential before disposal. Advanced materials such as metal oxide nanoparticles are also used for improved photocatalysis. Thiazole Yellow G is an important synthetic dye used in textiles and laboratory applications. Overall, effective degradation methods are necessary to reduce environmental and health hazards caused by dye pollutants.



Structure of Thiazole Yellow G

Reduced Graphene oxide nanoparticles

The effects of time, catalyst quantity, percentage degradation, and catalyst reusability for methyl orange dye were investigated

3.3.1 Effect of Time

An aqueous solution of Thiazole Yellow G (1×10^{-3} M) was used for the experiment. Before light irradiation, the solution was magnetically stirred in the dark for 30 minutes to achieve adsorption–desorption equilibrium between the dye and catalyst. Different beakers containing the dye solution were prepared for analysis. A fixed amount (0.050 g) of rGO was added as the photocatalyst. The degradation of the dye was studied over a time range from 0 to 285 minutes. It was observed that maximum degradation efficiency occurred between 210 and 255 minutes. The results were recorded in tables and represented graphically for better understanding.

Table 3.1 Effect of time on Thiazole Yellow G degradation with rG0

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Time (min)	Absorbance	%X	%D
0	0.782	100	0.00
15	0.782	100	0.00
30	0.782	100	0.00
45	0.782	100	0.00
60	0.682	87.21	12.78
75	0.663	84.78	15.21
90	0.598	76.47	23.52
105	0.542	69.30	30.69
120	0.488	62.40	37.59
135	0.382	48.84	51.15
150	0.336	42.96	57.03
165	0.248	31.71	68.28
180	0.188	24.04	75.95
195	0.126	16.11	83.88
210	0.099	12.65	87.34
225	0.050	6.39	93.60
240	0.050	6.39	93.60
255	0.050	6.39	93.60
270	0.050	6.39	93.60
285	0.050	6.39	93.60

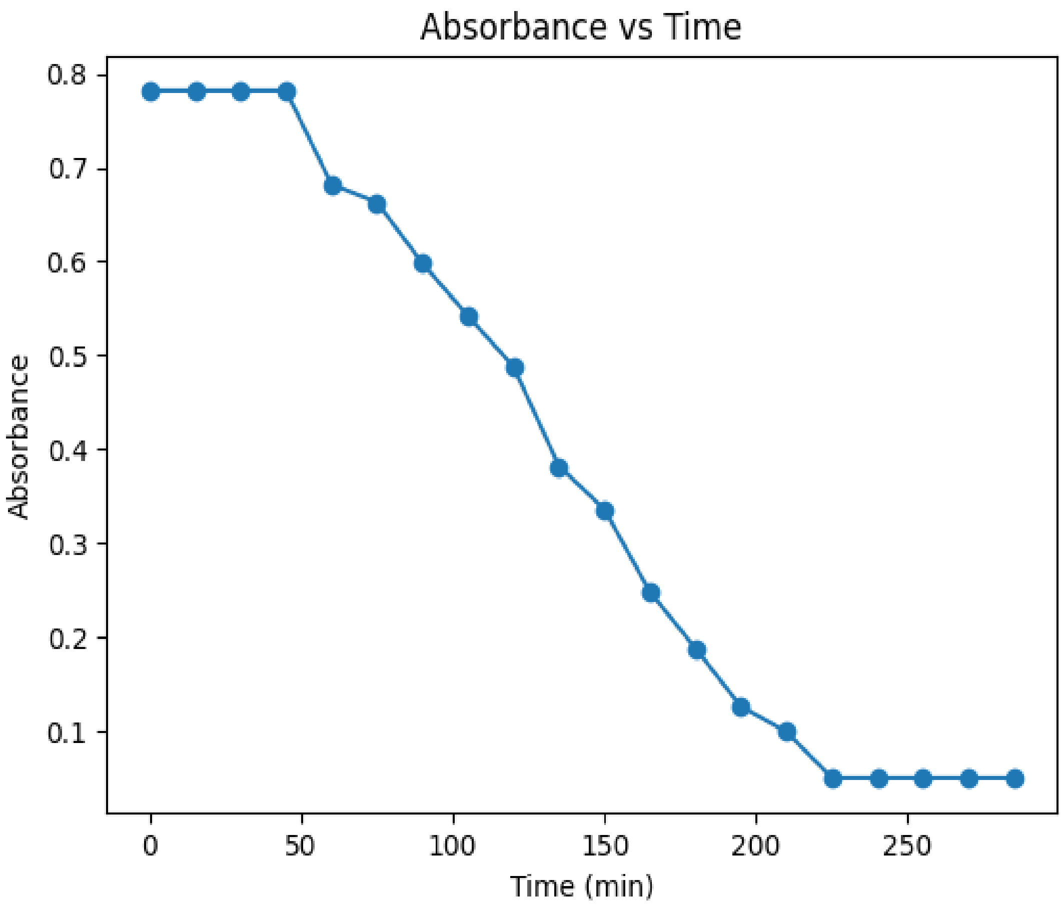

Figure -3.1 Effect of time on Thiazole Yellow G degradation with rG0

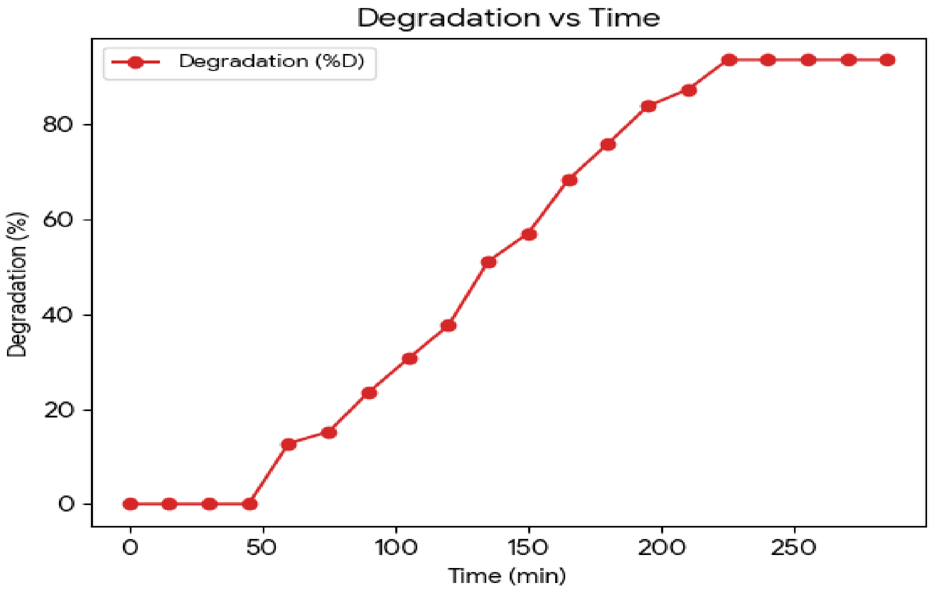

Fig 3.2 Effect of time on Thiazole Yellow G degradation with rGO

3.3.2 Effect of amount of catalyst

By doing the experiment with varying amounts of catalyst used in the process, the influence of catalyst amount was ascertained. By using different amounts of the catalyst and photodegrading the TYG dye for 180 minutes, the experiment's ideal amount of photocatalyst was found. The catalyst was utilized in amounts ranging from 0.025g to 0.150g, and the reactions were conducted. At a wavelength of 430 nm, the aliquots' absorbance was measured for equilibrium times ranging from 130 to 160 minutes. The results are displayed in graph figure 3.3 below and recorded in table

Table 3.2 Effect of amount of catalyst on Thiazole Yellow G dye degradation

Amount of catalyst (g.)	**Absorbance**	**% X**	**% D**
0.025	**0.155**	**18.20**	**81.80**
0.050	0.050	**6.39**	**93.61**
0.075	**0.050**	**6.39**	**93.61**
0.100	**0.050**	**6.39**	**93.61**
0.125	**0.050**	**6.39**	**93.61**
0.150	**0.050**	**6.39**	**93.61**

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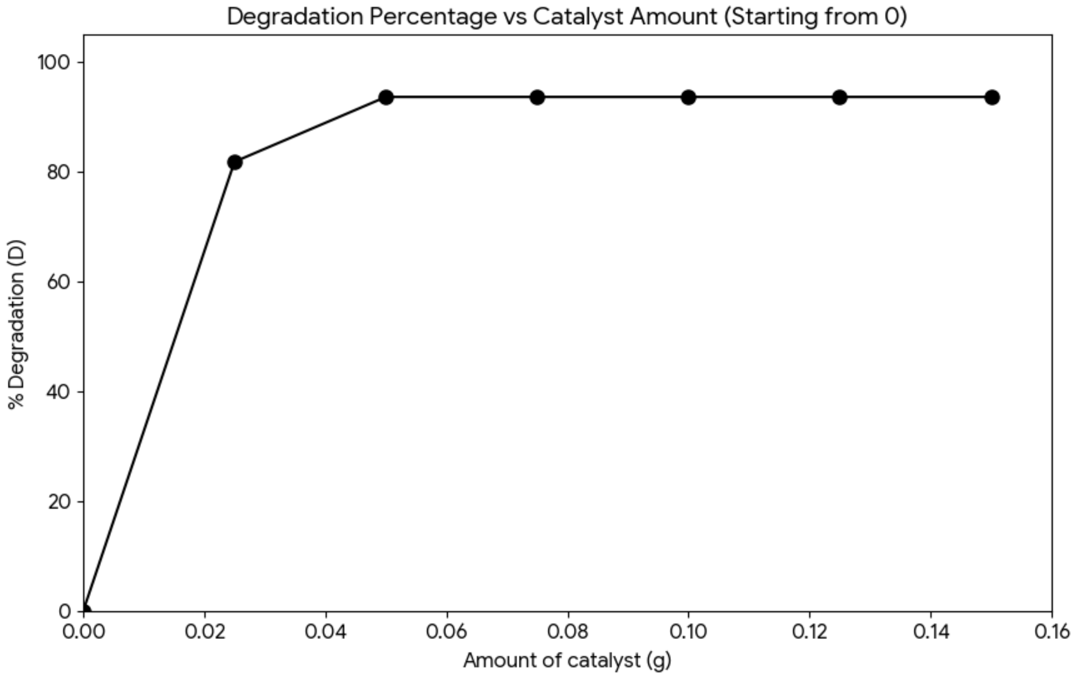

Fig 3.3 Effect of amount of catalyst on Thiazole Yellow G dye degradation.

According to the data above, 0.075g of vanadium nanoparticle catalyst was needed to break down Thiazole Yellow G dye over an equilibrium time of 140 to 160 minutes under visible light radiation.

3.3.3 Reusability of Catalyst:

The utilized catalyst was extracted from the degraded dye solution by centrifugation and filtration, then cleaned with distilled water, acetone, and oven drying. In order to determine the sustainability of the catalyst for a number of catalytic cycles, the reusability of the current nanomaterial catalyst was examined. It was found that rGO were effective up to four catalytic cycles, after which there was little loss in catalytic activity, as indicated in the table.

Table 3.3 Reusability of Catalyst

No. of catalytic cycles	**Absorbance**	**% X**	**% D**
1	**0.062**	**7.90**	**92.10**
2	**0.062**	**7.90**	**92.10**
3	**0.062**	**7.90**	**92.10**
4	**0.062**	**7.90**	**92.10**
5	**0.065**	**8.22**	**91.78**
6	**0.070**	**8.93**	**91.07**

Conclusion:

- ✓ Biomass-derived reduced graphene oxide (rGO) was successfully synthesized using eco-friendly and cost-effective methods.
- ✓ The prepared rGO-based composite showed enhanced structural and optical properties.
- ✓ XRD and Raman analysis confirmed the formation of defective but conductive graphitic structure.
- ✓ The photocatalyst exhibited excellent efficiency in degrading Thiazole Yellow G dye under light irradiation.
- ✓ Maximum degradation efficiency of about 90–95% was achieved under optimized conditions.
- ✓ The process followed pseudo-first-order kinetics with improved reaction rate.

- ✓ rGO played a key role in enhancing charge separation and reducing electron–hole recombination.
- ✓ Reactive oxygen species such as •OH and $O_2^{•-}$ were responsible for effective dye degradation.
- ✓ The catalyst showed good stability and reusability over multiple cycles.
- ✓ Overall, biomass-derived rGO is a promising, sustainable material for wastewater treatment applications.

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