

SUPPLEMENTARY MATERIAL

1. Calibration curves of RB and CV at 540 nm

Preparation of standard dye solutions

Stock solutions of RB and CV were prepared in DW. A series of standard solutions with concentrations of 0, 0.0025, 0.005, 0.01, 0.02, and 0.04 mM were obtained by successive dilution of the stock solutions. All solutions were freshly prepared prior to analysis.

UV–Vis absorbance measurements

UV–Vis absorbance measurements were performed using a microplate reader equipped with a 540 nm optical filter. DW was used as the blank, and its absorbance value was subtracted from all measurements. The wavelength of 540 nm was selected as a representative analytical wavelength for quantitative analysis of both dyes, as it provided stable absorbance responses within the linear range for RB and CV under the experimental conditions.

Calibration curves

Calibration curves were constructed by plotting the mean absorbance values against the corresponding dye concentrations. Linear regression analysis was performed using the least-squares method. The resulting calibration equations were:

- Rhodamine B (RB): $y=24.295x+0.0305$ ($R^2=0.998$),
- Crystal Violet (CV): $y=16.327x+0.0266$ ($R^2=0.9964$),

where y represents the absorbance at 540 nm and x is the dye concentration (mM). The excellent linearity observed confirms the suitability of the selected concentration range for quantitative analysis.

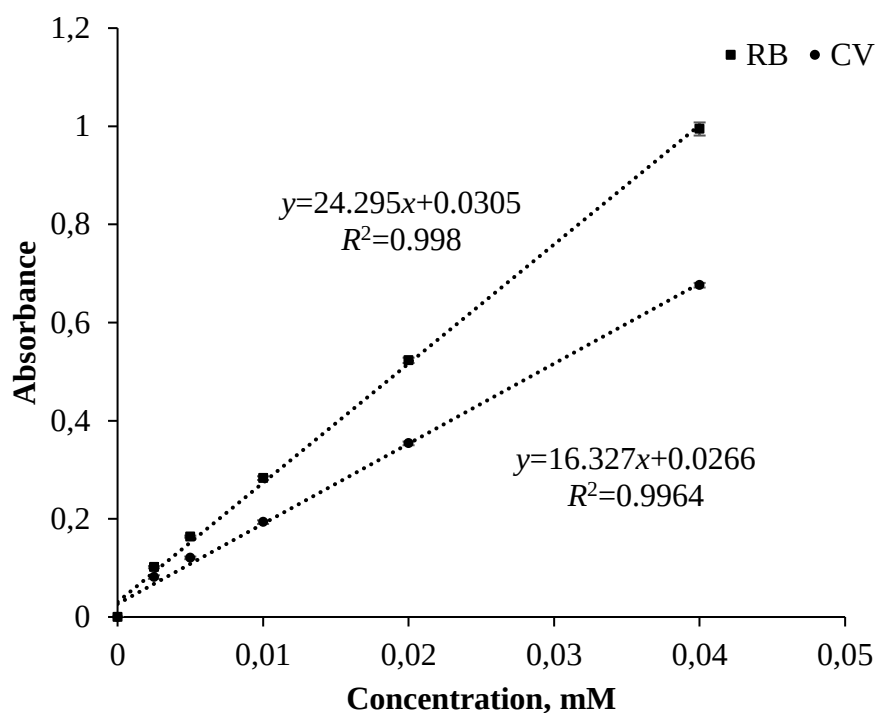


Figure S1. Calibration curves of Rhodamine B (RB) and Crystal Violet (CV) obtained from absorbance measurements at 540 nm. Standard dye solutions in the concentration range of 0–0.04 mM were analyzed in quadruplicate ($n=4$), and the mean absorbance values were used for linear regression analysis. The calibration curves exhibited excellent linearity with correlation coefficients of $R^2=0.998$ for RB and $R^2=0.9964$ for CV.

2. TEM and HRTEM Analysis

Transmission electron microscopy (TEM) and high-resolution TEM (HRTEM) analyses were performed to examine the morphology and crystallinity of TiO_2 nanoparticles. Samples were prepared by dispersing the nanoparticles in ethanol, followed by ultrasonic treatment and drop-casting onto carbon-coated copper grids. TEM, HRTEM, and selected area electron diffraction (SAED) images were acquired using a Hitachi H-9500 transmission electron microscope (Hitachi, Tokyo, Japan). Lattice fringe features were qualitatively analyzed from

HRTEM images to confirm the crystalline nature of the nanoparticles.

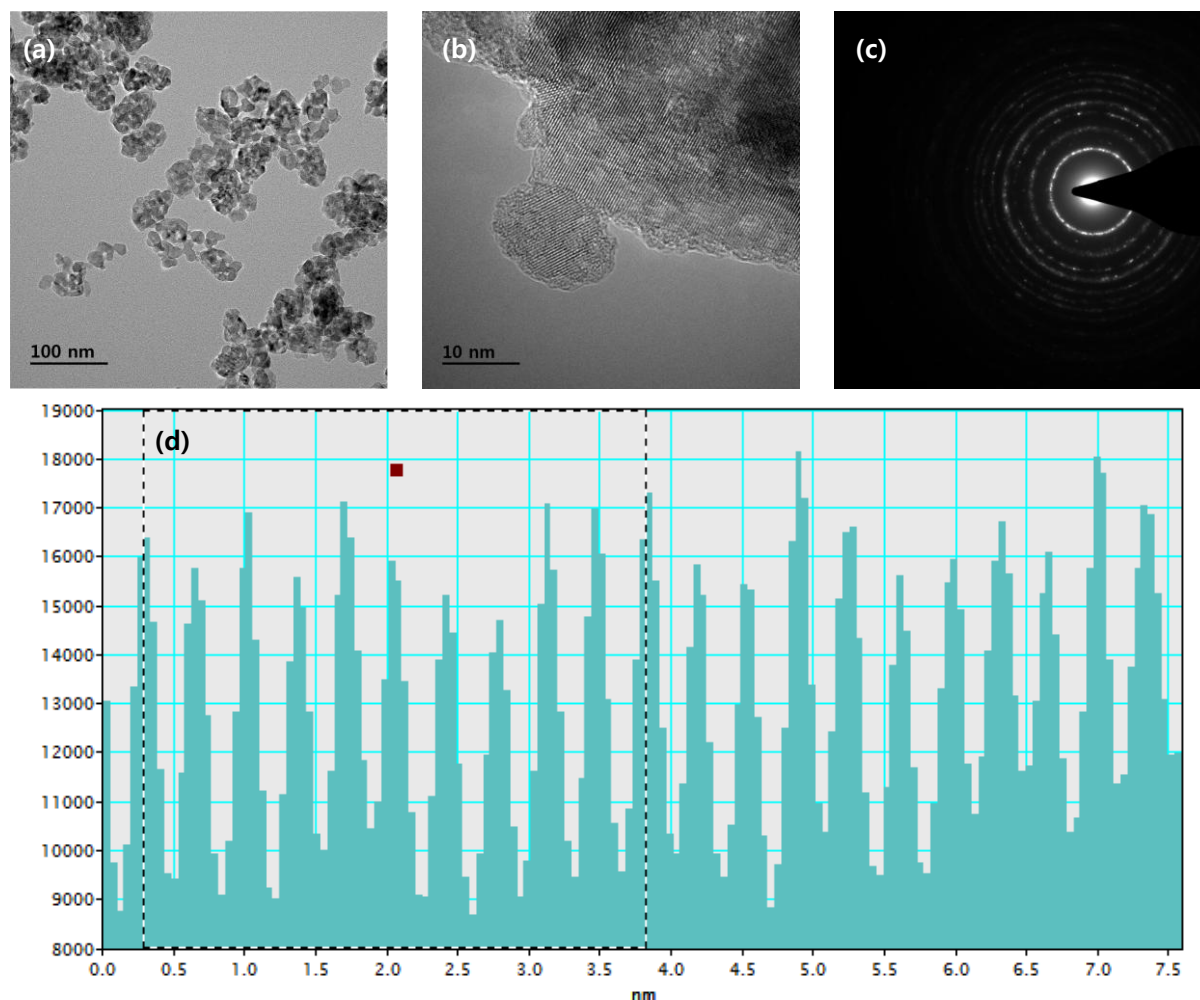


Figure S2. Transmission electron microscopy (TEM) and high-resolution TEM (HRTEM) characterization of TiO₂ nanoparticles. (a) Low-magnification TEM image showing aggregated TiO₂ nanoparticles with nanoscale dimensions. (b) HRTEM image revealing lattice fringes within individual TiO₂ nanoparticles. (c) Selected area electron diffraction (SAED) pattern exhibiting concentric diffraction rings characteristic of polycrystalline TiO₂. (d) Representative intensity profile extracted from the HRTEM image, illustrating periodic lattice fringe features. These data qualitatively confirm the nanoscale morphology and crystalline nature of the TiO₂ nanoparticles used in this study.

3. Kinetic modeling of dye adsorption

The adsorption kinetics of RB and CV on TAT were analyzed using both pseudo-first-order (PFO) and pseudo-second-order (PSO) kinetic models. Time-dependent adsorption data (q_t versus t) were obtained at an initial dye concentration of 50 mg L⁻¹, pH 7.0, and room temperature. Based on the adsorption profiles (Fig. 3), equilibrium was reached within 5 min; therefore, only experimental data collected before equilibrium ($t \leq 5$ min) were used for kinetic fitting to avoid mathematical bias associated with inclusion of equilibrium points.

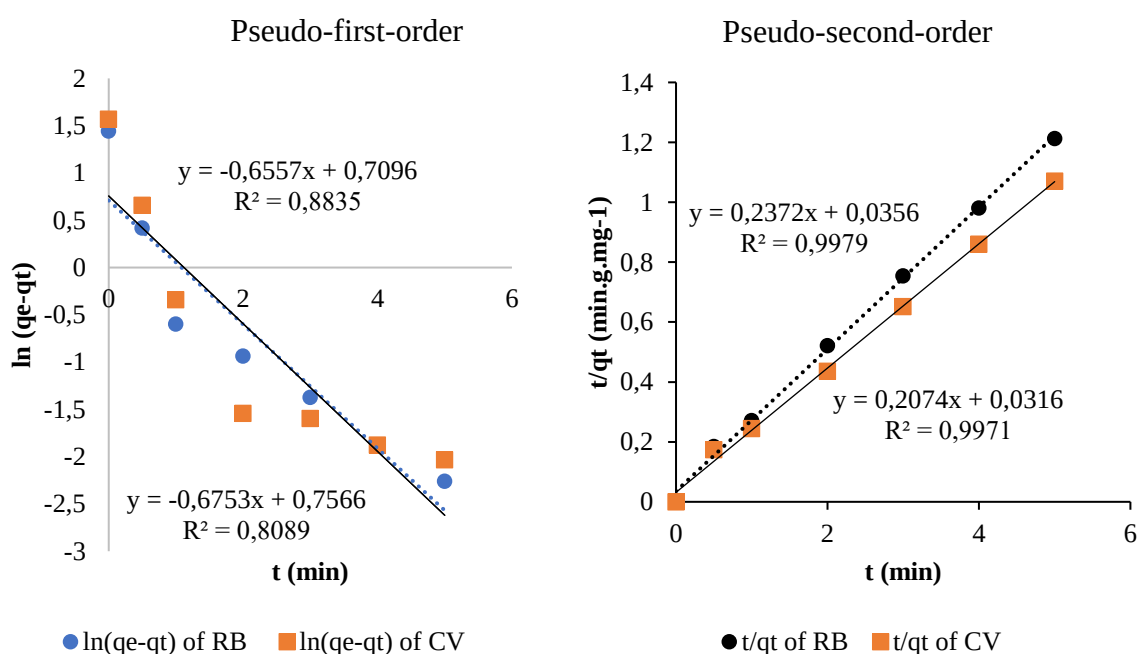


Figure S3. Pseudo-first-order (PFO) and pseudo-second-order (PSO) kinetic model fittings for the adsorption of Rhodamine B (RB) and Crystal Violet (CV) on TAT. Experimental data (symbols) and model fits (solid lines) were obtained using non-linear regression of adsorption data collected during the initial adsorption stage ($t \leq 5$ min), prior to equilibrium. Kinetic parameters derived from the fittings are summarized in Table 1.

4. Freundlich adsorption isotherm plotting

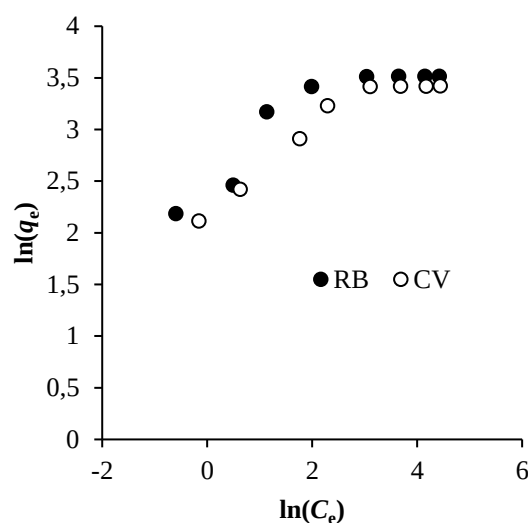


Figure S4. Freundlich isotherm plots for RB and CV adsorption on TAT. Freundlich isotherm plots for the adsorption of Rhodamine B (RB) and Crystal Violet (CV) on TAT. The experimental data exhibit noticeable deviation from linearity, indicating that the Freundlich model does not adequately describe the adsorption behavior under the studied conditions. Therefore, Freundlich fitting is provided here for completeness only and was not used for mechanistic interpretation.