

Comparative Reactivity of Triphenylmethane, Anthraquinone and Nitro Dyes towards Degradation using Titania Photocatalyst

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ABSTRACT

Titania (TiO₂) photodegradation of three dyes in aqueous media: picric acid (PA), alizarin red-S (ARS), and crystal violet (CV) showed a practical wastewater remediation technique in this work. The process unfolded in a photoreactor equipped with a 20 W UV-lamp, aerators, and heating elements. Spectroscopic characterization of TiO₂ and dyes was achieved using Fourier Transform Infrared (FTIR), X-ray diffraction (XRD) and UV-visible methods. Simulated dye wastewater were treated with TiO₂, and photodegradation rates were monitored by UV-Visible Spectrophotometry. Effect of pH, temperature, catalyst concentration, and dye concentration on the degradation rates was determined. Comparative analysis of dye reactivities was conducted utilizing desirability response derived from historical data within the framework of Response Surface Methodology. FTIR spectra of TiO₂ post-degradation revealed the adsorption of dye chromophores, Triphenyl methane, Anthraquinone and Nitro from CV, ARS and PA respectively. XRD and UV-vis spectra revealed the rutile phase of TiO₂ with a bandgap of 2.852 eV. Maximum percent degradation followed the order: CV > ARS > PA, reaching 72.1%, 59.8%, and 44.1%, respectively. This study accentuates the preference for lower temperatures, with CV emerging as the most reactive to TiO₂, and predicts the degradation efficiency of the photocatalyst for various compositions of dye wastewater.

KEYWORDS

desirability response, dyes, photodegradation, process parameters, titania photocatalyst

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INTRODUCTION

Toxic compounds contributing to environmental pollution pervade various environmental compartments, including water, air, and soil. Dyes, as a notable example, enter water bodies through diverse sources, spanning domestic to industrial discharges. These compounds are classified based on their functional groups, specifically the chromophores dictating both their dyeing capabilities and pollution potential.¹ Triphenylmethane, anthraquinone, and nitro dyes, exemplified by CV, ARS, and PA dyes, fall under this classification.^{2,3} These dyes serve multifaceted purposes, including dye synthesis, material dyeing, application in explosives, printing pigments, and utilization as indicators in chemical and biological laboratories.^{4,5,6} However, the discharge of dye-laden wastewater from treatment plants or industrial outfalls poses a significant threat to water bodies, potentially leading to adverse effects on human health, aquatic organisms, and plant photosynthesis.⁷

Degradation, a pivotal process, involves the transformation of complex toxic compounds into less harmful or eco-friendly products. Conducting degradation before wastewater discharge is crucial in preventing environmental pollution, mitigating risks to human health through the food chain, and averting bioaccumulation.^{8,9} Various degradation methods, such as photocatalysis, adsorption, coagulation, chlorination, ozonation, aerobic, and anaerobic processes, exist¹⁰. Photocatalysis, in particular, activates semiconductors with light energy, generating hydroxyl radicals and electronic holes, ultimately breaking down the intricate structures of pollutants (Figure 1 and equations 1-8):^{11, 12}



Figure 1 and Equation (1) delineate the photoactivation process of the TiO₂ photocatalyst upon exposure to Ultraviolet (UV) spectrum of sufficient energy ($h\nu$), resulting in the generation of holes (h^+) in the valence band (Vb) and electrons (e^-) in the conduction band (Cb).

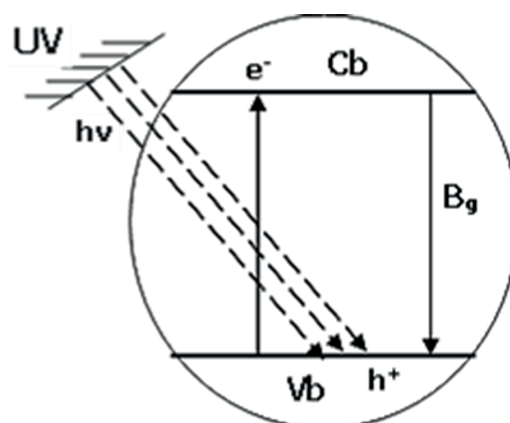


Figure 1: Excited TiO₂ particle ¹³

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The distance between the conduction and valence bands is known as Band gap, (Bg) as shown in figure 1. Subsequent photocatalytic effects are elucidated in equations (2), (3), and (4), wherein holes participate in oxidation reactions. Simultaneously, equation (5) illustrates reduction reactions facilitated by electrons. The degradation of the organic compound is detailed in equations (6) and (7), utilizing hydroxyl radicals previously generated by the holes. Notably, holes exhibit an exceptionally positive oxidation potential, enabling them to oxidize a wide array of chemicals, as illustrated in equation (8). The photoinduced reaction ceases upon discontinuation of the Ultraviolet light, prompting the recombination of holes and electrons within the TiO₂, thereby concluding the entire reaction sequence.¹⁴

Recognizing the complex composition of industrial dye wastewater, this research aims to discern and compare the degradation behaviors of Picric acid (PA), Alizarin red-S (ARS), and Crystal violet (CV) under identical reaction conditions. The obtained data was subjected to computation using Response Surface Methodology (RSM) software, a powerful tool widely employed in wastewater treatment and experimental design within engineering applications. RSM facilitates the exploration of interactions among key parameters, offering valuable insights into optimizing responses of interest.¹⁵ In this context, the tool was used to ascertain the optimal settings for control variables, namely pH, dye concentration, catalyst concentration, and temperature and identify the ideal conditions for the photocatalytic breakdown of the chosen dyes. The objective is to identify ideal conditions that yield either a minimum or maximum response, expressed as percent degradation, all under the umbrella of a desirability response set at 1.000. This work adds significant knowledge to the field of wastewater treatment optimization by forecasting the degradation efficiency of TiO₂ across different compositions of dye wastewater.

EXPERIMENTAL

Materials

Potassium hydrogen phthalate (KHP) from Hopkin & Williams, England; potassium dihydrogen phosphate (KH₂PO₄) and sodium hydrogen phosphate (Na₂HPO₄) from BDH Laboratory Poole, England; and potassium chloride (KCl), hydrochloric acid (HCl), and sodium hydroxide (NaOH) are the chemical reagents used in this study. These reagents were utilized to regulate the pH levels of the aqueous dye solutions according to the guidelines provided in Weast.¹⁶ Picric acid dye was sourced from LABOGENS Fine Chemicals in Punjab, India; Alizarin red-S dye was acquired from BDH Chemicals Limited in Poole, England; and Crystal violet dye was procured from KEM Light Laboratories in Mumbai, India.

Without any changes, all reagents were used exactly as they were purchased, and the necessary concentrations were made right away. The rutile TiO₂ photocatalyst used in the study was synthesized, and comprehensive papers on its characterization and production have already been released.¹⁷

Characterization methods

UV-visible spectrum and Bandgap determination of TiO₂

The UV-visible analysis of the photocatalyst was conducted using a solid-state LAMBDA™ 1050 UV/Vis/NIR spectrometer (PerkinElmer, Inc., Shelton, CT, USA). The band gap of a semiconductor is determined by the equation:¹⁸

$$E(\text{eV}) = \frac{hc}{\lambda_{\text{red}}} = \frac{1.240 \times 10^{-6} \text{ eV}}{\lambda(\text{m})} \quad (9)$$

In this equation, E in eV represents the band gap energy, c stands for the speed of light, h represents Planck's constant, and λ_{red} represents the red edge of absorption (i.e., the wavelength at which light absorption occurs). The term “band gap” refers to the energy difference between the valence band and the conduction band of a photocatalyst through

which electrons can jump from one band to another. Equation (9) is suitable for rough estimation of band gap energy values.

X-ray diffraction (XRD) crystallography of the photocatalyst

X-ray diffraction (XRD) crystallography is a technique capable of discerning the phases of crystalline samples.¹⁹ When powder samples are exposed to a beam of X-rays, they scatter the beam, and the intensity of scattered X-rays was measured. The XRD crystallography patterns of the TiO₂ photocatalyst were obtained using a powder X-ray diffractometer (Bruker D8 Advance) AXS Germany model, employing Cu-K α radiation, across the 2 θ range from 10° to 100° with intervals of 0.020°.

FTIR Analysis of the Photocatalyst and Dyes

Using a Perkin Elmer 100 FT-IR spectrometer, Fourier Transform Infrared (FTIR) spectroscopy was employed to examine the dyes prior to and during their degradation along with the photocatalyst. The wavelength range encompassed by the FTIR observations was 450 cm⁻¹ to 4000 cm⁻¹. The obtained spectra were evaluated using IR resolution software, with each spectrum being compared to its corresponding background spectrum. This analytical approach allowed for the comprehensive examination of molecular vibrations and structural changes in the photocatalysts and dyes, providing valuable insights into the chemical transformations occurring during the photocatalytic degradation process.

Calibration of the UV-Visible Spectrophotometer

To monitor the photocatalytic degradation process, an N4S Search Tech UV-Visible analyzer was calibrated using suitable aqueous solutions of crystal violet (CV), alizarin red-S (ARS), and picric acid (PA). To establish the calibration for CV, a 6-ppm solution was prepared with de-ionized water. Absorbance measurements were taken at various wavelengths within the range of 200-800 nm at 20 nm intervals. The resulting plot of Absorbance against wavelength facilitated the determination of the wavelength corresponding to the maximum absorbance (λ_{max}) of CV dye. Analogous procedures were replicated for ARS and PA, employing 15 ppm solutions for both dyes.¹⁶ Additionally, the spectrophotometer calibration involved measuring the molar absorptivity of each dye.

Concentrations ranging from 2 to 40 ppm for CV were prepared by dilution from the 400 ppm stock solutions. Absorbance measurements at λ_{max} were taken for each concentration. The Beer Lambert equation (equation 10) was applied to draw a plot of absorbance against concentration, from which the molar absorptivity (Extinction coefficient, ϵ) was determined using the slope. This calibration process ensures accurate and precise measurements during the subsequent UV-Visible spectrophotometric monitoring of the photocatalytic degradation reactions.²⁰

$$A = \epsilon bc \quad (10)$$

A is the absorbance, ϵ is the molar absorptivity, b, the path length of the sample holder and c, the concentration of the absorbing species. The same procedure was replicated for determining the molar absorptivity of Alizarin red-S (ARS) and Picric acid (PA). For these dyes, concentrations ranging from 5 to 100 ppm were prepared through dilution from their respective stock solutions.²¹

Construction of a photocatalytic reactor

A batch reactor was designed to optimize key factors such as time management, heat loss prevention, and ensuring maximum illumination. Constructed using strawboards, the degradation reactor was insulated using cotton wools to counteract electric transmission and mitigate heat loss by conduction. The complete reaction setup was

shielded with black polyethylene film to maximize UV light exposure and prevent external light interference. The design incorporated four compartments housing reaction vessels and heating elements. This effectively addressed efficiency concerns related to time management, as four experimental runs were carried out concurrently. A crucial consideration in the reactor design was the implementation of holes at the top, facilitating the connection of aerators to the reaction. These openings also served as access points for sampling at predefined time intervals during the progression of the reaction. The reactor design, crafted to enhance performance and precision, was adapted from the Ph.D. thesis of Odeyemi,²² attesting to the application of established research methodologies in the experimental setup.

Photocatalytic degradation process

Buffer solutions spanning a pH range of 2–13 were prepared according to established literature procedures.¹⁶ These buffers were then utilized to make up the dye stock solutions to the desired pH and overall quantity of 200 cm³. With each dye solution maintained at a known concentration, pH and temperature, initial absorbance was taken as (A_0). Then a precise amount of catalyst was introduced.

The reaction containers were subjected to a 120-minute reaction period. During this time, the aerators and UV-lamp were activated. Supernatant solution samples (approximately 2 cm³) were withdrawn at regular 15-minute intervals, and the final absorbance, taken as (A), was measured at maximum wavelength ($\lambda_{\max}$) of each dye.²³ Percent dye degradation was subsequently calculated by:²⁴

$$\% \text{ degradation} = \frac{A_0 - A}{A_0} \times 100 \quad (11)$$

Response Surface Methodology (RSM)

Data collected were treated by version 6.0.6 of Design Expert software, leveraging historical data design to assess and liken the dyes' reactivities in response to degradation by the titania. While percent degradation was the primary response variable the process variables were dye concentration, pH, temperature and catalyst concentration.^{25,26} The software facilitated the analysis of historical data to identify trends and patterns in the experimental outcomes.

Optimal degradation conditions were determined using the software, and the results were subjected to the desirability scale within the framework of Response Surface Methodology (RSM). A desirability value of precisely 1.000 indicated that the response variable of interest (percentage degradation) had been perfectly optimized under the given conditions. This systematic approach allowed for the identification of the most favorable parameter settings.

RESULTS AND DISCUSSION

Characterization results

TiO₂ Bandgap determination

Figure 2 shows the UV-visible absorption spectra of TiO₂. The spectral data perceives a strong cut off at 434.81 nm where the absorbance value is minimum. Using equation (9) and given values of the constants (hc) and (λ_{red}), the calculated bandgap of the TiO₂ is 2.852 eV which agrees with literature that the band gap of rutile TiO₂ falls between 2.8–3.0 eV.²⁷

XRD phase analysis of TiO₂

XRD spectra for the photocatalyst are presented in Figure 3. It reveals peaks agreeing with the rutile phase of TiO₂ at 41.32° (211), 39.18° (111), 36.15° (101), and 27.56° (110) which have already been published.²⁸

FTIR of dyes and photocatalyst

Figure 4 illustrates the FTIR spectra for the photocatalysts and the dyes before and after degradation in a superimposed form. In Figure 4(I),

the CV spectra depict (a) TiO₂ only, (b) TiO₂ + dye after degradation, and (c) dye only. Similar plots in Figures II and III correspond to ARS and PA dyes, respectively. A consolidated overview of the spectral assignments for the photocatalysts, dyes, and the photocatalyst after use is presented in Tables 1, 2, and 3, respectively.

In Figure 4(a), bands between 3350–1620 cm⁻¹ signifies Ti-O-H stretching vibrations while 1600–1630 cm⁻¹ shows H-O-H bending vibrations. These observations provide clear evidence of the presence of hydroxyl groups and water molecules in the photocatalyst, essential prerequisites for degrading dye molecules in solution.^{9,25} Additionally, a broad absorption band in the range of 470–490 cm⁻¹, as observed in Table 1, supports the existence of O-Ti-O bond, further confirming that TiO₂ particles were obtained, as reported in literature.^{26,27,32} The spectral assignments of the photocatalyst, although subtle, were detected by the FTIR instrument. Furthermore, evidence of their presence is also observed in the FTIR spectrum of the photocatalyst after degradation, XRD spectrum and UV-visible characterization result.

For Figure 4(b) in I, II, and III, bands observed at 3080–3100 cm⁻¹ and 1450–1600 cm⁻¹ indicate C-H and C=C aromatic stretching, respectively, revealing the aromatic structures present in all the dyes.³³ In Figure 4(I), the presence of the N-CH₃ peak at 2914.95 cm⁻¹ in CV (Tris(4-dimethylamino) phenylmethyl chloride) is indicative of a positive substituent, forming part of its chromophore. For ARS (1,2-dihydroxy-9,10-anthraquinone sulfonic acid sodium salt) in Figure 4(II), the chromophore is identified at 1663.63 cm⁻¹, while Figure 4(III) for PA (2,4,6-trinitrophenol) shows the negative substituent N=O at 1525.81 cm⁻¹, representing its chromophore. These spectral assignments are detailed in Table 2.

Comparative analysis of the FTIR spectra of the catalyst after degradation in Figure 4(c) of I, II, and III reveals that the dyes were degraded by and adsorbed onto the catalyst surface at wavenumbers ranging between 447 and 1635 cm⁻¹. This is further elucidated in the spectral assignment provided in Table 3. Consequently, the hydroxyl radicals present on the TiO₂ catalysts are observed to effectively degrade the dyes.⁹

UV-Visible Characterization of the dyes

The spectra of the ARS, PA, and CV dyes at their wavelength of maximum absorption ($\lambda_{\max}$) are shown in Figures 5(a–c), respectively. For the dyes CV, ARS, and PA, the measured values were 585 nm, 255 nm, and 355 nm, respectively. All the dyes shows significant absorption in the 240–300 nm UV wavelength region while only the CV dye shows a clear peak at 585 nm. These measured values are in good agreement with the data presented in Weast's CRC Handbook of Chemistry and Physics, 58th edition,¹⁶ confirming the precision and coherence of the experimental findings with accepted reference data.

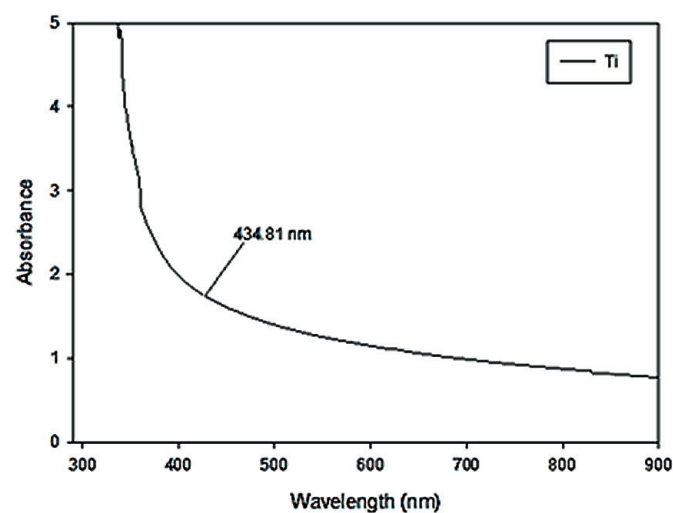


Figure 2: UV-visible spectra of the TiO₂ photocatalyst

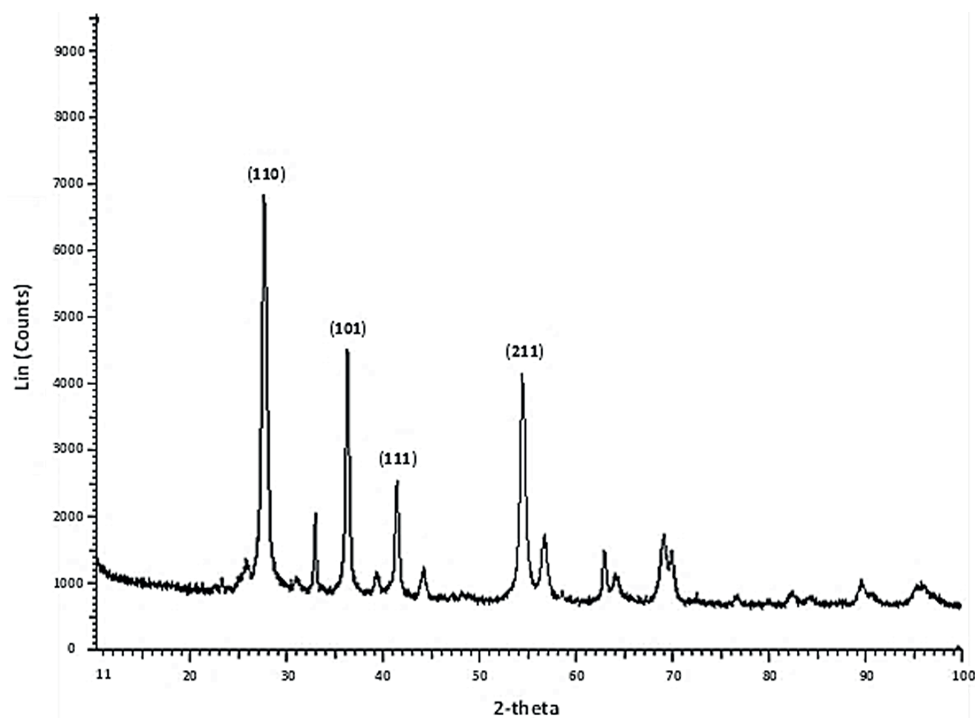


Figure 3: XRD spectra analysis of the TiO_2 photocatalyst

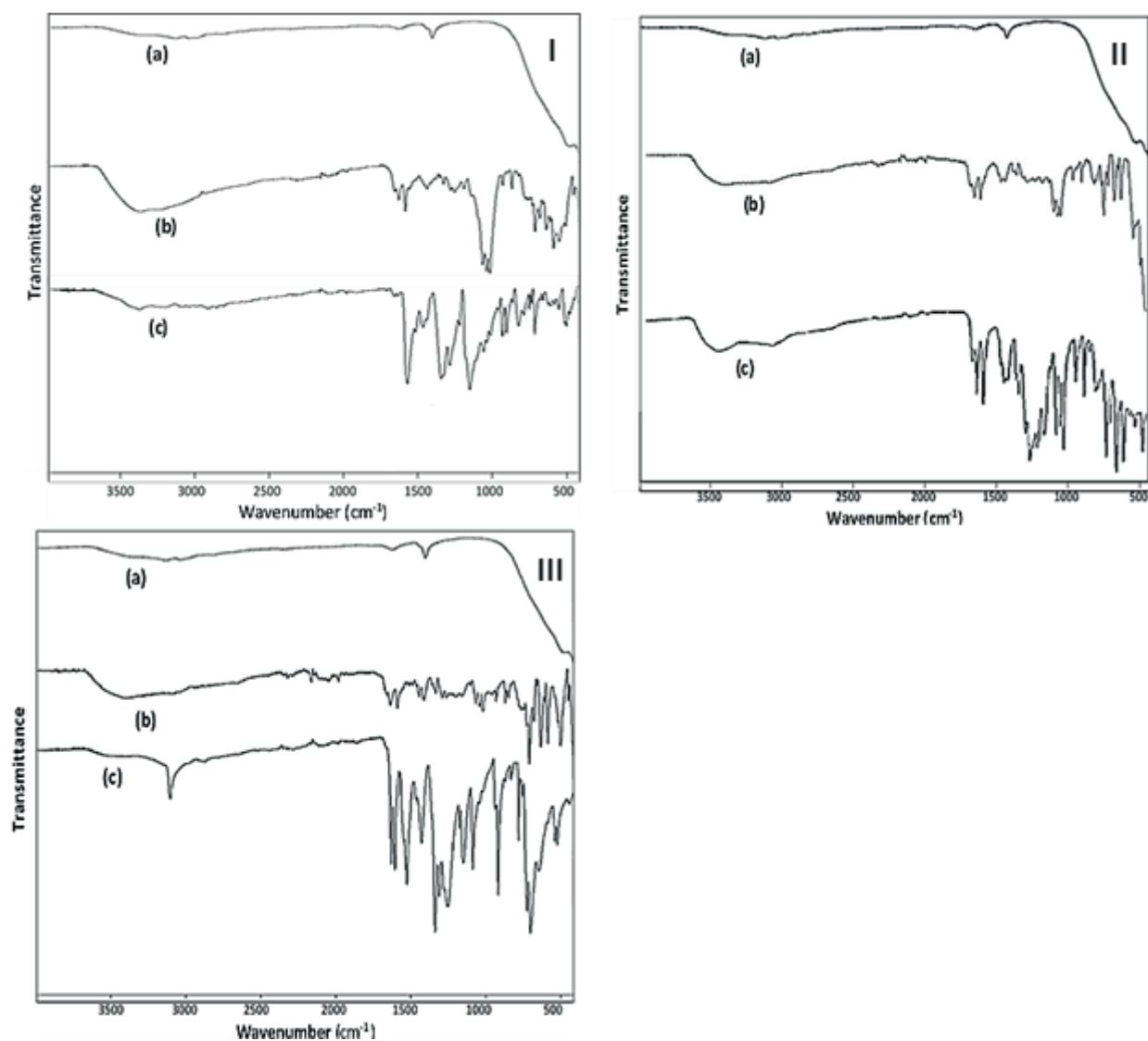


Figure 4: FTIR spectra of (I) picric acid with (a) TiO_2 only, (b) TiO_2 + dye after degradation, and (c) dye only; (II) alizarin red S and (III) crystal violet

Table 1: Infrared spectra assignment of TiO₂ Photocatalyst Infrared spectra assignment of the photocatalyst

Photocatalyst	$\bar{\nu}$ (Ti-O-H) cm ⁻¹	$\bar{\nu}$ (H-O-H) cm ⁻¹	$\bar{\nu}$ (O-Ti-O) cm ⁻¹
TiO ₂	3350 – 1620 cm ⁻¹	1627.92	480.39

Table 2: Infrared spectra assignment of CV, ARS, and PA

Infrared spectra assignment of the Dyes			
Vibration bands	Crystal violet (CV)	Alizarin red S (ARS)	Picric Acid (PA)
$\bar{\nu}$ (O-H) cm ⁻¹	-	3476.49	3532.95
$\bar{\nu}$ (C-H) cm ⁻¹ aro. str	3200.78	3093.8	3103.27
$\bar{\nu}$ (C-H) cm ⁻¹ ali. str	3087.63	-	-
$\bar{\nu}$ (N-CH ₃) cm ⁻¹	2914.95	-	-
$\bar{\nu}$ (C=O) cm ⁻¹	-	1663.63	-
$\bar{\nu}$ (C=C) cm ⁻¹ str	1470.88	1588.2	1607.26
$\bar{\nu}$ (N=O) cm ⁻¹	-	-	1525.81
$\bar{\nu}$ (C-H) cm ⁻¹ bend	1156.62	1154.91	1150.56
$\bar{\nu}$ (C-N) cm ⁻¹	-	-	1087.02

Table 3: Infrared spectra assignment of TiO₂ after degradation

Infrared spectra assignment of the photocatalyst after degradation			
Vibration bands	TiO ₂ with CV (CV)	TiO ₂ with ARS (ARS)	TiO ₂ with PA (PA)
$\bar{\nu}$ (Ti-O-H) cm ⁻¹	3385.37 - 1633.23	3416.36 - 1633.62	3402.63 - 1637.56
$\bar{\nu}$ (H-O-H) cm ⁻¹	1633.23	1633.62	1637.56
$\bar{\nu}$ (O-Ti-O) cm ⁻¹	447.82	501.44	448.76
$\bar{\nu}$ (O-H) cm ⁻¹	-	3416.36	3402.63
$\bar{\nu}$ (C-H) cm ⁻¹ aro. str	3255.21	3100.82	-
$\bar{\nu}$ (C-H) cm ⁻¹ ali. str	-	-	-
$\bar{\nu}$ (N-CH ₃) cm ⁻¹	-	-	-
$\bar{\nu}$ (C=O) cm ⁻¹	-	-	-
$\bar{\nu}$ (C=C) cm ⁻¹ str	1442.46	1588.89	1590.46
$\bar{\nu}$ (N=O) cm ⁻¹	-	-	-
$\bar{\nu}$ (C-H) cm ⁻¹ bend	-	1149.18	-
$\bar{\nu}$ (C-N) cm ⁻¹	-	-	-

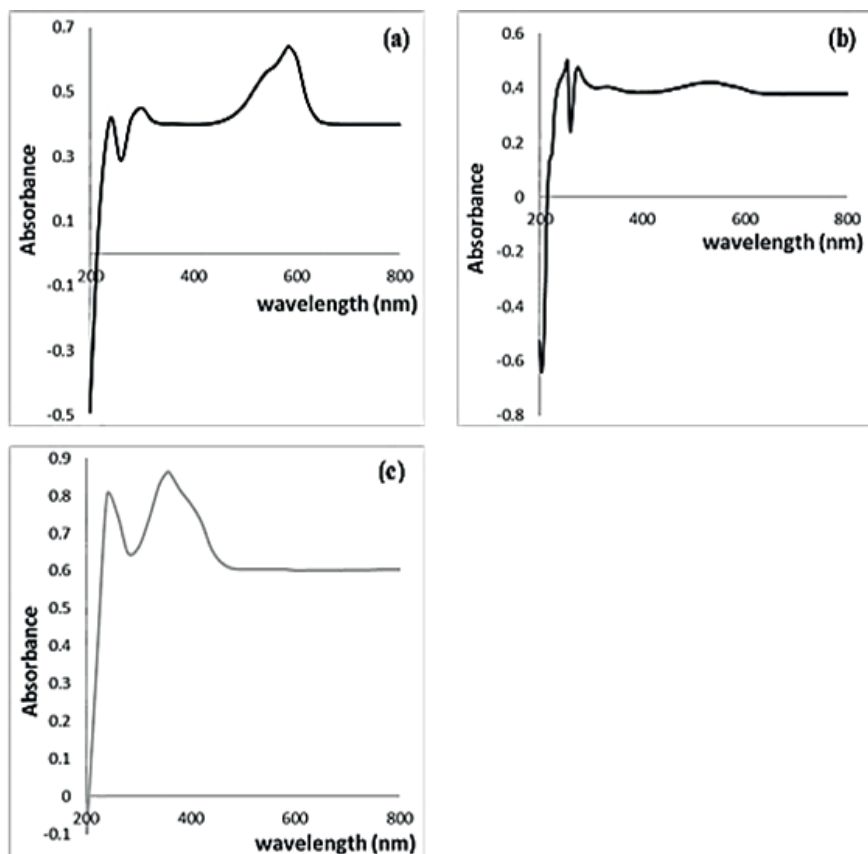


Figure 5: UV-visible spectrum of (a) CV, (b) ARS and (c) PA dyes

In Figures 6(a–c), the Beer-Lambert plots illustrate absorbance against different concentrations of CV, ARS, and PA, respectively. The linear nature of these plots indicates that the absorbance of each dye is directly proportional to its concentration, confirming adherence to Beer-Lambert's law. The molar absorptivity values obtained from the plots are 0.1046, 0.0333, and 0.0532 (M⁻¹cm⁻¹) for CV, ARS, and PA, respectively. High absorbance signifies that a significant amount of light is absorbed by the sample, and vice versa. In other words, the higher the molar absorptivity, the greater the light absorbed by the dye.²¹ Consequently, the values of molar absorptivity highlight that CV dye absorbs more light compared to PA and ARS. This insight into the

light-absorbing capabilities of the dyes is essential for understanding their behavior in photocatalytic degradation processes.

The Photocatalytic reactor

The reactor designed and implemented for the degradation of the dyes is presented as a 3D structure in Figure 7(a), with an accompanying orthographic drawing in Figure 7(b–d) providing detailed dimensions of the reactor.

With two upper and lower levels, the reactor was shaped like a rectangle. Six compartments made up the upper layer, four of which

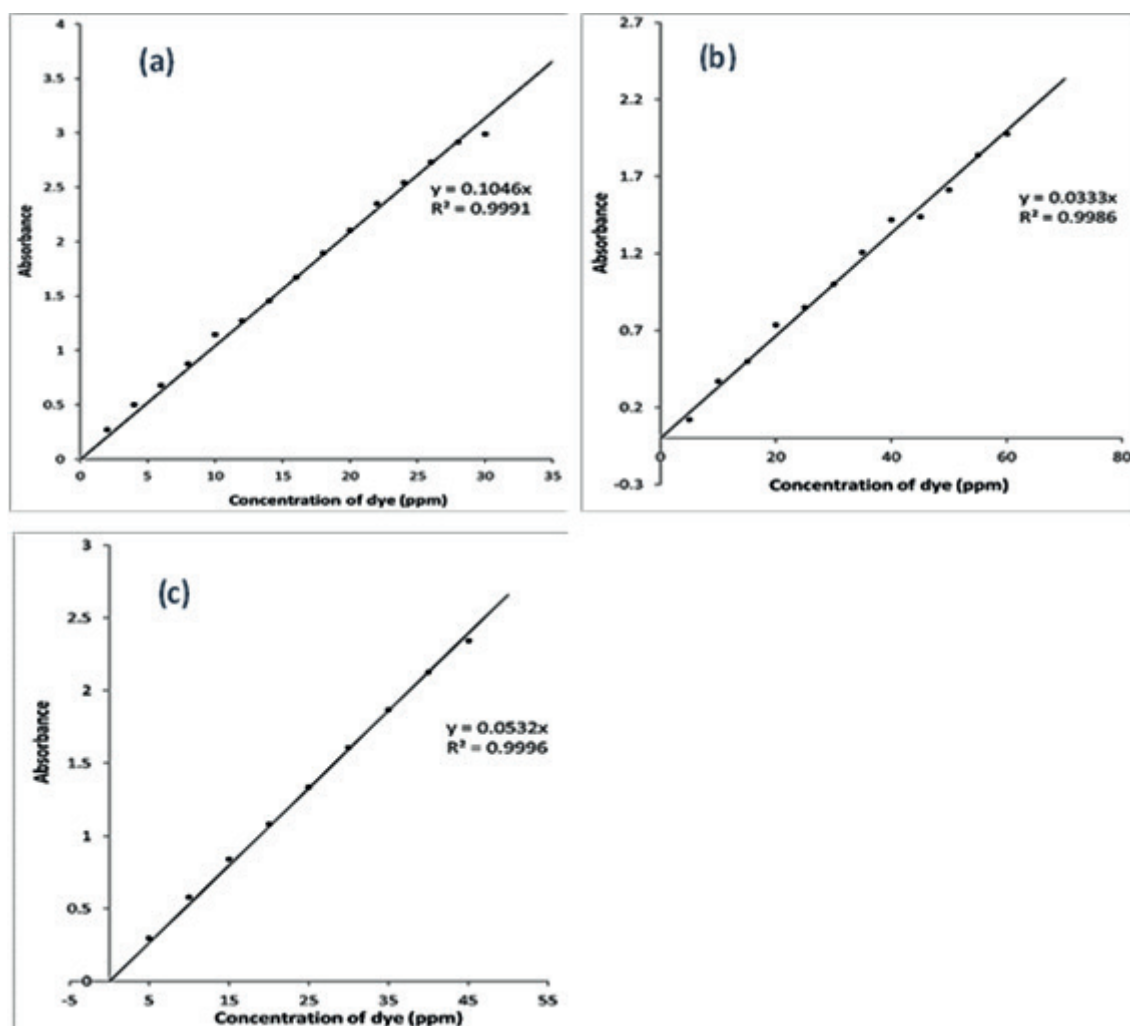


Figure 6: Beer-Lambert plots of absorbance against concentrations for (a) CV, (b) ARS and (c) PA dyes

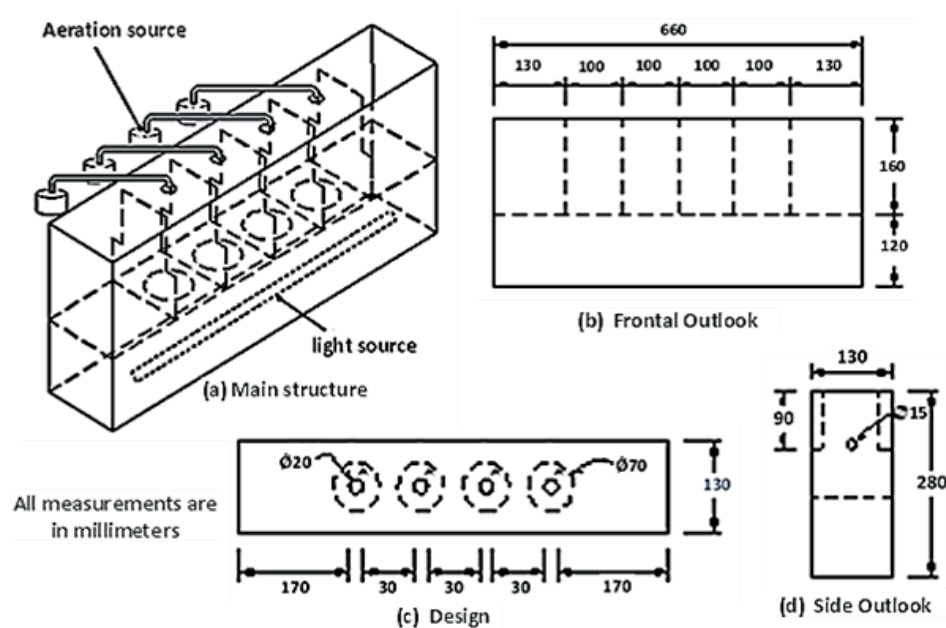


Figure 7: 3D structure with orthographic drawing of the photocatalytic reactor

were used to store glass jars that held the dye solutions. The remaining two compartments, one at each end, supported the heating element for the reactor. There were small circular holes at the top and bigger holes at the bottom of the reactor through which oxygen from aeration

pumps is supplied into the solution and light irradiate the reactants respectively. The reactor was also insulated throughout with layers of cotton wool to prevent radiation of heat, guaranteeing controlled and effective operation.

Relative reactivity of the dyes

The impact of criteria for deterioration was systematically investigated through optimization plots, revealing the interactions between each dye and titania.³⁴ The analysis of variance underscores the significant influence of all process variables on the yield of dye degradation.³⁵ Desirability values further indicates that optimal responses were achieved at pH 6.9, 7.5 ppm dye, 0.15 g/l catalyst amount, and 28.9 °C. These specific conditions are identified as points of optimization for all the dyes, serving as the basis for comparison. The desirability values highlight the efficacy of the photocatalytic degradation process under these specific parameter settings, providing valuable insights into the conditions that maximize the degradation efficiency for each dye.

Effect of pH

Figure 8 shows that the maximal dye degradation at the ideal pH of 6.99 is greatest for CV dye and least for PA dye. While ARS is slightly acidic and CV is basic and carries positive charges, PA is known for being extremely acidic and carrying negative charges. TiO₂ has a positively charged surface at pH < 6.25 and a negatively charged surface at pH > 6.25, according to literature studies.³⁶ This indicates that pH 6.25 is the point of zero charge for TiO₂. As a result, it is assumed that the photocatalyst will protonate less at pH 6.99. Because there are many hydroxyl (OH⁻) ions at this pH, there is less adsorption of ARS and PA, which causes ionic repulsion between the negatively charged catalyst.³⁷ Furthermore, at this pH, ARS is more degraded than PA since it is less acidic than PA. This means that at the ideal pH of 6.99, CV dye is more reactive than both ARS and PA, highlighting its greater reactivity with the TiO₂ photocatalyst.

Effect of dye concentration

In Figure 9, all the dyes demonstrate optimal degradation at a dye concentration of 7.5 ppm. However, higher degradation was observed for CV compared to PA and ARS. This observation can be explained by considering that at 7.5 ppm, there are more CV dye molecules present than PA and ARS, effectively covering the active sites on the same amount of catalyst. This increased the degradation rate for CV,^{38,39} leaving more active sites available on the catalyst for PA and ARS. Additionally, the residual catalyst sites impeded the radiation intensity from being absorbed by the dye molecules, consequently raising the turbidity of the solution.^{40–42} Degradation efficiency decreased because of the increased turbidity, which also increased the supernatant solution's absorbance. Therefore, the interplay between dye concentration and catalyst availability is crucial, with higher dye concentrations affecting the coverage of active sites and influencing the overall degradation rate.

Effect of the concentration of catalyst

For every dye in Figure 10, a catalyst concentration of 0.15 g/l is found to be ideal, where 64.95 % for CV shows the highest amount of degradation. When compared to the other dyes, CV's dye molecules are more strongly attracted to the catalyst's sites, which accounts for its increased reactivity. The different charges on the catalyst's surface and the CV dye are what cause this attraction. On the other hand, the ARS and PA catalyst surfaces show more comparable charges, which increases repulsions.^{37,43} These repulsions highlight the importance of the interaction between charge interactions and catalyst concentration in the photocatalytic degradation process by slowing down the degradation of both ARS and PA at the same catalyst concentration.

Effect of temperature

In Figure 11, the degradation efficiencies at a temperature of 28.9 °C are approximately 72 % for triphenylmethane dye, 59.8 % for anthraquinone, and 40.1 % for nitro dyes.

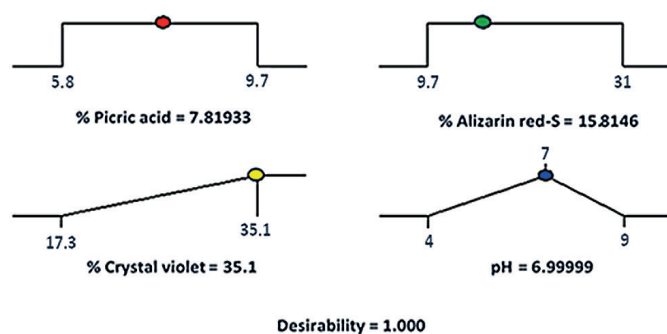


Figure 8: Comparison of the percent degradation of the dyes at optimum pH of 6.9

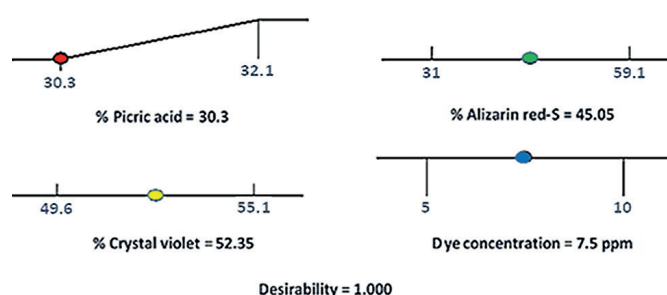


Figure 9: Comparison of percent degradation at optimum dye concentration of 7.5 ppm

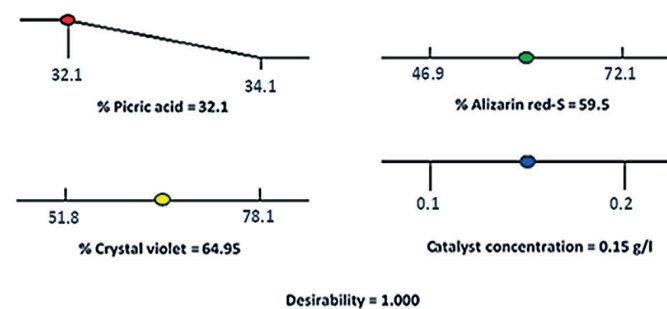


Figure 10: Comparison of percent dye degradation at 0.15 g/l catalyst concentration

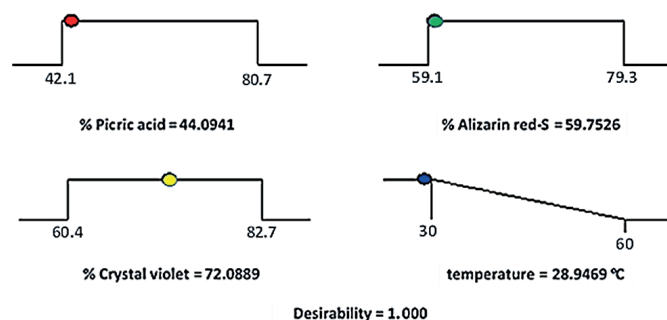


Figure 11: Comparison of percent dye degradation at temperature of 28.9 °C

This result is consistent with the explanation given by Mozia, Morawski, Toyoda, & Inagaki⁴⁴ which states that either the product's desorption or the dye substrate's adsorption affects the photocatalytic degradation of a dye. The percentage of degradation increases overall at 28.9 °C due to a considerable enhancement in the limiting reaction, or the adsorption of the CV dye substrate.

Reactivity between CV and PA dyes is reliably shown by ARS over a range of process conditions. The optimal responses and successful degradation of all dyes under the given conditions are

indicated by the desirability value of 1.000. This optimization highlights the effectiveness of the photocatalytic degradation process for triphenylmethane, anthraquinone, and nitro dyes at the given temperature, emphasizing the importance of temperature control in achieving optimal degradation outcomes.

CONCLUSION

Increasing global demand for clean water is imperative for the survival of both humans and animals. However, human activities such as dyeing contribute to water pollution, necessitating research on wastewater degradation to mitigate environmental impact. Titania photocatalyst, widely acknowledged in literature, shows promise for effective degradation. The extent of degradation observed in this study relies on the reactivity of specific dyes towards titania under various process conditions. The following results were obtained from a comparison of the reactivities of Picric Acid (PA), Alizarin Red-S (ARS), and Crystal Violet (CV) dyes at ideal process parameters: TiO₂ photocatalyst effectively degraded the chromophoric groups of CV, ARS, and PA dyes under optimized process parameters.

1. Process parameters were fine-tuned at pH 6.99, 7.5 ppm dye concentration, 0.15 g/l catalyst concentration, and 28.9 °C using response surface methodology, achieving a desirability of 1.000.
2. Maximum degradation levels were attained at 72%, 59%, and 44% for CV, ARS, and PA dyes, respectively, at a low temperature.
3. The reactivity order of the selected dyes is CV > ARS > PA.

This study predicts the potential of titania photocatalyst in degradation of various dye wastewater composition and highlights the significance of optimizing process parameters to enhance degradation efficacy.

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