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Sustainable Nanomaterials Synthesis for Efficient Toluidine Blue Dye Removal from Water

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Abstract

The scientific community is increasingly focusing on green synthesis of nanoparticles due to its inherent simplicity, eco-friendliness, and wide-ranging applications. In this particular study, we employed leaf extracts from the sausage tree (Kigelia Africana) to synthesize titanium dioxide nanoparticles (TiO2 NPs) in a single-step process.The TiO2 NPs synthesized through this green approach were subjected to a comprehensive characterization using a suite of analytical techniques. These techniques included Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), X-Ray Diffraction (XRD), Fourier-Transform Infrared Spectroscopy (FT-IR), Diffuse Light Scattering Spectroscopy (DLS), and Transmission Electron Microscopy (TEM).

1. Introduction

Water pollution caused by pollutants from various sources, including textile industries, poses a significant threat to the environment and living organisms. The discharge of toxic substances from textile effluents, such as Toluidine blue (TB) dye, can have severe detrimental effects on aquatic ecosystems and human health. Conventional wastewater treatment methods can be expensive and may create toxic secondary pollutants [1]. To address this issue, green synthesis of titanium dioxide nanoparticles (TiO2 NPs) using leaf extracts of the sausage tree (Kigelia Africana) was introduced as an eco-friendly and efficient approach. The synthesized TiO2 NPs demonstrated a spherical shape and anatase phase, making them suitable for photocatalytic applications [2]. The green-synthesized TiO2 NPs were then used for the photocatalytic treatment of textile wastewater, specifically targeting the removal of TB dye. Remarkably, the TiO2 NPs achieved 99.59% removal of TB dye within 60 minutes, as measured by a UV–Visible spectrophotometer.The study highlights the potential of green-synthesized TiO2 NPs as an effective and affordable catalyst for the treatment of wastewater from textile industries. Furthermore, this approach offers reusability of the catalyst, enhancing its practicality for large-scale dye removal applications in industrial settings [3]. In conclusion, the green synthesis of TiO2 NPs offers a promising solution for addressing water pollution caused by organic dyes in textile effluents. This eco-friendly approach provides an effective and sustainable method for wastewater treatment, contributing to the protection of aquatic ecosystems and human health.

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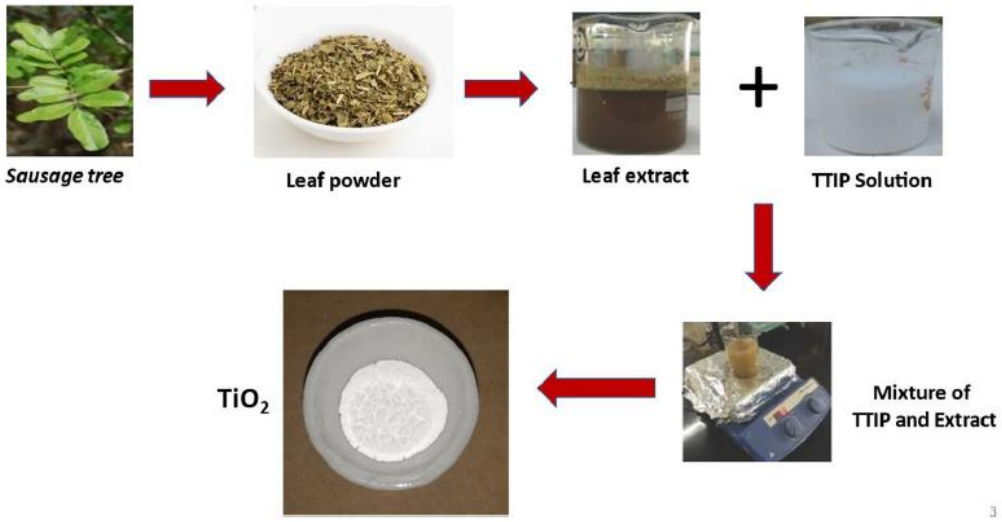

Fig. 2. Diagrammatic representations for Synthesis of TiO_2 NPs.

Table 1
Comparison of pseudo-first order rate constant and R^2 for the photodegradation of TB with previously reported work.

S. No	TB concentration	Catalyst	Catalyst Volume	k min^{-1}	R	Dye Removal (%)	Ref.
1	15 ppm	ZnO	20 mg	0.2141	0.945	97.24	Salim et al., et.al.
2	7 ppm	Mo-TiO_2	140 mg	76×10^4	–	–	Ameta et al., et.al
3	30 ppm	TiO_2 NPs	25 mg	0.763×10^{-3}	0.916	99.59	This work

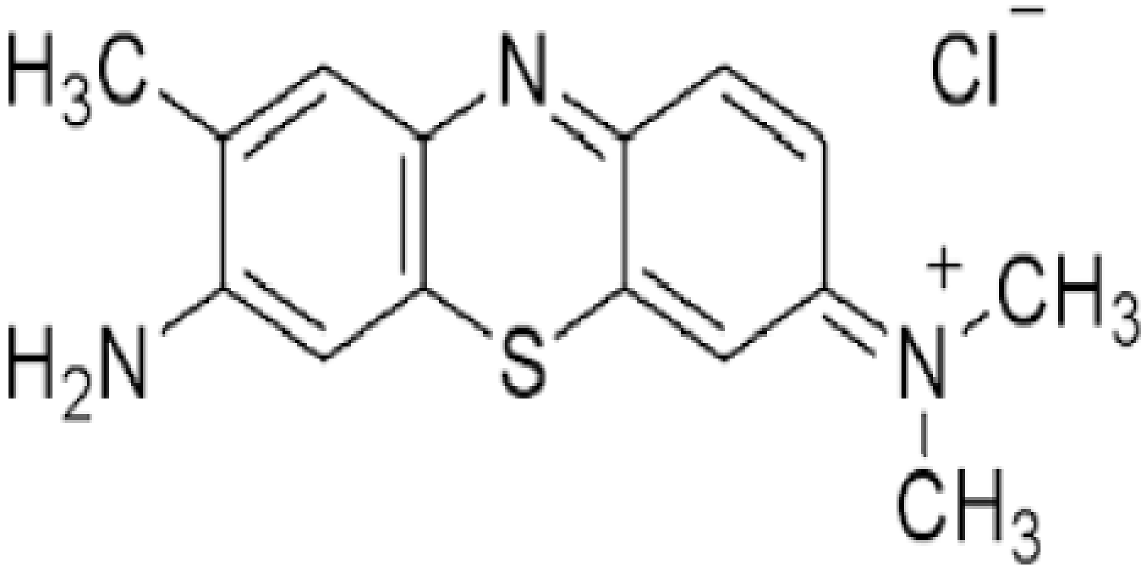

Fig. 1. Structure of Toludine Blue dye.

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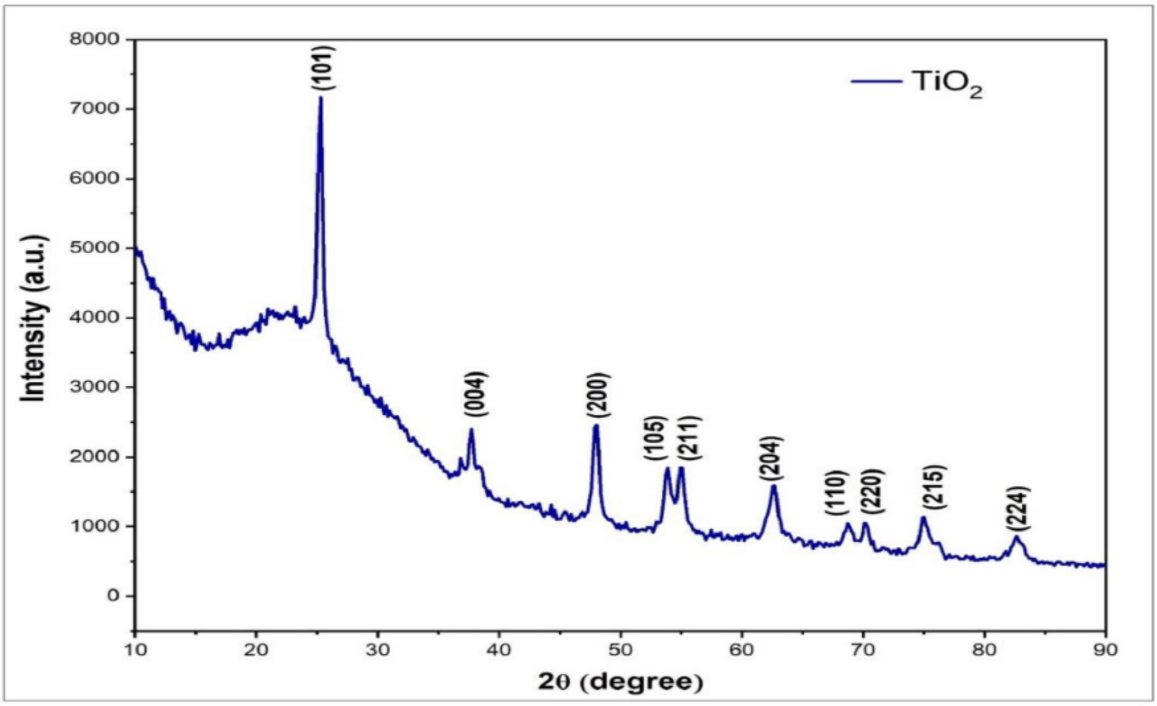

Fig.. 3. XRD pattern of green synthesized TiO_2 NPs.

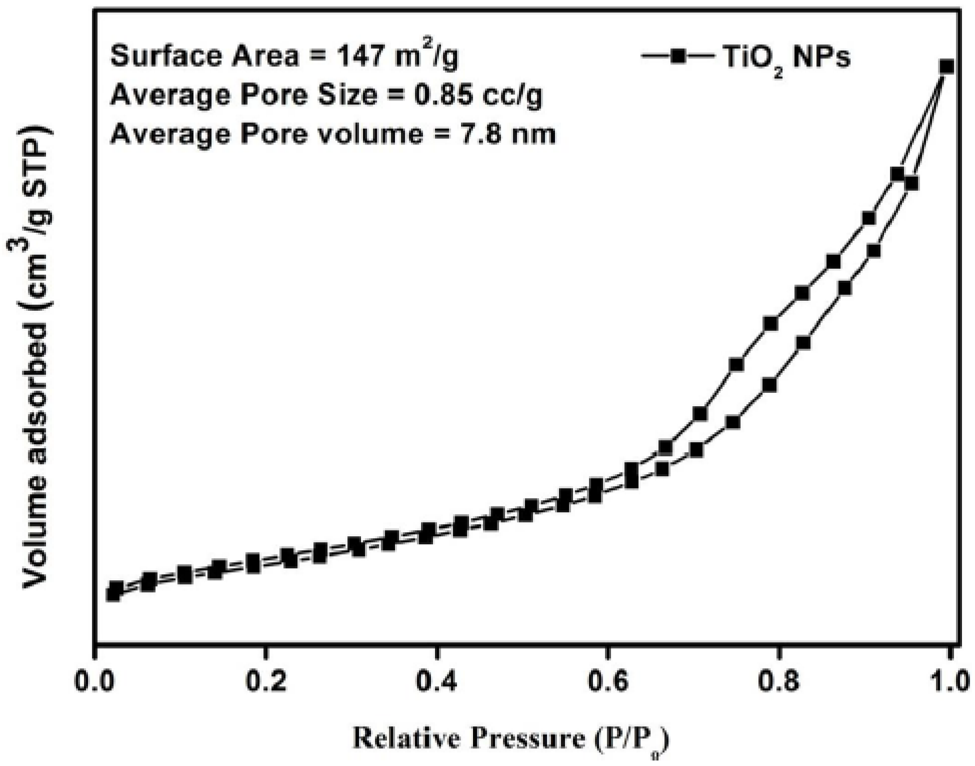

Fig. 4. BET data of green synthesized TiO_2 NPs.

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2. Experimental section

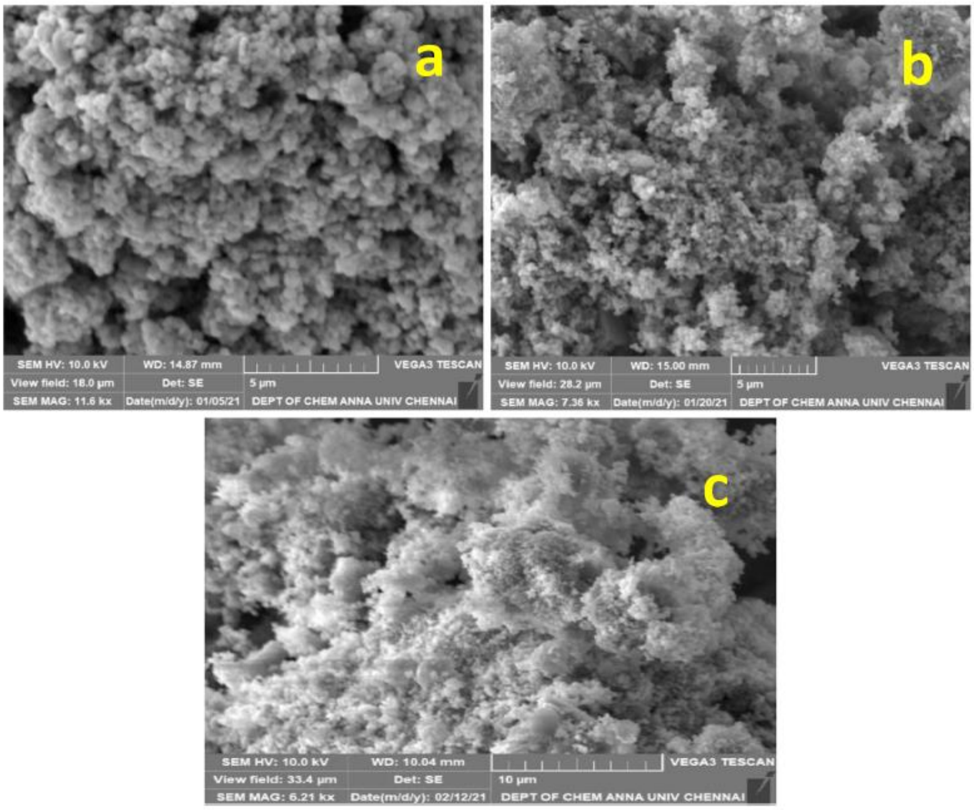

Fig. 5. SEM images of green synthesized TiO_2 NPs Fig. 4A) Leaf extract Fig. 4B) Flower extract, Fig. 4C) Fruit extract.

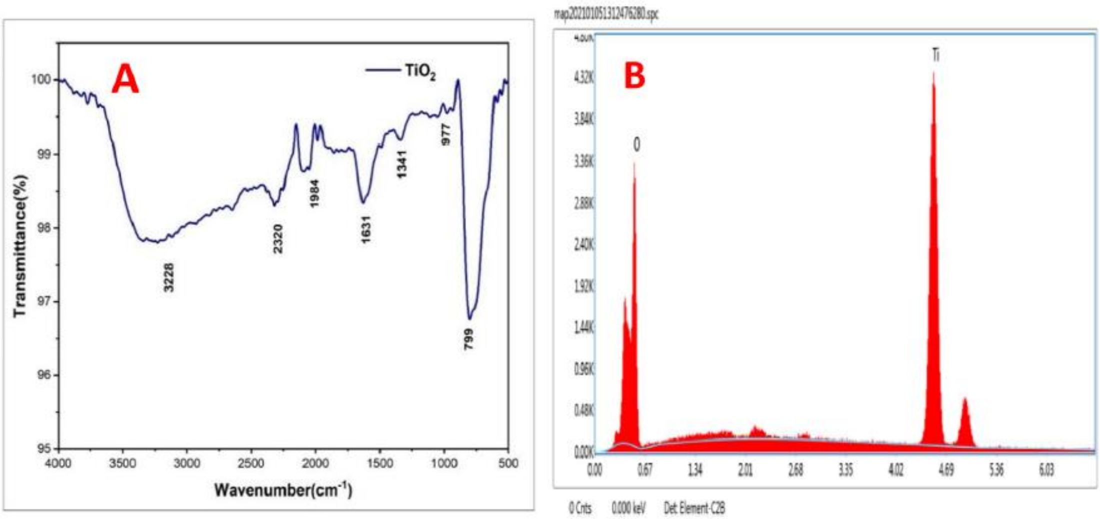

Fig. 6. A FT-IR spectrum of green synthesized TiO_2 NPs, Fig. 6B EDAX spectrum of green synthesized TiO_2 NPs.

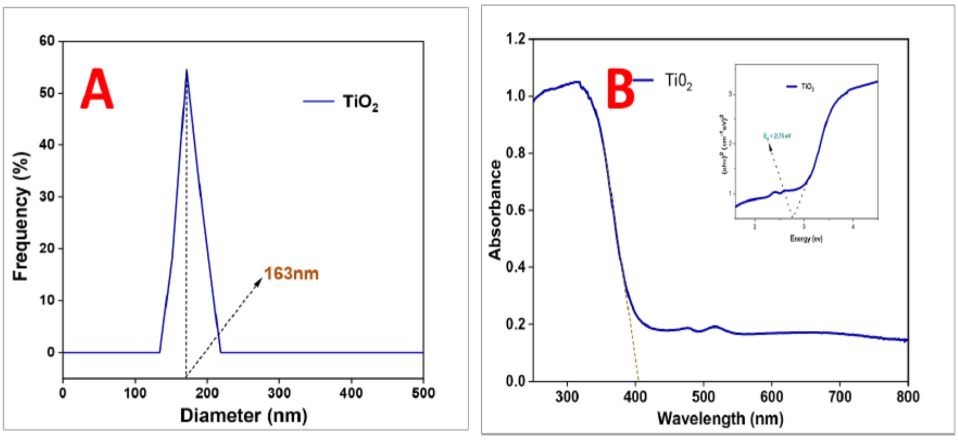

Fig. 7. A DLS plot for green synthesized TiO_2Nanoparticle, Fig. 7B UV-DRS spectrum of green synthesized TiO_2Nanoparticle.

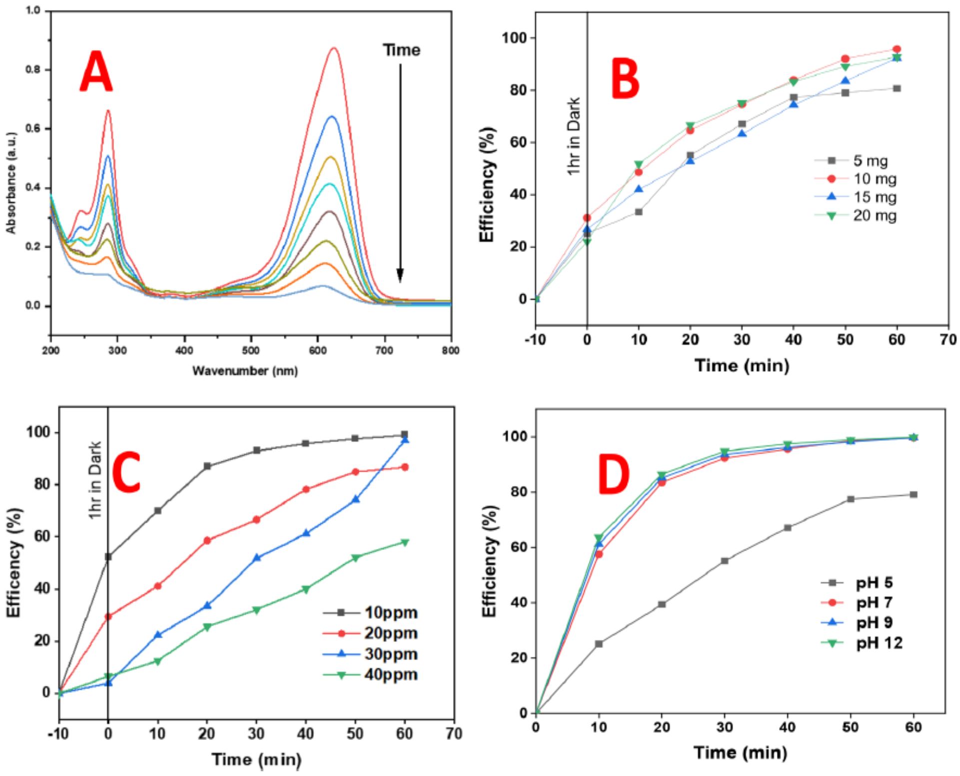

Fig. 8. A) Photodegradation of Toluidine Blue dye using green synthesized TiO_2 Nanoparticle, Fig. 8B). Effect of varying catalyst dosage on TB dye degradation, Fig. 8C) Effect of varying dye concentration on TB dye degradation, Fig. 8D). Effect of varying pH on TB dye degradation.

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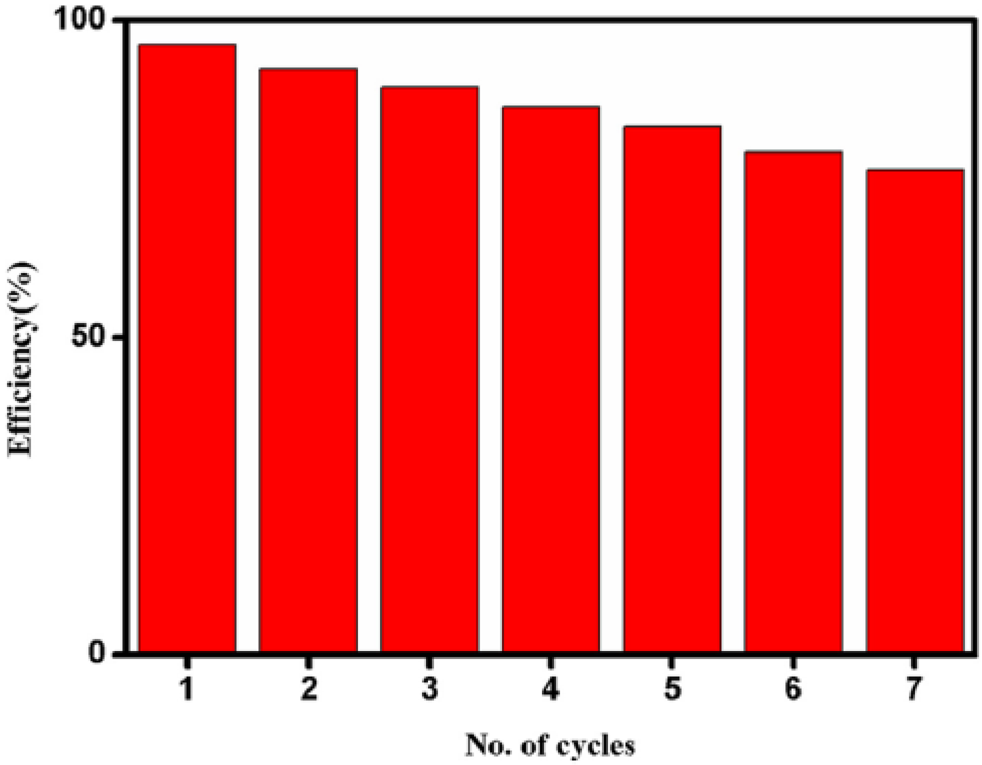

Fig. 9. Recycling efficacy chart of green synthesized catalyst.

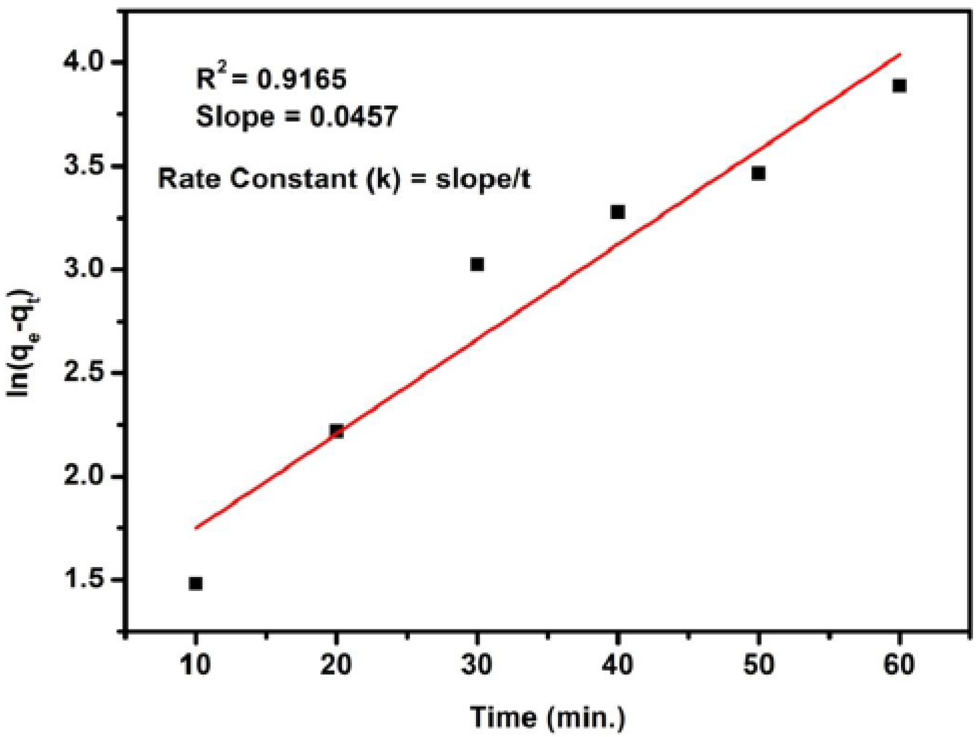

Fig. 10. Pseudo-first order kinetics model of TB dye Photodegradation.

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3. Characteristics of green synthesised TiO2

The X-ray diffraction (XRD) pattern of the green synthesized TiO2 NPs is shown in Fig. 3, which successfully unfolded its crystalline nature and anatase phase. The SEM analysis was performed to determine the shape and estimate the average grain size of the green synthesized TiO2 NPs. The SEM images evidenced the successful green synthesis of spherical-shaped TiO2 NPs with a diameter ranging from 50 to 200 nm, shown in Fig. 5. The FT-IR spectrum of the green synthesized TiO2 NPs recorded in the series of absorption bands 500 cm^{-1} to 4000 cm^{-1} is shown in Fig. 6A. The FT-IR spectrum of the green synthesized TiO2 NPs recorded in the series of absorption bands 500 cm^{-1} to 4000 cm^{-1} is shown in Fig. 6A. The X-ray Energy Dispersive Spectrometer (EDS) was employed to know the elemental composition of the green synthesized TiO2 NPs. The EDX spectrum is shown in Fig. 6B. The dynamic light scattering (DLS) technique was used to determine the particle size distribution of the green synthesized TiO2 NPs. To study the optical properties and confirm the green synthesis of TiO2 NPs, the analysis of the absorption spectra of the sample was also performed. The absorption spectrum of the green synthesized TiO2 NPs is presented in Fig. 7B.

4. Conclusion

This property allows the catalyst to be applied in the industrial removal of organic dyes from waste matrices in a faster and more efficient manner. (Please note that the "Fig. 1" reference may not be relevant in this text and should be removed unless you have an actual figure to include.) The green synthesis approach, utilizing natural leaf extracts, contributes to the sustainability of the process, minimizing environmental impact. Moreover, the high yields of TiO2 NPs obtained through this method make it a promising alternative to traditional chemical synthesis approaches, which often involve harsh chemicals and energy-intensive processes.

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