

PERFORMANCE ANALYSIS OF TANNIC ACID ADSORPTION ON $\text{SiO}_2/\text{TiO}_2$ PHOTOCATALYST TO SUPPORT WATER QUALITY PRESERVATION IN AQUATIC TOURISM AREAS

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Abstract

Maintaining water quality in aquatic tourism areas, such as rivers and lakes, is vital for ensuring both the environmental sustainability and attractiveness of these destinations. Organic pollutants, such as tannic acid, pose significant challenges to water quality, potentially affecting the overall experience for visitors and the health of local ecosystems. This study investigates the application of $\text{SiO}_2/\text{TiO}_2$ photocatalysts as a solution for removing tannic acid, with adsorption playing a crucial role in the photocatalytic process. Adsorption is a key step in the mechanism that enhances the efficiency of tannic acid removal from water, making it an essential process to examine for environmental management in tourism areas. The aim of this research is to analyze the influence of various parameters, including contact time, photocatalyst dosage, tannic acid concentration, and temperature, on the adsorption performance of tannic acid on $\text{SiO}_2/\text{TiO}_2$ photocatalysts. The study is designed to optimize these variables to maximize the pollutant removal, contributing to water quality preservation in areas where aquatic tourism thrives. Adsorption measurements were carried out using a Total Organic Compound (TOC) Analyzer to determine the optimum conditions for maximum pollutant removal. The results reveal that the adsorption equilibrium was achieved after 60 minutes of contact time, with a maximum adsorption capacity of 28.042 mg/g. A photocatalyst dosage of 0.1 g/L resulted in an adsorption capacity (q_e) of 26.284 mg/g, while increasing the tannic acid concentration to 40 mg/L enhanced q_e to 67.18 mg/g. The highest adsorption capacity (q_{max}) of 105.263 mg/g was obtained at 20°C.

Keywords: Adsorption, photocatalyst, tannic acid, water

A. INTRODUCTION

The preservation of water quality in aquatic tourism areas, such as rivers, lakes, and coastal zones, is crucial for both environmental sustainability and the economic viability of these destinations (Sendra et al., 2023). These regions attract numerous visitors due to their natural beauty, recreational opportunities, and the ecosystem services they provide. However, maintaining pristine water conditions is a challenging task, especially in environments exposed to organic pollutants (Krithiga et al., 2022). One such pollutant, tannic acid, poses a significant threat to water quality. Tannic acid is a naturally occurring polyphenol found in plants, particularly in leaves, bark, and fruits, and often enters aquatic environments through runoff from vegetation or human

activities such as agriculture and industry (Baldwin & Booth, 2022). Its presence in water can result in undesirable color changes, increased chemical oxygen demand (COD), and potential toxicity to aquatic organisms, which not only harms local ecosystems but also degrades the experience for tourists (Maisuria et al., 2022). Polluted water bodies may deter visitors due to unpleasant aesthetics, foul odors, and health concerns, directly impacting tourism-related businesses and the local economy.

Contaminated aquatic environments, especially those used for recreational activities like swimming, boating, and fishing, can significantly reduce tourist comfort and satisfaction (Agustina & Aprinica, 2022). Water quality is a key factor in determining the overall appeal of a tourism destination, and the presence of visible or harmful pollutants can lead to a decline in visitor numbers. Pollutants such as tannic acid, which causes discoloration and contributes to poor water clarity, can negatively affect the visual appeal of aquatic sites. Additionally, the presence of such organic contaminants can raise concerns about the health risks associated with water-based recreational activities, further reducing tourist comfort (Yadav et al., 2021). As aquatic tourism areas rely heavily on their natural resources to attract and retain visitors, ensuring the cleanliness and safety of these water bodies is essential for maintaining their long-term attractiveness and economic sustainability.

To address these challenges, researchers have explored various methods for removing organic pollutants from water. Among these, advanced oxidation processes (AOPs) have gained significant attention due to their ability to degrade a wide range of contaminants (Giwa et al., 2021). Photocatalysis, a form of AOP, involves the use of a semiconductor material to generate reactive species that can break down pollutants upon exposure to light. Titanium dioxide (TiO_2) is one of the most extensively studied photocatalysts due to its strong oxidative power, non-toxicity, chemical stability, and relatively low cost (Prastika & Alamsah, 2022). However, TiO_2 alone has certain limitations, such as a tendency to aggregate, a limited surface area for adsorption, and reduced efficiency in the visible light spectrum (Suhan et al., 2023). To overcome these limitations and enhance its photocatalytic performance, composite materials like $\text{SiO}_2/\text{TiO}_2$ have been developed. The incorporation of silica (SiO_2) into the photocatalyst structure increases the surface area and provides more adsorption sites, which is crucial for improving the removal efficiency of organic pollutants like tannic acid (Tuama et al., 2024).

Adsorption is a critical step in the photocatalytic degradation process as it governs how well pollutants interact with the catalyst surface before degradation occurs. The efficiency of photocatalysis depends largely on the initial adsorption of pollutants, making adsorption capacity an essential factor to optimize. Previous studies have highlighted the importance of optimizing adsorption parameters, such as contact time, photocatalyst dosage, pollutant concentration, and temperature, to maximize pollutant removal rates. Although extensive research has been conducted on the adsorption of various organic pollutants, including phenolic compounds and dyes, there is a limited body of work focused on the adsorption behavior of tannic acid, particularly in aquatic environments where tourism plays a vital role.

Given the significance of maintaining high water quality in aquatic tourism areas, there is a clear need for effective and optimized methods to remove organic pollutants like tannic acid. This study aims to investigate the performance of $\text{SiO}_2/\text{TiO}_2$ photocatalysts in the adsorption of tannic acid from water, focusing on how different parameters—such as contact time, photocatalyst dosage, tannic acid concentration, and temperature—affect adsorption capacity. By examining

these factors, the research seeks to provide a comprehensive understanding of the adsorption process and its potential to improve water quality in environments crucial for tourism.

Previous research has shown that the adsorption capacity of photocatalysts is influenced by surface properties, pollutant characteristics, and operating conditions. For instance, increasing the photocatalyst dosage and contact time generally enhances adsorption capacity, though a saturation point may be reached beyond which no further adsorption occurs. Pollutant concentration also plays a dual role: higher concentrations can drive greater adsorption initially but may also lead to surface saturation. Temperature is another key variable, influencing both adsorption kinetics and equilibrium. Lower temperatures are often favorable for adsorption due to reduced desorption rates, whereas higher temperatures may accelerate the photocatalytic degradation process. Despite these insights, further investigation is needed to understand how these parameters interact in the context of tannic acid removal in aquatic tourism areas, where water temperatures are often elevated due to geographical and seasonal factors.

The primary objective of this research is to analyze the adsorption performance of $\text{SiO}_2/\text{TiO}_2$ photocatalysts for tannic acid removal from water. By optimizing the variables of contact time, photocatalyst dosage, tannic acid concentration, and temperature, this study aims to provide insights into enhancing pollutant removal efficiency. The findings are expected to contribute to more effective water management practices, supporting the preservation of water quality in aquatic tourism areas and improving the overall experience and comfort of tourists visiting these destinations.

B. RESEARCH METHOD

This research was conducted at the Chemical Engineering Operations Laboratory, University of Jember. The research activities started in April 2024 and ended in September 2024. The tools used in this research include a 50 mL Erlenmeyer flask, hot plate and magnetic stirrer, thermometer, sample collector, analytical balances, watch glass dish, laboratory spatula, spray bottle, volumetric pipette, stopwatch, clamps, and stands. The materials used in the experiment include tannic acid, $\text{SiO}_2/\text{TiO}_2$ nanocomposite photocatalyst, distilled water, ice cubes, aluminum foil, and oil paper. The research conducted at the Chemical Engineering Operations Laboratory includes the following variables:

- a. Independent variables: contact time effect (0, 10, 20, 30, 40, 50, 60 minutes), photocatalyst dosage effect (0.1, 0.2, 0.4, 0.6 g/L), tannic acid concentration effect (5, 10, 20, 40 mg/L), and temperature effect (20, 30, 40, 50 °C).
- b. Controlled variables: stirring speed (230 rpm), tannic acid concentration (5 mg/L), and distilled water volume (50 mL).
- c. Dependent variable: tannic acid adsorption percentage.

The general procedure for this experiment involves weighing the tannic acid and $\text{SiO}_2/\text{TiO}_2$ nanocomposite photocatalyst, adding the nanocomposite photocatalyst, tannic acid, and distilled water into a 50 mL Erlenmeyer flask, and then stirring the mixture using a hot plate and magnetic stirrer. Samples of approximately 2 mL will be taken using a volumetric pipette at each interval of the independent variables. The collected samples are stored in a sample collector, covered with aluminum foil, and the percentage of tannic acid adsorption is measured using a TOC (Total Organic Compound) Analyzer to determine the tannic acid quantity. After collecting the data, an analysis will be conducted to determine the effects of contact time, photocatalyst dosage, tannic acid concentration, and temperature on the adsorption of tannic acid on the $\text{SiO}_2/\text{TiO}_2$ photocatalyst.

C. FINDINGS AND DISCUSSION

Photocatalytic Activity

The photocatalytic performance for the degradation of tannic acid was evaluated using a reactor equipped with a UV lamp as a light source. A total of 0.01 g of SiO₂/TiO₂ nanocomposite was added to 100 mL of tannic acid solution. Before irradiation with 365 nm UV light from a 500 W Xenon lamp, the mixture was stirred for 1 hour to achieve adsorption-desorption equilibrium. A 2 mL sample of the solution was taken to determine the organic carbon concentration using a TOC analyzer. Based on Figure 1, the highest removal efficiency was observed at 1 wt% Si/TiO₂.

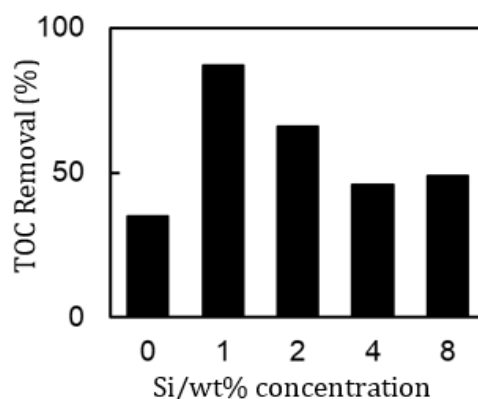


Figure 1. TOC Removal Efficiency of Tannic Acid for TiO₂ and SiO₂/TiO₂ Samples

To understand the role of adsorption in the overall photocatalytic reaction, the photocatalyst's performance was then determined as a function of temperature. Other photocatalysis parameters, such as light intensity, contact time, photocatalyst dosage, and tannic acid dosage, were normalized (set as controlled variables). Since the photocatalytic reaction is not affected by heat from the reaction system, the difference in overall photocatalytic performance with changes in temperature will only be due to the difference in the extent of tannic acid adsorption. As shown in Figure 2, an increase in the reaction system temperature decreases the photocatalytic performance. This clearly indicates that the decline in photocatalytic performance is caused by the reduced ability of the photocatalyst to adsorb tannic acid, which suggests that adsorption plays a significant role in determining the overall efficiency of the photocatalytic process.

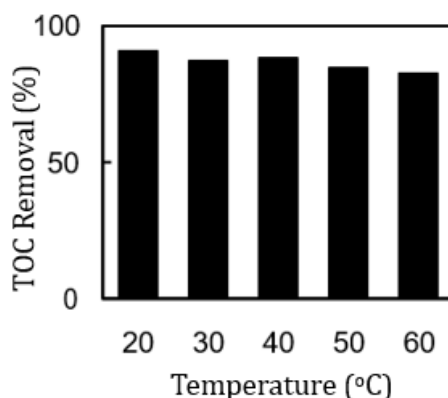


Figure 2. TOC Removal of Tannic Acid Based on Temperature Variations

Tannic Acid Adsorption by SiO₂/TiO₂ Photocatalyst

• Effect of Contact Time

Table 1. Adsorption Amount Effect of Contact Time

Contact time effect	
t (min)	qt (mg/g)
0	0
10	14.333
20	19.546
30	24.61
40	27.467
50	27.612
60	28.042

Contact time is one of the factors that can influence the adsorption process. The longer the contact time between the adsorbent and the adsorbate, the better the adsorption and diffusion processes take place until equilibrium (saturation) is reached. The purpose of determining the effect of contact time is to identify the maximum or equilibrium diffusion time of SiO₂/TiO₂ photocatalyst within tannic acid particles. In this study, the optimal time was determined based on the amount of adsorbed substance, with contact time variations of 10, 20, 30, 40, 50, and 60 minutes. The SiO₂/TiO₂ photocatalyst dosage was set at 0.1 g/L and the tannic acid concentration at 5 mg. The trend in the graph of contact time's effect on the amount of adsorbed tannic acid is shown in Figure 3. The tannic acid adsorption process on SiO₂/TiO₂ photocatalyst increased with prolonged contact time. This occurs because, at the beginning of the adsorption process, the adsorbent surface has fewer interactions with the adsorbate molecules, making the adsorption process less effective. As the contact time increases, more tannic acid molecules occupy the active sites of the SiO₂/TiO₂ photocatalyst, resulting in a higher amount of adsorbed substance. The maximum adsorption equilibrium was reached at 60 minutes, with an adsorption amount of 28.042 mg/g. Increasing the contact time beyond the optimal point may cause some of the adsorbed molecules to desorb due to prolonged contact time.

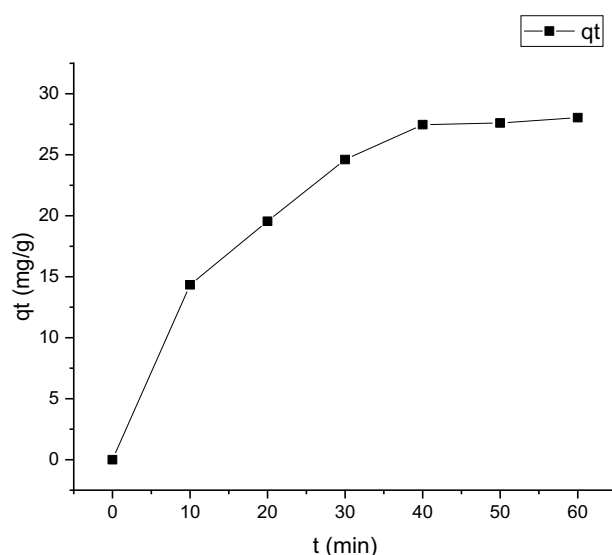


Figure 3. Graph Trend of the Effect of Contact Time on Tannic Acid Adsorption by SiO₂/TiO₂ Photocatalyst

- **Effect of Photocatalyst Dosage and Tannic Acid Concentration**

Table 2. Adsorption Amount of Photocatalyst Dosage Effect	
Photocatalyst dosage effect	
w (g/L)	qe (mg/g)
0,1	26.284
0,2	23.653
0,4	21.505
0,6	14.83

Based on Table 2 and Figure 4, it was found that the amount of q_e decreases as the photocatalyst concentration increases. This indicates that the adsorption rate of tannic acid on the active sites of the photocatalyst decreases. This is due to the decreasing number of available empty active sites on the $\text{SiO}_2/\text{TiO}_2$ photocatalyst. Additionally, the higher concentration of the $\text{SiO}_2/\text{TiO}_2$ photocatalyst increases the potential for agglomeration between photocatalyst particles, which reduces the surface area available for contact, as indicated by the decrease in the adsorption capacity of tannic acid.

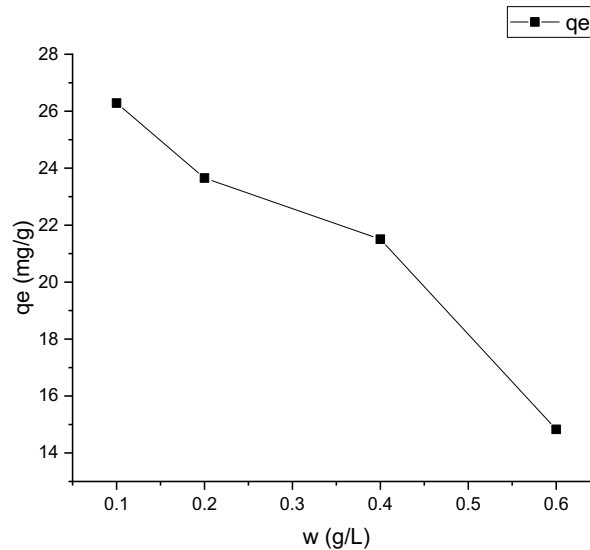


Figure 4. Adsorption Trend Graph of Photocatalyst Dosage Effect

Based on Table 3 and Figure 5, it can be observed that as the initial concentration of tannic acid increases, the adsorption capacity of tannic acid at equilibrium also increases, indicating a directly proportional relationship between the initial concentration and the adsorption capacity. This trend suggests that higher concentrations of tannic acid provide more molecules that are available to interact with and be adsorbed onto the active sites of the $\text{SiO}_2/\text{TiO}_2$ photocatalyst. The increase in adsorption capacity can be attributed to the fact that at higher concentrations, the driving force for mass transfer is greater, leading to more efficient adsorption of tannic acid molecules onto the surface of the photocatalyst.

Table 3. Adsorption Amount of Tannic Acid Concentration Effect	
Effect of tannic acid concentration	
C (mg/L)	qe (mg/g)
5	25.014
10	43.17
20	65.55
40	67.18

Furthermore, the abundance of available tannic acid molecules ensures that a larger number of active sites on the photocatalyst are occupied until saturation is reached. This phenomenon highlights the importance of the availability of active sites and the role of concentration gradients in facilitating the adsorption process. Such findings are crucial for optimizing the use of SiO₂/TiO₂ photocatalysts in water treatment applications, where pollutant concentration plays a key role in determining the efficiency of adsorption and degradation processes.

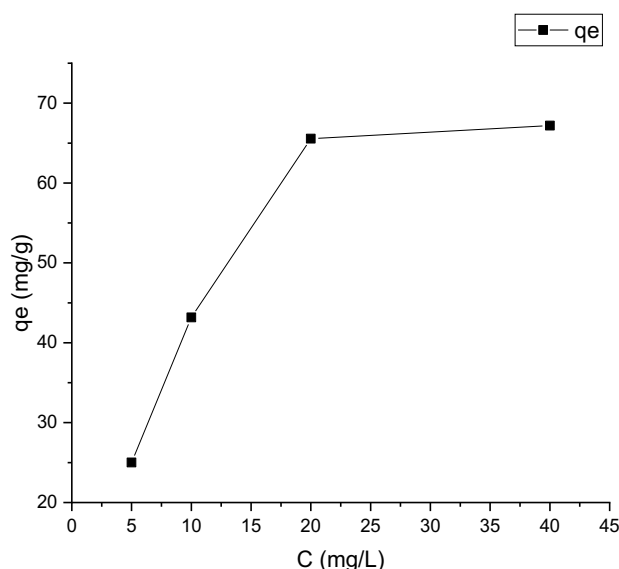


Figure 5. Adsorption Trend Graph of Tannic Acid Concentration Effect

- **Effect of Temperature**

Tabel 4. Adsorption Amount of Temperature Effect	
Effect of temperature	
T (°C)	qmax (mg/g)
20	105.263
30	86.206
40	81.967

Based on the data in Table 4 and Figure 6, it is shown that as the adsorption temperature increases, the maximum adsorption capacity of tannic acid decreases, indicating an inverse relationship between temperature and maximum adsorption capacity. This observed trend suggests that the adsorption process is thermodynamically controlled and is exothermic in nature. As temperature increases, the kinetic energy of the tannic acid molecules also increases, which leads to a reduction in the rate of adsorption onto the adsorbent surface. In exothermic processes, heat is released during adsorption, and higher temperatures supply additional energy that disrupts

the adsorption equilibrium, reducing the ability of tannic acid to bind to the active sites of the SiO₂/TiO₂ photocatalyst.

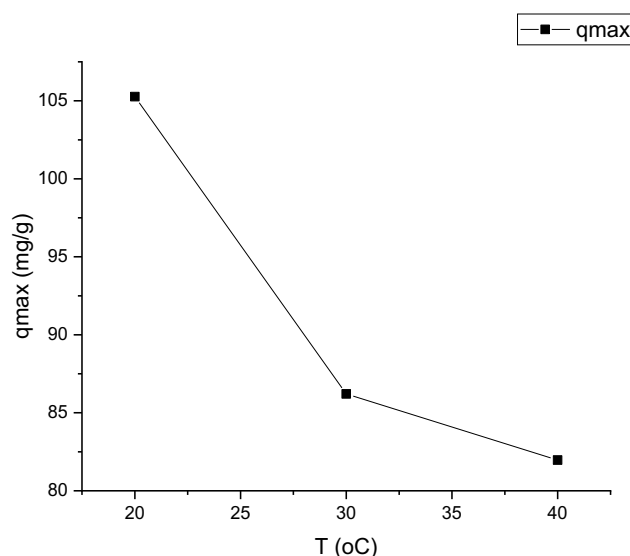


Figure 6. Adsorption Trend Graph of Temperature Effect

Moreover, the decrease in maximum adsorption capacity with increasing temperature can be attributed to the enhanced solubility of tannic acid at higher temperatures. When tannic acid dissolves more readily in the solvent (water), it becomes less likely to interact with the adsorbent surface, as the solute molecules are more dispersed in the solution. This makes it harder for the tannic acid molecules to come into close contact with the active sites on the SiO₂/TiO₂ photocatalyst, leading to a lower adsorption efficiency. The reduction in adsorption capacity at higher temperatures also indicates that the adsorption is largely driven by weak intermolecular forces, such as van der Waals interactions and hydrogen bonding, which are more effective at lower temperatures. These findings suggest that controlling the temperature is crucial to optimizing the adsorption process, especially in applications where maintaining high adsorption capacity is necessary, such as in wastewater treatment or other environmental remediation processes.

D. CONCLUSION

Based on the research findings, it is evident that the adsorption of tannic acid onto the SiO₂/TiO₂ photocatalyst is significantly influenced by factors such as contact time, photocatalyst dosage, tannic acid concentration, and temperature. The study successfully determined the optimal conditions for maximum adsorption capacity, with the equilibrium achieved after 60 minutes, a dosage of 0.1 g/L, and an initial tannic acid concentration of 40 mg/L. Lower temperatures were found to enhance the adsorption process, with the highest adsorption capacity observed at 20°C. These results align with the objective of optimizing pollutant removal in aquatic tourism areas, highlighting the potential of SiO₂/TiO₂ photocatalysts for environmental management in water bodies. This research contributes to the understanding of adsorption as a crucial step in photocatalytic degradation, emphasizing its role in maintaining water quality in tourist destinations. Future research could focus on expanding the application of SiO₂/TiO₂ photocatalysts in real-world aquatic environments, exploring the long-term effects of varying environmental factors such as pH and dissolved organic matter. Additionally, studies are underway to investigate

the potential use of this photocatalyst in combination with other advanced oxidation processes to further enhance water treatment efficiency.

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