DEVOTION
Journal of Research and Community Service
Volume 6, Number 11, November 2025
e-ISSN: 2797-6068 and p-ISSN: 2777-0915

Immobilization of TiO_2 / Bentonite Photocatalyst on Glass Plate For Photodegradation of Methyl Green Dye

Sheilatina*, Misbahani, Surya Lubis, Ilham Maulana, Elly Sufriadi
Universitas Syiah Kuala, Indonesia
Email: sheilatina@usk.ac.id*, misbahani@usk.ac.id, suryalubis@usk.ac.id, ilhammaulana@usk.ac.id, ellysufriadi@usk.ac.id

KEYWORDS
Bentonit, Fotokatalis, Immobilisasi, Methyl green, TiO_2

ABSTRACT
Textile industry waste containing synthetic dyes poses significant environmental challenges due to their toxic, mutagenic and carcinogenic properties. Methyl green (MG), a cationic dye widely used in the textile industry, requires effective degradation methods to reduce its environmental impact. This study presents a new approach using a TiO_2/Bentonite composite photocatalyst immobilized on glass plates through the brush-coating method with double-sided adhesive tape (DSAT) as the adhesive medium. This study aims to immobilize TiO_2/Bentonite composites on glass plates using double-sided adhesive tape (DSAT) with the brush coating method to improve the separation and reusability of photocatalysts. Photocatalytic activity is tested against degradation of MG under fluorescent light by varying the photocatalyst mass, pH, and concentration of MG. The results showed that the optimum conditions were achieved at a mass of 60 mg, pH 3, and an MG concentration of 15 mg/L, with a degradation rate constant (k) of 0.0542 $minutes^{-1}$ and a degradation efficiency (%R) of 98.02% in 60 minutes. This mobilized photocatalyst can be reused for up to 5 cycles with a reduction in efficiency to 90.51%. The implication of this study is the availability of a photocatalyst system that is stable, easy to separate, and can be reused, so that it has the potential to be applied in the treatment of dye waste in a sustainable manner.

INTRODUCTION

The industry in Indonesia and worldwide is growing rapidly, one of which is the textile industry. In the textile industry, dyes are materials widely used in the dyeing process of textile materials. Data from the Central Statistics Agency (BPS) shows that textile production increased by 13.74% from 2021 to 2022. This increase results in higher dye waste in the liquid effluents of the textile industry. Generally, the dyes used in the textile industry are synthetic dyes because synthetic dyes have advantages such as a variety of colors, guaranteed availability, brightness, resistance to fading, and affordability. However, synthetic dyes contain substances that are difficult to dissolve or decompose (Slama et al., 2021). The dyes in the waste can cause adverse effects on the environment, such as allergies and hypersensitivity in humans, and damage aquatic ecosystems due to their toxic, mutagenic, and carcinogenic properties. Therefore, it is very important to properly decompose or treat dye-containing waste (Angelova et al., 2016).

The method widely used in several studies to treat dye waste in the textile industry is the biological method, using microbes. However, most of these dyes have large molecular sizes with stable aromatic structures, making them difficult to decompose biologically. Other methods include chemical methods such as oxidation, ozonation, and photochemistry, as well

as physical methods like ion exchange, membrane filtration, and ultrafiltration. However, these methods have disadvantages, such as the formation of harmful by-products, high operational costs, and secondary environmental pollution (Katheresan, 2018). Therefore, a more effective method to treat dye waste is needed, namely the *photocatalysis* method. In addition to low operational costs, photocatalysis can decompose contaminants and convert waste into environmentally friendly end products such as mineral salts, carbon dioxide, and water (Coromelci, 2022).

Photocatalysis is a chemical method that uses a semiconductor as a catalyst and light as an energy source to activate the catalyst. This method employs semiconductors that degrade toxic organic compounds and disinfect bacteria by producing hydroxyl radicals ($\cdot OH$), which are powerful oxidizers. The hydroxyl radicals react with pollutants, breaking them down into simpler, harmless compounds, resulting in clarified water due to dye degradation. One commonly used semiconductor in photocatalysis is titanium dioxide (TiO2) (Miyake et al., 2015).

Titanium dioxide (TiO2) is widely used in photocatalysis because it has good electronic properties, a relatively high band gap of 3.2 eV, low toxicity, and high photocatalytic activity and thermal stability (Cao et al., 2017; Liŭ et al., 2016). However, TiO2 has low adsorption capacity for pollutants, so it requires an adsorbent to bring the pollutants closer to the photocatalyst surface, enhancing its photocatalytic activity. Common adsorbents used to increase photocatalyst activity include activated carbon, chitosan, and bentonite. Several studies have combined bentonite as an adsorbent with TiO2 semiconductors (Aji et al., 2016).

Bentonite is a natural mineral often used as a photocatalyst carrier because it has pores that absorb pollutants such as dyes. Bentonite has swelling properties, meaning it can expand and enlarge its pores, thus increasing the active surface area and adsorption capacity (Nisa et al., 2018). Lubis et al. (2018) prepared and characterized TiO2/Bentonite composites to degrade blue black naphthol dye, achieving a maximum degradation of 99.83% after 120 minutes of UV light radiation and 90 minutes of sunlight. Sari et al. (2021) synthesized TiO2/Bentonite alginate granule composites by impregnation to degrade methylene blue dye, reaching 82.33% maximum degradation after 100 minutes irradiation. These studies show that TiO2 combined with bentonite carriers results in better dye degradation than TiO2 alone. However, both use powder-form photocatalysts that are difficult to separate from pollutants, which makes the separation process time-consuming and costly, limiting reusability.

Meanwhile, Ismail et al. (2015) studied immobilization of TiO2/DSAT photocatalysts for photodegradation of anionic (reactive red 4) and cationic (methylene blue) dyes, finding the photocatalyst reusable for up to 30 cycles. Thus, immobilization of photocatalysts on glass plates using double-sided adhesive tape (DSAT) is promising to strengthen TiO2 adhesion to glass and increase photocatalyst reusability through multiple degradation cycles.

In this study, the manufacture of *TiO2/Bentonite* photocatalysts immobilized on glass plates coated with DSAT will be conducted using the Brush-Coating method. Degussa P25 type titanium dioxide will be used because it contains nanoparticles and a mixture of rutile and anatase crystals, making it ideal for photocatalysis. The *TiO2/Bentonite* composite materials will be characterized using SEM-EDX (Scanning Electron Microscopy-Energy Dispersive X-Ray) and XRD (X-Ray Diffraction). The photocatalytic activity will be tested by degrading *Methyl green (MG)* dye, a cationic dye, using visible light radiation from fluorescence lamps. MG dye (Figure 1) is widely used in the textile industry, leading to high dye concentrations in liquid waste that pollute aquatic environments. This study aims to improve photocatalyst reusability by immobilizing *TiO2/Bentonite* on glass plates. The influence of photocatalyst mass, dye concentration, and pH on the reaction kinetics will also be observed.

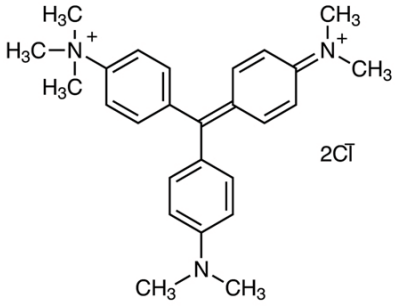

Figure 1. Structure Methyl green

Synthetic dye waste from the textile industry, especially *methyl green* (MG), which is carcinogenic, is an urgent environmental problem to be addressed. Conventional methods such as biological, physical, and chemical treatments often have limitations, including the formation of harmful byproducts, high operational costs, and inefficiencies in degrading dyes with complex structures (Katheresan et al., 2018). Alternatively, heterogeneous photocatalysis using titanium dioxide (TiO_2) has been widely studied for its ability to decompose pollutants into harmless compounds (Coromelci, 2022). However, the application of TiO_2 in powder form faces significant constraints during separation and reuse, which increases the cost and processing time. Some studies have attempted to address this by supporting TiO_2 on porous materials such as bentonite to enhance its adsorption capacity, such as those conducted by Lubis et al. (2018) and Sari et al. (2021), which successfully degraded Naphthol Blue Black and Methylene Blue, respectively. Although effective, this powder-shaped system still presents the problem of post-reaction separation.

Based on this gap, the catalytic *immobilization* strategy is a promising solution. Ismail et al. (2015) demonstrated the advantages of the TiO_2/DSAT (Double-Sided Adhesive Tape) immobilization system on glass plates, which can withstand up to 30 cycles of use for the degradation of various dyestuffs. Adopting this concept, this study introduced a novelty by developing a *TiO_2/Bentonite* composite immobilized on a glass plate using a DSAT adhesive. This approach combines the high adsorption advantages of bentonite, which naturally has an affinity for cationic dyes such as MG, with the photocatalytic activity of TiO_2 and ease of separation from the reaction system. Thus, this study not only aims to test the photocatalytic performance of immobilized *TiO_2/Bentonite* composites in degrading MG but also to evaluate their stability and reusability through multiple use cycles, a critical aspect for sustainable applications.

Specifically, this study aims to fabricate a photocatalyst of immobilized *TiO_2/Bentonite* on glass plates, characterize it using XRD and SEM, and test its photodegradation activity against MG under fluorescent lamp radiation by varying catalyst mass, pH, and dye concentration. Ultimately, this research is expected to provide photocatalyst material solutions that are effective, efficient, easy to separate, and reusable, thereby contributing to the development of more practical and sustainable waste treatment technology and reducing the environmental pollution impact from the textile industry.

RESEARCH METHOD

This study used an experimental laboratory design conducted in the Chemistry Laboratory, utilizing a controlled setting to ensure reproducibility and minimize experimental errors. All trials were conducted in triplicate (n = 3) to validate the consistency and reliability of the results. The experimental approach followed a systematic factorial design, in which the main operational parameters (photocatalyst mass, pH, and dye concentration) were varied

independently while maintaining other conditions constant. This methodological framework allowed isolation of the effects of individual parameters on photocatalytic performance and facilitated the identification of optimal degradation conditions. The temperature and intensity of light were maintained constant throughout the experiment to eliminate interfering variables. The experimental workflow included five main phases: (1) preparation and characterization of bentonite, (2) synthesis of TiO_2/Bentonite composites, (3) immobilization of photocatalysts on glass plates, (4) evaluation of photocatalytic activity under various conditions, and (5) reuse assessment through multiple degradation cycles.

The tools used in this study were a magnetic stirrer, analytical balance, oven, 100 mesh sieve, glassware, centrifuge, UV-Vis spectrophotometer, fluorescence lamp (PHILIPS), sonicator (VC X 500), glass plates, glass cells, aeration pump (Concord 9900 model), double-sided adhesive tape (DSAT), pH meter, and petri dish. Composite characterization was performed using SEM-EDX (scanning electron microscopy–energy dispersive X-ray) and XRD (X-ray diffraction).

The materials used in this study included aquaades, TiO_2 Degussa P25 (Sigma Aldrich), MG dye ($C_{26}H_{33}Cl_2N_3$) (Merck), and bentonite taken from the Nisam area, North Aceh.

Characterization of the synthesized TiO_2/Bentonite photocatalyst was carried out using X-ray diffraction (XRD) and scanning electron microscopy (SEM) on cross sections. XRD characterization aimed to determine the compounds present in bentonite and TiO_2/Bentonite composites, while SEM characterization on cross sections aimed to observe the surface morphology of the TiO_2/Bentonite photocatalysts.

The preparation of fresh bentonite was carried out in accordance with the procedure previously conducted by Lubis et al. (2019). The TiO_2/Bentonite composite was prepared by mixing 4 g of titanium dioxide (TiO_2) powder of Degussa P25 with 1 g of bentonite in 50 mL of aquaades. The solution was then sonicated for 1 hour, resulting in a homogeneous mixture (Sheilatina et al., 2024).

The TiO_2/Bentonite immobilization was carried out by bonding the TiO_2/Bentonite composite to glass plates coated with double-sided adhesive tape (DSAT) using the brush-coating method with mass variations of 20, 40, 60, 80, and 100 mg. The glass plates coated with the TiO_2/Bentonite photocatalyst were then air-dried overnight (Nawawi et al., 2017).

The activity of the immobilized TiO_2/Bentonite composite photocatalyst on glass plates was tested by varying several parameters, namely the photocatalyst mass, the pH of the dye solution, and the initial dye concentration. The working mechanism of the photocatalytic activity test of TiO_2/Bentonite composites on glass plates used to degrade MG dye followed the procedure carried out by Sheilatina et al. (2024).

The activity of TiO2/Bentonite composite photocatalyst in degrading MG dyes was determined by measuring the absorbance value of MG dyes before and after radiation with fluorescence lamps at certain time intervals. The work scheme carried out refers to Sakinah et al., 2024. The percentage degradation of MG dyes was measured using the percent elimination equation (%R) (equation 1). Meanwhile, for the determination of the constant rate of removal of MG dyestuffs, the Langmuir-Hinshelwood kinetics model (equation 2) was used.

$$\%R=(Co-ct)/Co\times100\% \quad (1)$$

Information:

Co = Initial concentration of dye before radiation

Ct = Concentration of dye at time t: 0, 15, 30, 45 and 60 minutes

$$\ln(Co/C)=-kt \quad (2)$$

where Co is the initial concentration of the dye, and C is the concentration of the degraded dye at time t, whereas k is the velocity constant calculated from the slope ln(Co/C) to time t.

TiO2/Bentonite photocatalysts mobilized on glass plates were evaluated for efficiency and reuse in photocatalytic reactions on MG dyes. The surface of the glass plate is cleaned by soaking the glass plate in aqueduct and irradiated using a fluorescence lamp for 30 minutes to remove the dye residue and intermediate residue remaining on the surface of the photocatalyst. Photodegradation is carried out at the condition of the photocatalyst mass, pH and initial concentration of the optimum dye that has been obtained previously, the TiO2/Bentonite photocatalyst on the glass plate is used repeatedly until the photocatalyst activity decreases or is no longer able to degrade, each application is carried out for 60 minutes.

RESULTS AND DISCUSSION

The results of bentonite preparation from Nisam, North Aceh, obtained fresh bentonite powder which is light brown/cream (Figure 2.a). TiO2/Bentonite composite in the form of a white paste was immobilized on a glass plate by the brush coating method and using DSAT as its adhesive (Figure 2b.). Photocatalyst immobilization is carried out to make the photocatalyst stay on the surface of a medium, namely glass, so that the photocatalyst can be used repeatedly.

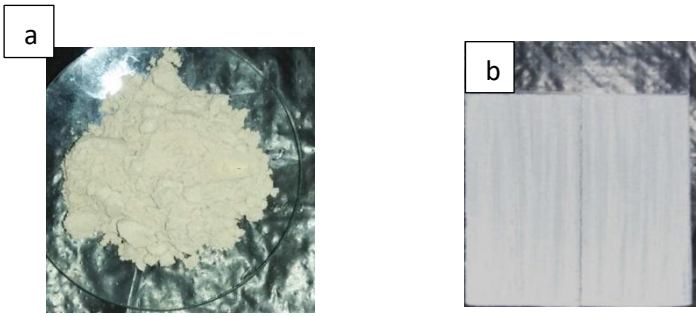

Figure 2.a) Fresh bentonite, b) TiO2/Bentonite composite that has been immobilized on glass plate

Bentonite and TiO2/Bentonite composites were then characterized with XRD instruments to determine the compounds present in the TiO2/Bentonite composite and the crystal phases formed. The results of the XRD test were then matched between the composite peaks made with the peaks contained in the database using inorganic COD 967103590. TiO2/Bentonite composites that have been immobilized on glass plates were characterized using a crosssection SEM instrument to see the morphology of the photocatalyst at several mass variations used.

Characterization of bentonite and TiO2/Bentonite composites was carried out using XRD instruments. Figure 3 shows the presence of peaks that appear at the diffraction angle of 2θ. The bentonite diffraction pattern in figure 3(a) shows peaks at an angle of 2θ of about = 20°, 35°, and 63° which are montmorillonite compounds, and at 2θ about 26° are quartz compounds, while at 2θ about 28° are compounds composed of Al, Si, and O in the form of SiO2 and Al2O3 compounds (Reza et al., 2014). The peaks of TiO2/bentonite composite diffraction are found at angles of 2θ = 25.26°, 37.82°, 48.10°, 53.98°, 55.04°, and 62.70°. The peaks correspond to the peaks on the database using inorganic COD 967103590. The results obtained are similar to those reported by Aji et al., 2016 that the diffraction pattern of TiO2 composites is shown at 2θ = 25.31, 38.85, 48.34, 53.91, and 62.72 which are characteristic of diffraction of TiO2 anatase crystals (Figure 3b). Figure 3 shows the results of X-Ray diffraction for TiO2/Bentonite, bentonite, and TiO2 degussa P25 composites.

(a) (b)

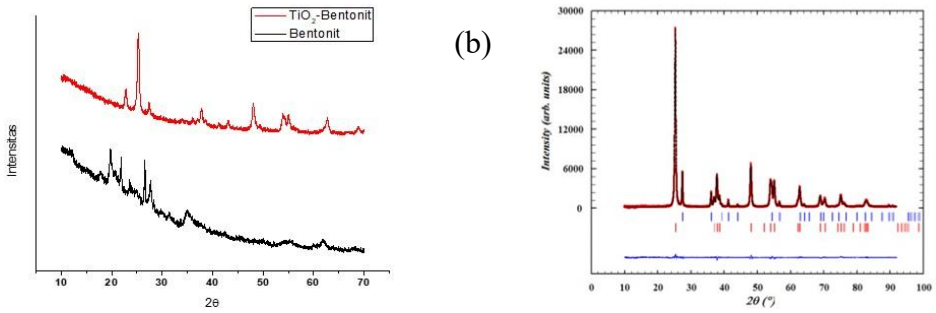

Figure 3. Diphroctograms for (a) Bentonite and TiO2/Bentonite composites, b) TiO2 degussa p25 (González et al., 2020).

Figure 3(a) shows the peaks of the XRD results for the TiO2/Bentonite composite samples, where the highest peak found in the TiO2/Bentonite composite diphroctogram is at an angle of 2θ = 25.26° indicating the presence of a large amount of TiO2 compounds. The reflection at 2θ shows that the crystal phase contained in the TiO2/Bentonite composite is the anatase crystal phase. These results show that the formation of the TiO2/Bentonite composite does not significantly change the crystallinity of TiO2, meaning that it does not significantly reduce its photocatalytic activity (Aji et al., 2016).

Immobilized TiO2/Bentonite Photocatalyst Activity Test on Glass Plate for MG Dye Degradation

The photocatalytic activity of the TiO2/Bentonite composite was tested on the degradation of MG dyes using fluorescence lamp light as a light source. The test was carried out by varying several parameters such as the mass of the photocatalyst, the pH of the dye solution and the concentration of the dye. The determination of the concentration of the dye solution after radiation was carried out using a UV-Vis spectrophotometer.

Effect of Photocatalyst Mass

The mass of the photocatalyst tested gave the highest photodegradation reaction kinetic rate for the MG dye was at 60 mg with a value of k = 0.0488 and a value of % R = 96.44 within 60 minutes of radiation under fluorescence light (Figure 4).

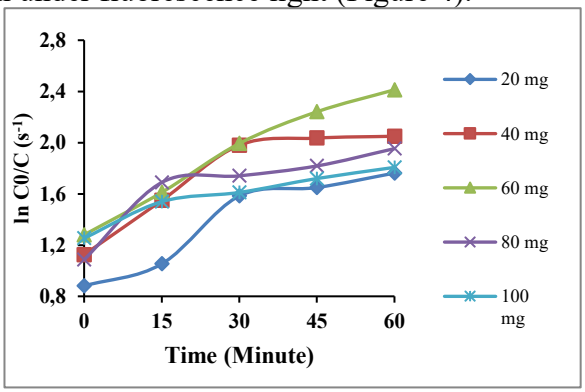

Figure 4. The kinetics of the reaction on the effect of the mass of the photocatalyst on the degradation of the pigment MG with a concentration of 15 mg/L and the initial pH (7).

Figure 4 shows the linear regression ln C0/C vs t of the photodegradation kinetics of the MG dye from the variation in the mass of the photocatalyst. The image shows that composites with masses of 20, 40, 80, and 100 are not good enough in reaction kinetics in degrading MG dyes, so from the image it can be seen that the more composites are immobilized

on the glass plate, the more the reaction kinetics rate will increase, but too much photocatalyst will also make the surface of the composite thick and flat so that it can cover the active side of the photocatalyst (Sun et al., 2015). The activity of the TiO2/Bentonite composite photocatalyst mobilized on the glass plate which is optimal to degrade the MG dye is 60 mg, this result is similar to that reported by Ariski et al., 2021 that the optimum % R value obtained is at a mass of 0.05 g, which is 96.38% in the radiation time for 60 minutes, and when the mass is increased to 0.1 g the photocatalytic activity decreases.

MG dyes have a higher value of degradation reaction kinetic activity when degraded using a photocatalyst with a mass of 60 mg, but its kinetic value decreases when the mass is added to 100 mg, because plates with a mass of 100 mg have a very thick and even (less porous) coating, so it can mask the active side of the photocatalyst and inhibit the performance of the photocatalyst. And also MG dyes have a larger molecular structure so that it will be difficult to enter the surface of the photocatalyst with a mass of 100 mg which has a thick and flat surface, so that with a photocatalyst mass of 60 mg it has achieved optimal reaction kinetics. As for the photocatalyst mass of 20 mg, it has a thinner, coarse, and uneven surface structure, so it is not good enough at degrading MG dyes due to the lack of active sides (Sun et al, 2015). These results are related to the results of the SEM crosssection test that has been performed, which shows that photocatalysts with a mass of 100 mg have a flat and thick surface (Figure 5).

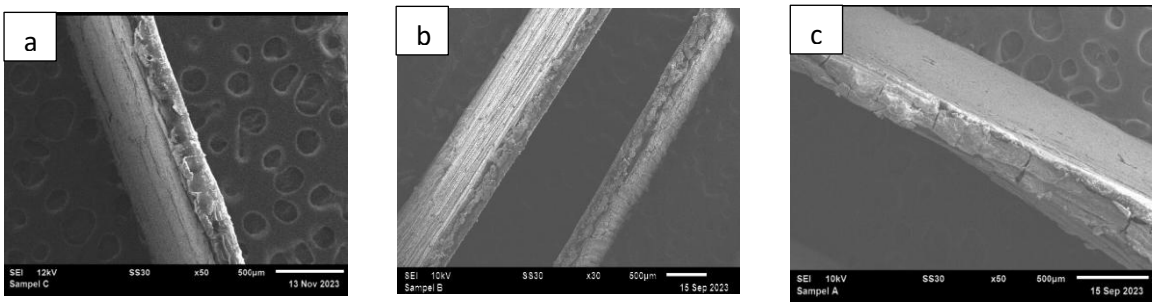

Figure 5. Transverse morphology of TiO2/Bentonite composite samples a) 20 mg, b) 60 mg, c) 100 mg

The mass of the photocatalyst affects the number of electrons, holes and other active sides that are formed, thus affecting the effectiveness of the photocatalytic reaction that occurs.

Effect of pH of MG Dye Solution

Photocatalytic activity is greatly influenced by the pH of the dye solution to be degraded. This is due to the process of adsorption of dye molecules to the surface of the photocatalyst depending on the pH conditions used. The pH of MG dye with a concentration of 15 mg/L is regulated at acidic to alkaline conditions, namely pH 3, 5,7, 9, and 11. Figure 6 shows that the highest photocatalytic activity of MG dye degradation was at an acidic pH of 3 with a value of k = 0.0542 and the % R obtained was 98.02% within 60 minutes. This is because in acidic conditions, the more H+ ions will react with O2- so that it will increase the amount of H2O2, therefore the more OH- will be formed. The amount of OH- that is formed will increase the amount of hydroxyl radicals that play a role in degrading dyes. In addition, the bentonite contained in the photocatalyst has a negatively charged surface, so it will accelerate adsorption to the cationic MG dye, making it easier for the photocatalyst to degrade the dye.

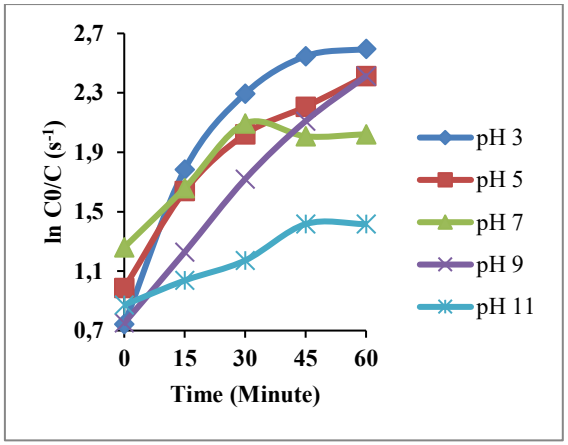

Figure 6. Reaction kinetics on the effect of pH of MG dye on photocatalyst reaction with a dye solution concentration of 15 mg/L, photocatalyst mass 60 mg

However, at the alkaline pH, the kinetics of the photocatalytic reaction tend to decrease, this is due to the alkaline state of the release of Cl- ions will be inhibited due to being replaced by OH- ions present in the solution so that the interaction of MG with the adsorbent surface becomes small (Khairil et al., 2021).

Effect of MG Dye Concentration

Another condition that affects the photocatalytic activity of composites is the concentration of degraded dye solutions. Figure 7 shows that with an increase in the concentration of MG dye, it will decrease the performance of photocatalysts, because the greater the concentration of MG dye, the more molecules there will be. The large number of molecules causes competition between molecules in dyes to be adsorbed by catalysts to be increased. In addition, a high concentration of dyes will affect the light or light that reaches the photocatalyst a little, thus minimizing the energy of photons that hit the photocatalyst and resulting in the ability of electrons to be excited to be smaller, thus producing less radical OH and a decrease in the ability to oxidize dyestuffs. The decrease in photocatalytic efficiency at low concentrations of MG dyes (5 and 10 mg/L) is due to the limited number of active sides, so not all MG molecules react with the active side of the photocatalyst. In contrast, at concentrations of 20–25 mg/L, MG molecules cover the surface of the photocatalyst and inhibit photon penetration, which has an impact on decreased photocatalytic activity (Rafiq et al., 2021). The optimum concentration of MG dye solution obtained was 15 mg/L with a k value of K = 0.0542 min-1 and % R = 98.02% within 60 minutes of irradiation with fluorescence lamps.

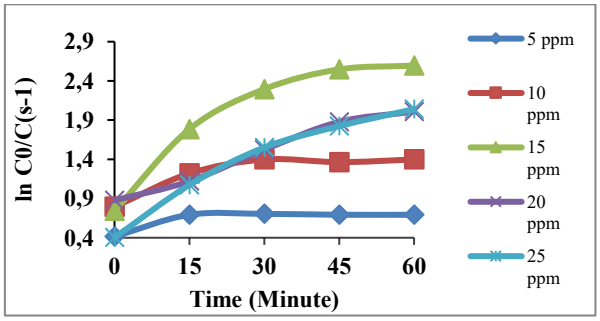

Figure 7. Reaction kinetics on the effect of MG dye concentration on photocatalyst reactions (m=60 mg; pH=3)

Photodegradation of MG Dyes Using TiO2 and Bentonite Photocatalysts

This test was conducted to see the comparison of the kinetics of the photodegradation reaction of the TiO2 catalyst, bentonite, with the TiO2/Bentonite composite against the MG dye. Photodegradation was carried out at the optimum conditions of a photocatalyst mass of 60 mg, a pH of solution of 3 and a concentration of 15 mg/L of a solution of MG dye.

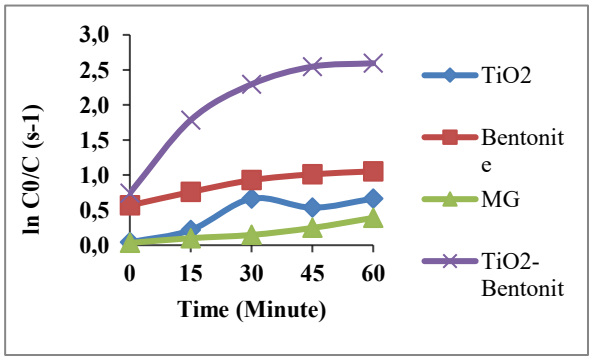

Figure 8. The kinetics of the reaction on the degradation of the MG dye using a photocatalyst of TiO2 and mobilized bentonite on a glass plate.

Based on Figure 8, the highest degradation reaction kinetics for MG dyes lie in the use of TiO2/Bentonite photocatalyst composites with a k-value of 0.0542 min-1 and a %R of 98.02%. This is because MG dyes are cationic dyes that naturally have a high affinity for negatively charged surfaces, such as bentonites. The electrostatic interaction between MG and bentonite allows for an efficient adsorption process, where the MG molecule is attracted and retained on the surface of the bentonite without undergoing any changes in chemical structure. The addition of bentonite to the TiO2 photocatalyst system makes a significant contribution to improving photocatalytic performance, while also addressing the limitations of TiO2 which is known to have low adsorption capacity. In the TiO2/Bentonite composite, bentonite acts as an adsorbent that facilitates the initial absorption of MG molecules, while TiO2 acts as a photocatalyst that degrades the dye into a simpler compound through the process of photodegradation. Because the adsorption properties of bentonite are physical and reversible, the absorbed MG molecules have the potential to experience desorption if there are changes in environmental conditions such as pH, temperature, or the ionic strength of the medium (Elystia et al., 2024). The k-values of the photocatalyst activity of TiO2, Bentonite, and TiO2/Bentonite respectively for the degradation of MG dyes are shown in Table 1.

Table 1. Values k and % R of the photocatalyst activity of TiO2, Bentonite, and TiO2/Bentonite for the degradation of MG dyes

Yes	Photokatalis	k (velocity constant) ($^{minute-1}$)	% R
		MG	MG
1.	TiO2	0,0129	51,39
2.	Bentonite	0,0219	68,77
3.	TiO2/Bentonit	**0,0542**	**98,02**
4.	Photolysis	0,0396	33,99

Degradation of MG Dye Using Other Sources of Rays

In this study, the activity of TiO2/Bentonite photocatalysts was tested using light from other sources, namely sunlight and UV light. This test was carried out at the optimum conditions obtained previously, namely a mass of 60 mg, pH 3, and a concentration of 15 mg/L of MG dye. The use of sunlight is intended for the application of TiO2/Bentonite photocatalysts in the environment because solar energy is environmentally friendly and economically valuable, so the use of sunlight as a source of photons for the degradation of dye waste is considered very effective and efficient (Borges et al., 2016).

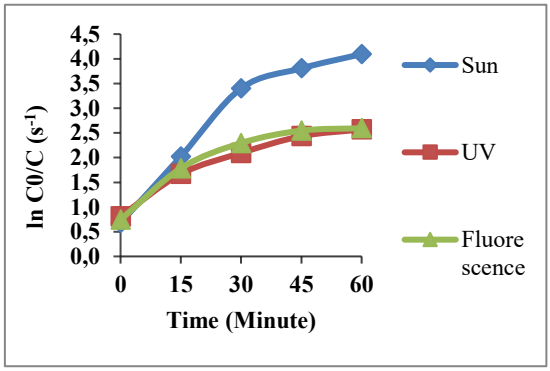

Figure 9. Reaction kinetics on the degradation of MG dyes using multiple light sources

Figure 9 shows that photocatalysts irradiated with sunlight provide higher photodegradation reaction kinetics compared to UV light and fluorescence lamps for the MG dye (k = 0.0814, % R = 99.60) in the radiation time of 60 minutes. This is because sunlight consists of UV rays with different wavelengths, namely UV A (320-400 nm), UV B (290-320 nm) and UV C (200-290 nm) (Shaktivel et al., 2003). Fluorescence lamps consist of only 5.08 nm UV and 215 nm Vis, while the UV lamp used is 254 nm. Therefore, sunlight provides a lot of photon energy that is absorbed to the surface of the photocatalyst so that the excitation of electrons and the formation of radical compounds is more to degrade the MG dye.

Reusability of Immobilized TiO2/Bentonite Photocatalyst on Glass Plate

Reusability tests were performed on TiO2/Bentonite composites immobilized on glass plates through 4 consecutive use cycles. The purpose of this test is to evaluate the stability and consistency of the photocatalyst performance during repeated use, as well as to assess the resistance of the material to structural degradation and degradation of photocatalytic efficiency.

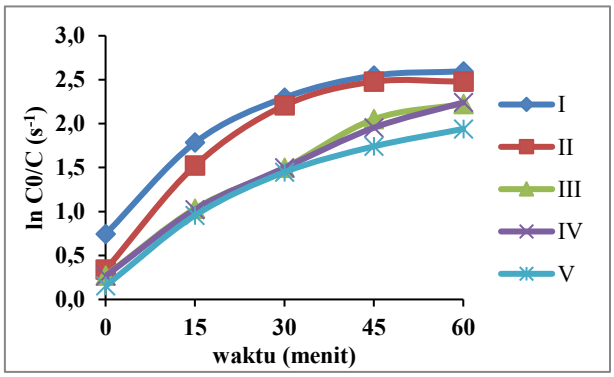

Figure 10. Reaction kinetics on immobilized TiO2/Bentonite photocatalyst reusability on glass plates on degradation of MG dyes.

In figure 10, it can be seen that there is a decrease in the kinetic value of the photocatalyst reaction in the MG substance with each repetition carried out. For MG dyestuffs, the decrease in reaction kinetics values was 0.0542, 0.0517, 0.0424, 0.0419, and 0.0374, respectively, with the % R of 98.02%, 96.81%, 94.4%, 94.46%, and 90.51%. The decrease in reaction kinetics and % R in the reuse of TiO2/Bentonite composite photocatalysts is due to the presence of MG dye molecules that have not been desorpted from the photocatalyst surface.

This results in the adsorption and electron excitation processes being disrupted, resulting in the degradation effectiveness of MG dyes decreased (Sheilatina et al., 2024). The k-value of the immobilized TiO2/Bentonite photocatalyst reusability on the glass plate at MG degradation can be seen in Table 2.

Table 2. Value k of immobilized TiO2/Bentonite photocatalyst on glass plate for degradation of MG dyes

No	Concentration of dye (mg/L)	K (velocity constant) ($^{minute-1}$)	%R
		MG	MG
1.	I	0,0542	98,02
2.	II	0,0517	96,81
3.	III	0,0424	94,4
4.	IV	0,0419	94,46
5.	V	0,0374	90,51

CONCLUSION

The TiO_2/Bentonite composite immobilized on glass plates demonstrated strong photocatalytic activity in degrading MG dye, achieving optimal performance at 60 mg catalyst mass, pH 3, and 15 mg/L initial dye concentration, with a reaction rate constant of 0.0542 and 98.02% degradation efficiency within 60 minutes. Reusability tests over five cycles revealed a gradual decline in photocatalytic efficiency, likely due to residue buildup or surface property changes on the composite. Future research could explore surface regeneration techniques or alternative immobilization methods to enhance the durability and sustained activity of the photocatalyst across multiple usage cycles.

REFERENCES

Aji, N. R., Wibowo, E. A. P., Ujiningtyas, R., Wirasti, H., & Widiarti, N. (2016). Sintesis komposit TiO_2-bentonit dan aplikasinya untuk penurunan BOD dan COD Air Embung UNNES. *Jurnal Kimia VALENSI, 2*(2), 114–119.

Angelova, R., Baldikova, E., Pospiskova, K., Maderova, Z., Safarikova, M., & Safarik, I. (2016). Magnetically modified *Sargassum horneri* biomass as an adsorbent for organic dye removal. *Journal of Cleaner Production, 137*, 189–194.

Ariski, M. G. (2021). *Degradasi zat warna Methyl Green dengan katalis ZnO menggunakan metode fotosonolisis* (Doktoral, Universitas Negeri Padang).

Borges, M., Ramos, M. S., Cuevas, E., García Cabrera, R., & Esparza, P. (2016). Photocatalysis with solar energy: Sunlight-responsive photocatalyst based on TiO_2 loaded on a natural material for wastewater treatment. *Solar Energy, 135*, 527–535. https://doi.org/10.1016/j.solener.2016.06.022

Cao, X., Luo, S., Liu, C., & Chen, J. (2017). Synthesis of bentonite-supported Fe_2O_3-doped TiO_2 superstructures for highly promoted photocatalytic activity and recyclability. *Advanced Powder Technology, 28*(3), 993–999.

Coromelci, C., Neamtu, M., Ignat, M., Samoila, P., Zaltariov, M. F., & Palamaru, M. (2022). Ultrasound assisted synthesis of heterostructured $TiO_2/ZnFe_2O_4$ and $TiO_2/ZnFe_{1.98}La_{0.02}O_4$ systems as tunable photocatalysts for efficient organic pollutants removal. *Ceramics International, 48*(4), 4829–4840.

Elystia, S., Iner, A., & Edward, H. S. (2024). Pemanfaatan adsorben beads komposit chitosan-bentonite dalam pengolahan air gambut. *Jurnal Reka Lingkungan, 12*(1), 11–23.

González-Burciaga, L. A., Núñez-Núñez, C. M., Morones-Esquivel, M. M., Avila-Santos, M., Lemus-Santana, A., & Proal-Nájera, J. B. (2020). Characterization and comparative performance of TiO_2 photocatalysts on 6-mercaptopurine degradation by solar heterogeneous photocatalysis. *Catalysts, 10*(1), 118.

Ismail, W. I. N., Ain, S. K., Zaharudin, R., Jawad, A. H., Ishak, M. A. M., Ismail, K., & Sahid, S. (2015). New TiO_2/DSAT immobilization system for photodegradation of anionic and cationic dyes. *International Journal of Photoenergy*, 232741.

Katheresan, V., Kansedo, J., & Lau, S. Y. (2018). Efficiency of various recent wastewater dye removal methods: A review. *Journal of Environmental Chemical Engineering, 6*(4), 4676–4697.

Khairil, D. F. (2021). *Optimasi penyerapan Malachite Green menggunakan C-sinamalkaliks [4] resorsinarena basil sintesis sebagai adsorben* (Doktoral, Universitas Negeri Padang).

Liŭ, D., Li, Z., Wang, W., Wang, G., & Liú, D. (2016). Hematite-doped magnetic TiO_2 nanocomposites with improved photocatalytic activity. *Journal of Alloys and Compounds, 654*, 491–497.

Lubis, S., Sheilatina, & Sitompul, D. W. (2019). Photocatalytic degradation of indigo carmine dye using α-Fe_2O_3/bentonite nanocomposite prepared by mechanochemical synthesis. *IOP Conference Series: Materials Science and Engineering, 012142*, 1757–8981. (JCC 2018, Semarang, Indonesia).

Miyake, M., Mano, T., Nishimoto, S., & Kameshima, Y. (2015). Water treatment efficacy of various metal oxide semiconductors for photocatalytic ozonation under UV and visible light irradiation. *Chemical Engineering Journal, 264*, 221–229.

Nawawi, W. I., Zaharudin, R., Zuliahani, A., Shukri, D. S., Azis, T. F., & Razali, Z. (2017). Immobilized TiO_2-polyethylene glycol: Effects of aeration and pH of methylene blue dye. *Applied Sciences, 7*(5), 508.

Nisa, A. K., Wardhani, S., & Purwonugroho, D. (2018). Tempe wastewater degradation using TiO_2-N/bentonite–alginate granule photocatalyst with ultraviolet light irradiation. *IOP Conference Series: Materials Science and Engineering, 299*(1), 012030.

Rafiq, A., Ikram, M., Ali, S., Niaz, F., Khan, M., Khan, Q., & Maqbool, M. (2021). Photocatalytic degradation of dyes using semiconductor photocatalyst to clean industrial water pollution. *Journal of Industrial and Engineering Chemistry, 97*, 11–128.

Sakinah, S., Julinawati, F., Fathurrahmi, & Sheilatina. (2024). Immobilisasi α-Fe_2O_3/bentonit sebagai fotokatalis pada fotodegradasi zat warna methylene blue. *Jurnal Global Ilmiah, 2*(3). https://doi.org/10.55324/jgi.v2i3.153

Sari, A. R., Wardhani, S., & Mutrofin, S. (2021). Sintesis granul TiO_2-bentonit/alginat untuk fotodegradasi metilen biru. *The Indonesian Green Technology Journal, 10*(2).

Sheilatina, S., Fathurrahmi, F., Frastiwi, F., Nawawi, W. I., & Sabar, S. (2024). Immobilization of TiO_2/bentonite/α-Fe_2O_3 photocatalyst on glass plates and their study on the degradation of indigo carmine dyes. *AIP Conference Proceedings, 3082*(1).

Slama, H. B., Bouket, A. C., Pourhassan, Z., Alenezi, F. N., Silini, A., Cherif-Silini, H., Oszako, T., Luptakova, L., Golińska, P., & Belbahri, L. (2021). Diversity of synthetic dyes from textile industries, discharge impacts and treatment methods. *Applied Sciences, 11*(14), 6255. https://doi.org/10.3390/app11146255

Sun, Q., Hu, X.-L., Zheng, S.-L., Sun, Z.-M., Liu, S.-S., & Li, H. (2015). Influence of calcination temperature on the structural, adsorption and photocatalytic properties of TiO_2 nanoparticles supported on natural zeolite. *Powder Technology, 274*, 88–97.