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# The Effect of Sacrificial Agents in the Photodegradation of Methylene Blue Using Ag-$Fe_3O_4$ Nanoparticles

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***Abstract***

*Organic dyes in water are hazardous pollutants due to their toxic properties. One method capable of decomposing these pollutants is photocatalysis. Magnetite ($Fe_3O_4$) is an iron oxide that can be used as a photocatalyst material and synthesized using the coprecipitation method. These properties facilitate the separation of impurities from the medium. However, $Fe_3O_4$ has limited photocatalytic activity, so it needs to be composited with silver (Ag) to increase light absorption. Ag material can be produced using $AgNO_3$ as a source of silver ions. The resulting catalyst, with the addition of Sacrificial Agent solutions, was tested for photocatalytic Methylene Blue solution. The XRD, EDX, SEM, and Photocatalytic characterization results showed a crystalline $Fe_3O_4$ structure and appropriate material composition. The maximum degradation percentage achieved by $Fe_3O_4$/Ag with the addition of methanol was 94.11%, with a degradation rate of 0.02360 k/min, compared to pure $Fe_3O_4$.* This study present a novel approach by integrating sacrificial agents into $Fe_3O_4$ and *Ag-$Fe_3O_4$ photocatalytic systems to improve methylene blue degradation performance under irradiation light.*

**Keywords:** *$Fe_3O_4$; Silver Nitrate; Photocatalytic; Methylene Blue; Degradation*

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## INTRODUCTION

The most important natural resource for living things to survive on Earth is water [1]. Water has become an integral part of living things and is always found in environments dominated by water. Therefore, it is necessary to monitor the quality and quantity of water [2]. As time passes, clean water sources are becoming increasingly limited due to contamination by inorganic waste. Inorganic waste is highly toxic because it contains non-degradable metal ions that are difficult to decompose over a prolonged period, causing them to accumulate in the environment [3]. One type of inorganic waste material is dyes, which are harmful to the aquatic environment [4]. The chemicals contained in dyes are generally toxic, carcinogenic, and flammable [5]. The compounds contained in dyes are difficult to remove because they are resistant to aerobic treatment, which can cause ecological problems. Therefore, it is necessary to treat the organic compounds from dye waste before disposal to prevent environmental contamination [6]. One

type of dye commonly found in textile waste is Methylene Blue [7].

Methylene Blue (MB) is a thiazine dye commonly used in the textile industry due to its low cost and availability. However, MB compounds have a benzene structure that is difficult to break down naturally and are toxic, carcinogenic, and mutagenic [8]. Methylene Blue is also categorized as a hazardous chemical for humans and animals with the ability to burn organs, such as the eyes and skin, when used excessively. In addition, the use of MB can cause several effects, such as irritation of the digestive tract if ingested and cyanosis if inhaled. Therefore, in wastewater treatment efforts, MB can be removed or degraded. Photocatalysis is the most commonly used method in enhanced oxidation, as it utilizes light as an external energy source to form electron-hole pairs [9]. The photocatalysis method can serve as an alternative solution to environmental problems due to its simplicity, capability to degrade various organic pollutants, relative affordability, environmental friendliness, and efficiency, making it a suitable application in Indonesia [10]. Photocatalysis uses light to generate electron-hole pairs that activate oxidation-reduction reactions with water, producing potent oxidising agents such as hydroxyl radicals (•OH). These substances break down polymers and sever the chain structures of compounds found in dyes. These reactions are activated when oxides combine with ultraviolet (UV) light or visible light in the presence of a catalyst.. Catalysts that can be used include metal or semiconductor materials such as, $Fe_3O_4$, CdS, $TiO_2$, and ZnO [11].

Among these semiconductor photocatalyst materials, $Fe_3O_4$ magnetic nanoparticles have attracted attention due to their low toxicity, large surface area, effective electrical, optical, chemical, and superparamagnetic properties. Therefore, $Fe_3O_4$ is considered a magnetic field material that can be used as an adsorbent or to hold other molecules on its surface [12]. $Fe_3O_4$ has an inverse cubic structure with a mixture of oxides ($Fe^{3+}$ and $Fe^{2+}$)[13]. $Fe_3O_4$ can be utilized in drug delivery, metal absorbents, catalyst, electrochemical biosensors, and drug delivery [14]. $Fe_3O_4$ has a valence gap between Fe (4s) and O (2p) with an energy of 2.1 eV (309-206 nm). Therefore, $Fe_3O_4$ can be used as a catalyst under ultraviolet or visible light irradiation.

The photocatalytic ability of $Fe_3O_4$ can be enhanced by composite with metal atoms, such as Ag (Silver). In metal oxide photocatalysts, light-stimulated electrons easily transfer to the Fermi level of the doped metal atoms through a Schottky contact, which prevents electron de-excitation and thereby improves the catalytic performance of metal oxides [15]. The synthesis of magnetic nanoparticles can utilize the coprecipitation method, where the breaking of continuous bonds in metal compounds in solution results in the precipitation of solid material [16].

The purpose of this study is to determine the effect of adding a sacrificial agent on the effectiveness of Ag-$Fe_3O_4$ nanoparticles in degrading methylene blue using the following testing parameters X-Ray Diffractometer (XRD), Scanning Electron Microscope (SEM-EDX), and photocatalytic testing using irradiation light.

## METHOD

The research method used in this article is coprecipitation and quantitative analysis. Nanoparticles are synthesized by mixing magnetite $Fe_3O_4$ and $AgNO_3$. The Ag- $Fe_3O_4$ nanoparticle production process was carried out at the Physics Laboratory of Malang State University, while SEM and XRD testing were conducted at the Advanced Mineral Laboratory of Universitas Negeri Malang.

The tools used in this study were a beaker glass, spatula, analytical balance, magnetic stirrer, Whatman filter paper, oven, mortar, and pH indicator. The materials used in this study were $FeCl_3 \cdot 6H_2O$, $FeCl_2 \cdot 4H_2O$, $AgNO_3$, $NH_4OH$, distilled water, methylene blue, and sacrificial

agents (ethanol, methanol, propanol).

2.1 Synthesis of $Fe_3O_4$

The solution was prepared by dissolving 7,95 g of $FeCl_3 \cdot 6H_2O$ in 50 mL of distilled water. Similarly, 2,95 g of $FeCl_2 \cdot 4H_2O$ was dissolved in 50 mL of distilled water. Next, the two solutions were mixed in a glass beaker at 450 rpm for 10 minutes. Then, 18 mL of $NH_4OH$ is added dropwise to the mixture of the first and second solutions. $FeCl_3 \cdot 6H_2O$ and $FeCl_2 \cdot 4H_2O$ are stirred continuously for 60 minutes at 700 rpm until a pH of 10 is achieved. The resulting precipitate is then washed, filtered, and dried. The chemical reaction can be expressed as follows:

$$2FeCl_3 + FeCl_2 + 8NH_4OH \rightarrow Fe_3O_4 + 4H_2O + 8NH_4Cl$$

2.2 Synthesis of Ag-$Fe_3O_4$

The Ag ions used are derived from $AgNO_3$. A total of 0,5 g of $AgNO_3$ is added to a mixture of 7,30 g of $FeCl_3 \cdot 6H_2O$ and 2,98 g of $FeCl_2 \cdot 4H_2O$, each dissolved in 50 mL of distilled water. Then, $NH_4OH$ was added dropwise, and the solution mixture was stirred continuously for 60 minutes. The precipitate that formed was then washed, filtered, and dried. The powder obtained was then characterized.

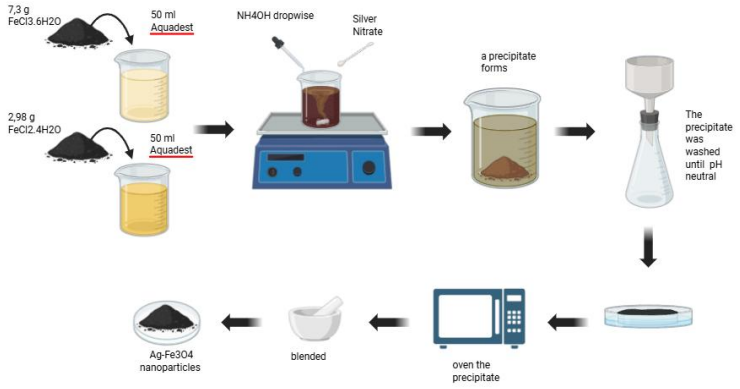



**Figure 1.** Synthesis of Ag-$Fe_3O_4$

2.3 Degradation Procedure

The photodegradation of MB with $Fe_3O_4$ and Ag-$Fe_3O_4$ nanoparticles was carried out in a glass cuvette, as shown in Figure 2. In the photocatalysis process, a cuvette measuring containing the catalyst and solution was placed in a black box for 120 minutes. The photocatalytic activity of $Fe_3O_4$ material was analyzed by detecting changes in MB concentration after administering the photocatalytic material with 50 W UV-Visible Light. The sensor used was AS-7431. After that, $O_2$ bubbles could be observed, indicating the evolution of the reaction gas. Data from the reacted suspension was collected periodically and evaluated with a LED light for 1 minute. 0,5 mL sacrificial agent was added to 10 mL MB solution for review the effectiveness degradation. Before UV irradiation, the suspension was stirred under dark conditions for 30 minutes to achieve adsorption–desorption equilibrium. Therefore, the photocatalytic degradation data presented in the graph were obtained after the dark adsorption process.

Based on these measurements, wavelength, light intensity, and degradation time data were obtained. The transmitted light intensity of the methylene blue solution was measured using the AS-7431 spectral sensor at the 680 nm channel, which was selected as the closest available wavelength to the maximum absorbance region of methylene blue (~664 nm). The absorbance value was calculated using the Beer–Lambert equation, where ($I_0$) is the light

intensity of aquades as the reference and ($I$) is the transmitted light intensity of the methylene blue solution. Furthermore, the degradation percentage was determined from the decreasebin absorbance during irradiation.

$$A = -\log(10)\frac{I}{I_0} \quad (1)$$

$$\text{Degradation (\%)} = \frac{A_0 - A_t}{A_0}\ x\ 100\ \% \quad (2)$$

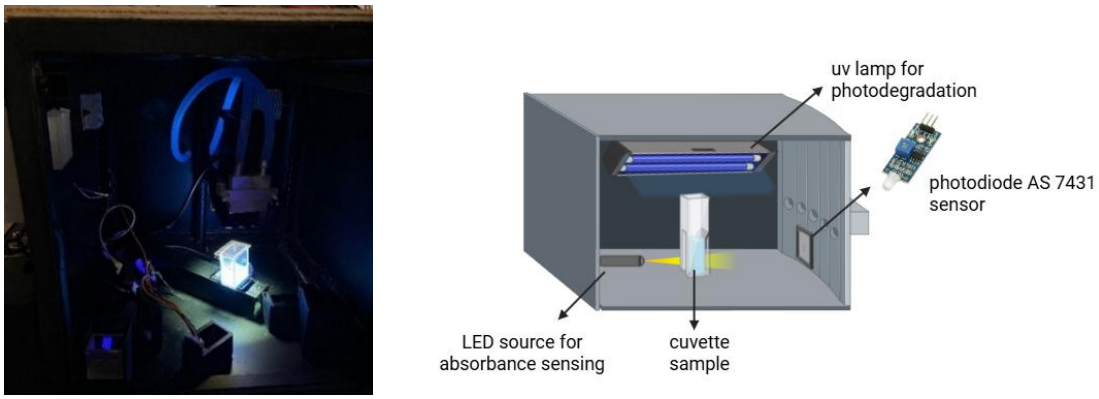



**Figure 2.** Set-up Instrument Photodegradation

**Table 1** Photocatalytic test conditions

| Parameter | Condition |
|---|---|
| Methylene Blue Condition | 10 ppm |
| Catalyst mass | 0,5 g |
| Sacrificial agent concentration | 0,5% v/v |
| pH | Not adjusted |
| Stirring rate | Manual stirring |
| Light source | 50 W lamp |
| Wavelenght range | 415 – 680 nm |
| Reactor type | Self-designed photoreactor |
| Distance | 10 cm |
| Reactor geometry | Cuvette glass |
| Sampling schedule | 10 mm x 30 mm x 80 mm |
| Separation method | Centrifuge |

## RESULTS AND DISCUSSION

### 3.1. Crystal structure of $Fe_3O_4$ and Ag-$Fe_3O_4$ materials

The crystal structure of $Fe_3O_4$ and Ag-$Fe_3O_4$ nanoparticles is shown in Figure 3, which was analysed using XRD. It can be observed that $Fe_3O_4$ (black) and Ag-$Fe_3O_4$ (red) exhibit sharp peaks, confirming the particles' crystallinity. The $Fe_3O_4$ XRD pattern shows diffraction peaks at $2\theta \approx 30{,}2^\circ$, $35{,}6^\circ$, $57{,}2^\circ$, and $62{,}8^\circ$, corresponding to the (200), (311), (511), and (440) indices, respectively, and matching JCPDS no. 19-0629. The identified peaks are consistent with those reported by Yahya et al [17] , which indicate that $Fe_3O_4$ is pure. Meanwhile, the XRD pattern of the Ag-modified sample shows additional peaks. There are four additional diffraction peaks at angles $2\theta \approx 38{,}1^\circ$, $44{,}3^\circ$, $64{,}4^\circ$, and $77{,}5^\circ$, corresponding to AMCSD 0011135, which are hkl reflections from (111), (200), (220), and (311).

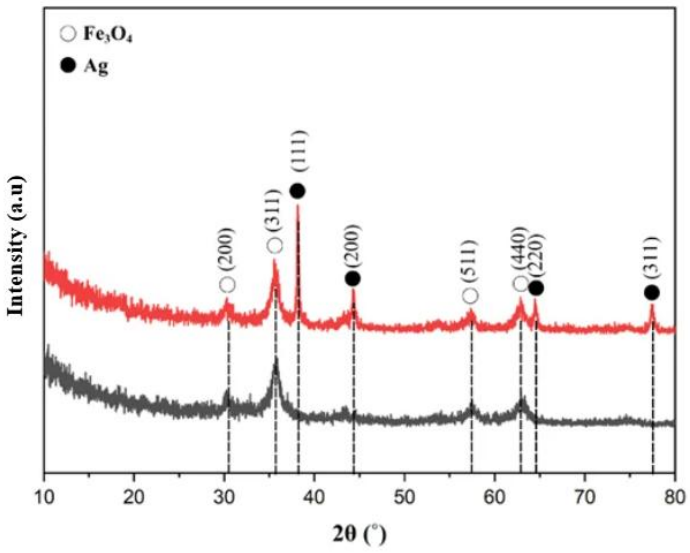



**Figure 1.** XRD diffraction patterns of nanoparticles (a) $Fe_3O_4$ (black), and (b) Ag-$Fe_3O_4$ (red)

3.2. Morphology and Properties of $Fe_3O_4$ and Ag-$Fe_3O_4$ Crystals

The surface morphology of $Fe_3O_4$ and Ag-$Fe_3O_4$ nanoparticles was obtained using Scanning Electron Microscopy (SEM). Figure 4a shows that the pure $Fe_3O_4$ sample has a non-homogeneous morphology, with high particle agglomeration into clumps. This condition can be attributed to the intrinsic properties of $Fe_3O_4$ nanoparticles, which have high surface energy, leading to aggregation. Meanwhile, Figure 4.b shows that after adding Ag, the sample morphology changed significantly, with the particles appearing smoother and more evenly distributed than in pure $Fe_3O_4$. This indicates that Ag acts as a nucleation centre, thereby controlling crystal growth, producing a more uniform particle distribution, and preventing excessive agglomeration. In addition, the presence of Ag promotes the development of larger crystals than in pure $Fe_3O_4$. This is also in line with research Saeed et al [18], which reports that Ag metal doping can modify the surface and improve the morphological regularity of semiconductor materials.

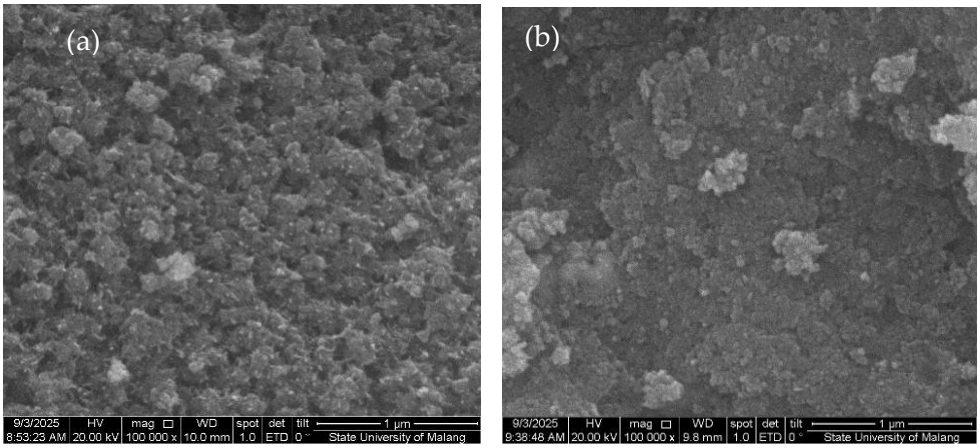



**Figure 2.** SEM results of nanoparticles a.) $Fe_3O_4$, and b.) Ag- $Fe_3O_4$

The formation of Ag-$Fe_3O_4$ was further investigated using EDX analysis. The EDX spectrum of Ag-$Fe_3O_4$ (Figure 5.a) shows the presence of silver (Ag), oxygen (O), and ferrite (Fe) with weight percentages of 5,76 wt% (1,80 at%), 27,61 wt% (58,07 at%), and 66,62 wt% (40,14 at%), respectively. These values indicate that the Ag content is relatively low but evenly distributed

throughout the material. This is evidenced by the mapping results, which show an even distribution of Ag on the particle surface (Figure 5 b). The homogeneous distribution of Ag can lead to a greater number of active surface sites, thereby increasing charge transfer during the photocatalytic process. The presence of Ag on the surface can reduce the recombination rate of electron-hole pairs formed during light irradiation, thereby expanding the reactivity for pollutant degradation.

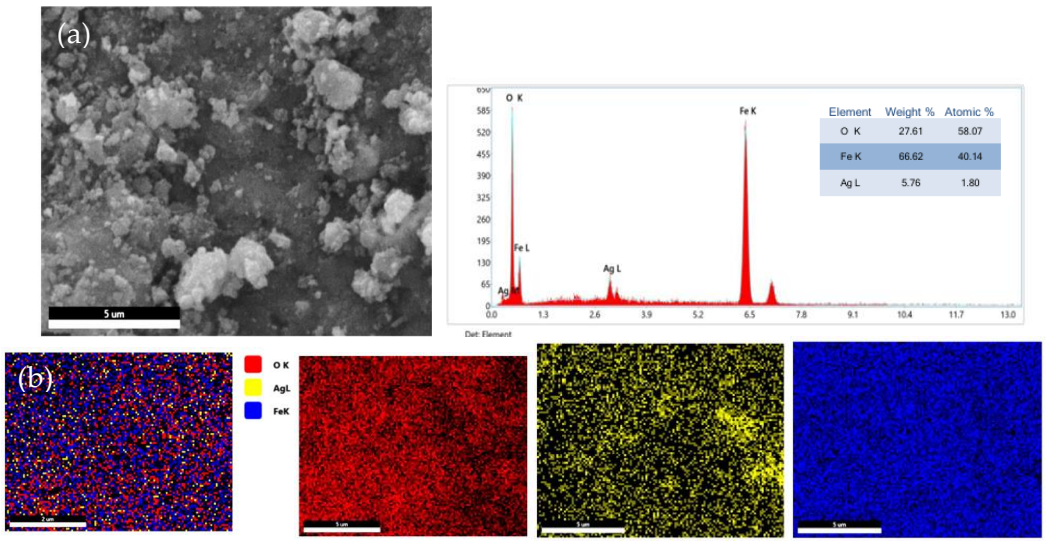



**Figure 3.** a.) EDX spectrum of Ag-$Fe_3O_4$ and b.) Mapping of Ag-$Fe_3O_4$

### 3.3. Photocatalytic Activity of $Fe_3O_4$ and Ag-$Fe_3O_4$ Nanoparticles

The MB standard curve was prepared using variations of 2-10 ppm by diluting the stock solution and then measuring its absorbance using the maximum wavelength of the stock solution ($\lambda$ = 680 nm). The characterisation of photocatalyst effectiveness was observed from the MB absorption spectrum. The results were then processed, and a graph of MB testing over 30 minutes was generated, as shown in Figure 6, to show the relationship between concentration (PPM) and absorbance.

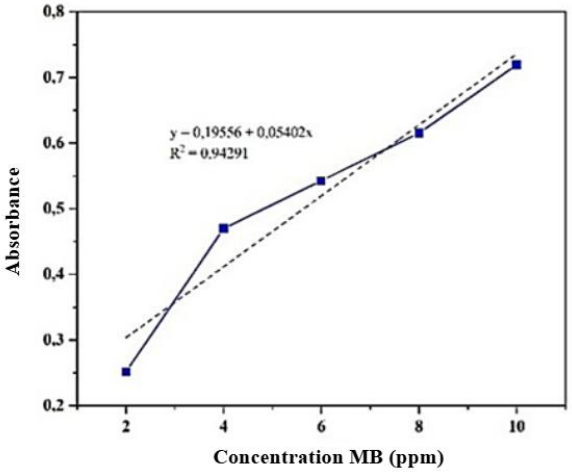
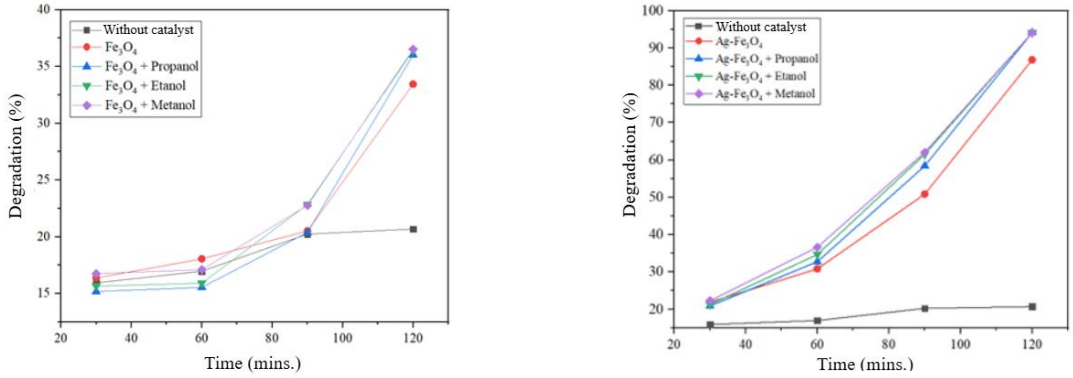



**Figure 4.** MB Standard Absorbance Curve




(a) (b)

**Figure 5.** Percentage degradation of (a) $Fe_3O_4$ and (b) Ag-$Fe_3O_4$ after 120 minutes of irradiation

The standard MB curve results are shown in Figure 6, with a gradient of m = 0,195556 ± 0,05091 and a y-intercept of c = 0,05402 ± 0,00767. The test solution was prepared by adding 5% SA (methanol, ethanol, and propanol) to the MB solution. Measurements were taken to determine the effectiveness of the test solution without a catalyst, with a catalyst, and with SA addition. Based on its optical properties, the MB solution showed a maximum absorption wavelength ($\lambda$max) of 680 nm in the visible-light region. This is because at this wavelength was selected because it is close to the characteristic absorbance, allowing concentration changes during the photocatalytic degradation process to be monitored through absorbance measurements [19]. In addition, the absorption peak is independent of the catalyst type, making the selected wavelength suitable for evaluating MB degradation performance [20]. The standard curve results demonstrate a linear relationship between absorbance and MB concentration (ppm). This behavior is consistent with the Lambert–Beer law, which states that absorbance is directly proportional to the concentration of the absorbing species [21]. Previous studies have also reported that methylene blue exhibits a linear increase in absorbance with increasing concentration in the wavelength region around 664–665 nm [22].

The degradation percentage under uncatalysed conditions was 15,9% during the first 30 minutes and did not show significant absorbance during 120 minutes of irradiation. In contrast, the degradation percentage increased considerably in the presence of $Fe_3O_4$ and Ag-$Fe_3O_4$ catalysts, particularly after 120 minutes of irradiation. These results indicate that the addition of $Fe_3O_4$, Ag-$Fe_3O_4$, and sacrificial agents enhanced the photocatalytic degradation of methylene blue (MB). The presence of $Fe_3O_4$ can accelerate MB degradation due to its effective photocatalytic properties under visible light [21]. Furthermore, the Ag-$Fe_3O_4$ catalyst exhibited a higher degradation percentage compared to $Fe_3O_4$ alone. The presence of Ag may facilitate electron transfer and suppress electron–hole recombination, thereby improving photocatalytic efficiency during the degradation process [22]. Under visible-light irradiation, photogenerated electrons and holes can participate in redox reactions that produce reactive species such as •OH and $\bullet O_2^-$ radicals, which contribute to MB degradation. In addition, the sacrificial agent acts as a hole scavenger, helping to suppress charge recombination and improve photocatalytic performance. These findings are consistent with previous studies [23], which reported that Ag-modified photocatalysts exhibit improved response in the visible-light region. Detailed degradation percentages for each treatment are presented in Tables 2 and 3.

**Table 2** Percentage of methylene blue degradation over 120 minutes

| Treatment time (minutes) | Degradation (%) | | | | |
|---|---|---|---|---|---|
| | Without Catalyst | $Fe_3O_4$ | $Fe_3O_4$ + Propanol | $Fe_3O_4$ + Ethanol | $Fe_3O_4$ + Methanol |
| 30 | 15,94 | 16,37 | 15,18 | 15,65 | 16,75 |
| 60 | 16,97 | 18,05 | 15,55 | 15,91 | 17,10 |
| 90 | 20,24 | 20,51 | 20,38 | 22,84 | 22,76 |
| 120 | 20,68 | 33,44 | 36,03 | 36,41 | 36,52 |

**Table 3** Percentage of methylene blue degradation over 120 minutes

| Treatment time (minutes) | Degradation (%) | | | | |
|---|---|---|---|---|---|
| | Without Catalyst | Ag-$Fe_3O_4$ | Ag-$Fe_3O_4$ + Propanol | Ag-$Fe_3O_4$ + Ethanol | Ag-$Fe_3O_4$ + Methanol |
| 30 | 15,94 | 21,91 | 20,86 | 21,27 | 22,25 |
| 60 | 16,97 | 30,82 | 32,75 | 34,67 | 36,61 |
| 90 | 20,24 | 50,82 | 58,40 | 61,51 | 62,05 |
| 120 | 20,68 | 86,81 | 94,10 | 94,08 | 94,11 |

In the photocatalysis process, the concentration of degraded MB decreases over time as irradiation continues. The MB degradation curve with $Fe_3O_4$ and Ag-$Fe_3O_4$ additions is steeper than that without a catalyst, indicating a significant increase in photocatalytic activity. In the process without catalysts, degradation only reached 20,68% after 120 minutes. Meanwhile, with the addition of $Fe_3O_4$, the percentage increased to 33,44%, and with the addition of SA, it increased to 36,52% after 120 minutes of irradiation. Meanwhile, with the addition of Ag-$Fe_3O_4$ catalyst, the percentage increased to 86,81%, and with the addition of SA, the percentage increased to 94,11% during 120 minutes of irradiation. The difference in effectiveness between SA is due to the ability of each compound to act as a hole scavenger, where the carbon chains of methanol and ethanol are shorter [23], allowing them to be more easily oxidised and to recombine electron-hole pairs more effectively than propanol [24]. In general, the Ag-$Fe_3O_4$ material showed higher photocatalytic activity in degrading MB than $Fe_3O_4$.

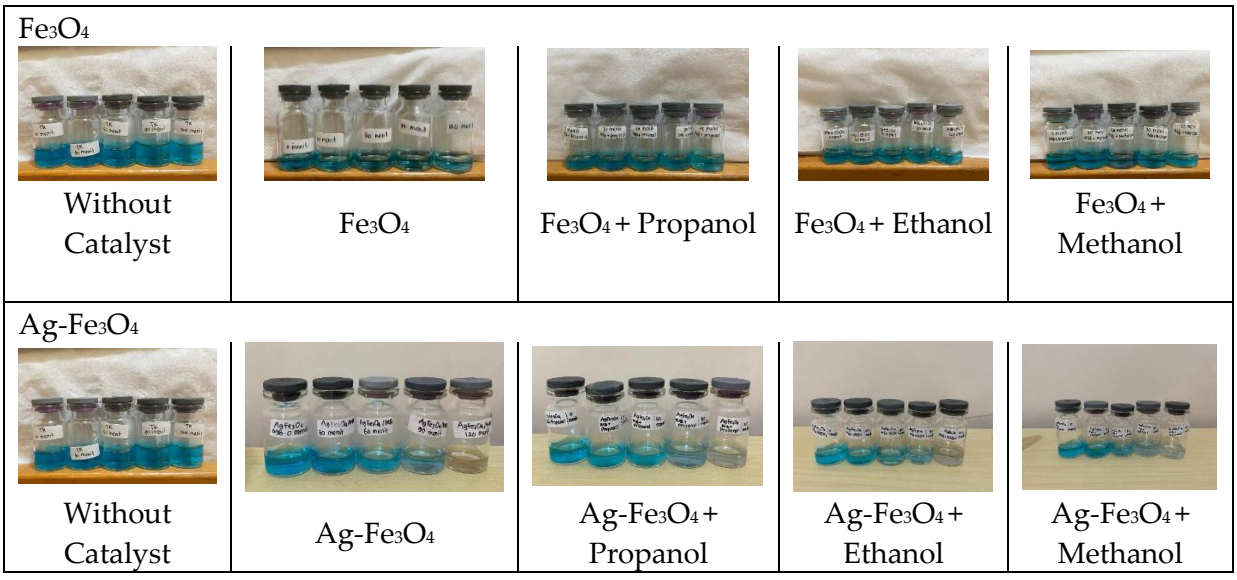



**Figure 8** Results of degradation during 120 minutes of exposure

The rate of photocatalytic activity can be demonstrated through the following first-order reaction rate equation (Maddu et al.).

$$C_t = C_0 \exp(-kt) \quad (3)$$

where Ct is the concentration after treatment, C0 is the initial concentration, k is the degradation constant or rate, and t is the treatment time. The degradation rate can be determined from the curve relating $\ln(C_t/C_0)$ to treatment time t using the following equation.

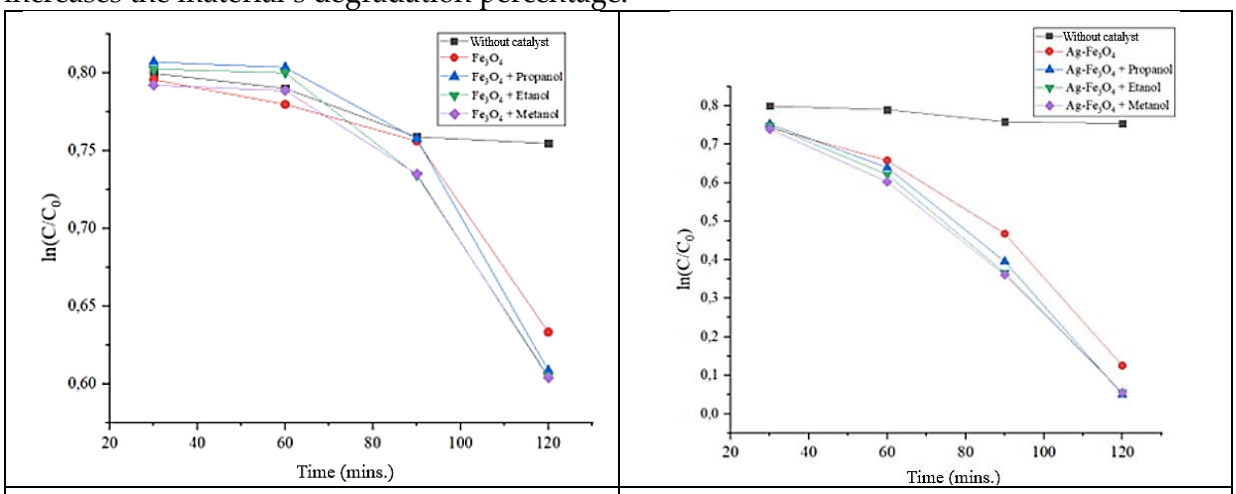
$$\ln\left(\frac{C}{C_0}\right) = -kt \quad (4)$$

The rate of photocatalytic activity is determined by k; the greater k, the higher the rate of degradation and the better the photocatalytic activity [26]. The rate of photocatalysis without a catalyst is 0,00072 $min^{-1}$. Meanwhile, the photocatalysis rate for $Fe_3O_4$ material is 0,00243 $min^{-1}$, and for Ag-$Fe_3O_4$ material in pure MB solution is 0,01688 $min^{-1}$. The degradation rate values obtained for $Fe_3O_4$ and Ag-$Fe_3O_4$ photocatalytic activity are presented in detail in Table 4.

**Table 4** Degradation rate constant k ($min^{-1}$)

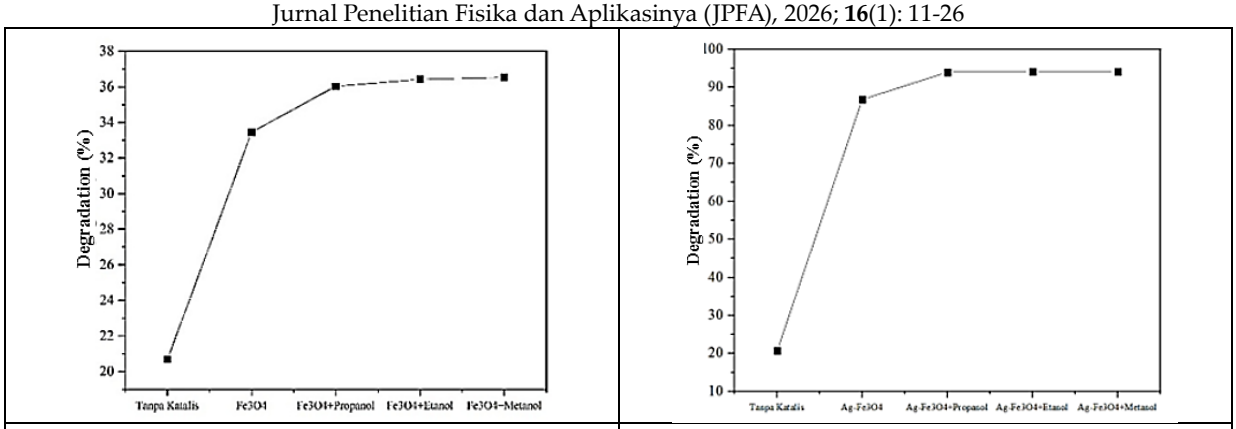
| Sample | | Sample | |
|---|---|---|---|
| Without Catalyst | 0,00072 | Without Catalyst | 0,00072 |
| $Fe_3O_4$ | 0,00243 | Ag-$Fe_3O_4$ | 0,01688 |
| $Fe_3O_4$ + Propanol | 0,00295 | Ag-$Fe_3O_4$ + Propanol | 0,02346 |
| $Fe_3O_4$+ Ethanol | 0,00302 | Ag-$Fe_3O_4$ + Ethanol | 0,02356 |
| $Fe_3O_4$ + Methanol | 0,00311 | Ag-$Fe_3O_4$ + Methanol | 0,02360 |

The results of preliminary data processing (intensity) using Equation 1 show that the greater the decrease in absorbance, the higher the degradation value. Thus, as shown in Figure 9, after 120 minutes of irradiation, the sample exhibited the highest absorbance and the most significant degradation percentage among the other samples. The results of this study are in line with those of [27], who reported that a decrease in absorbance indicates a higher degradation rate and increases the material's degradation percentage.




(a) (b)

**Figure 9** Absorbance versus time (a) $Fe_3O_4$, and (b) Ag-$Fe_3O_4$




(a) (b)

**Figure 10** Percentage degradation of methylene blue by samples (a) $Fe_3O_4$ series and (b) Ag-$Fe_3O_4$ series during 120 minutes of irradiation

Based on (Figure 10.a), the results of photocatalytic activity show that the Ag-$Fe_3O_4$ catalyst is likely more stable than pure $Fe_3O_4$. The Ag material in Ag-$Fe_3O_4$ acts as an electron trap via the Schottky effect, thereby increasing charge transfer and preventing electron-hole pair recombination [24] In addition, a maximum methylene blue degradation of 96.11% was achieved with SA addition using the Ag-$Fe_3O_4$ catalyst. The presence of Ag metal has been proven to increase photocatalytic activity. This increase may be due to Ag's plasmonic properties and its ability to transfer electrons in bimetallic systems [28]. Ag material can also significantly enhance electron-hole pair separation, which is important for photocatalytic efficiency. The photocatalytic reaction is triggered when the catalyst absorbs photons with energy higher than the band gap energy. Electrons in the valence band are rapidly excited to the conduction band, and oxygen reduction reactions occur. Electron excitation produces hydroxyl radicals (–OH), superoxide ($O_2$), and other radicals that act as MB degradation agents. The presence of hydroxyl groups (–OH) on the $Fe_3O_4$ surface can cause the formation of negatively charged sites when these groups dissociate in water, releasing protons ($H^+$). This leaves negatively charged oxygen atoms [29]. In solution, holes react with hydroxyl ions, producing reactive hydroxyl radicals that participate in the chain-breaking process. At the same time, electrons react with oxygen molecules, producing superoxide radical anions that participate in the degradation of organic dyes. Hydroxyl radical generators, such as $H_2O_2$, under UV light, are used to increase the oxidation capacity of organic dyes [30]. In addition, Ag nanoparticles increase the charge generated through local surface plasmon resonance (LSPR) and enhance light absorption. $Fe_3O_4$ nanoparticles are active sites that reduce oxygen to produce $H_2O_2$, which is used in the photocatalytic process [30]. In addition, SA plays a role in the photocatalytic process by acting as an electron donor and a hole scavenger, thereby slowing electron-hole recombination [31]. Alcohols such as methanol, ethanol, and propanol are often used as SA because they oxidise quickly and produce reactive organic radicals [32]. However, its effectiveness can be influenced by molecular structure. Methanol has the simplest structure, making it easily oxidised and producing highly reactive CH2OH• radicals, thereby increasing oxidative formation (•OH, •O2-) to a higher degree than ethanol and propanol [33]. Meanwhile, ethanol will form $CH_3CHOH$• radicals that are more reactive than propanol because they have higher energy and seek pairs to stabilise themselves. As a result, ethanol radicals react more quickly with dissolved oxygen to form ROS such as •$O_2^-$ and •OH, which play a significant role in MB degradation. In contrast, propanol radicals, which are more stable and sterically hindered, do not transfer electrons as readily as ethanol, so their contribution to ROS formation

is minor. Therefore, ethanol radicals are more reactive and more effective at increasing the rate of MB photocatalytic degradation [33]

**Table 5** Comparison of the photodegradation results of $Fe_3O_4$ material on methylene blue for 120 minutes

| Materials | PPM | Method | Performance (%) | Ref |
|---|---|---|---|---|
| $Fe_3O_4$/ Chitosan | 7 | Green synthesis | 94,7 | [34] |
| $Fe_3O_4$/ Ag/$TiO_2$ | 7 | Green synthesis | 97,6 | [35] |
| Ag-$Fe_3O_4$ | - | Green synthesis | 73 | [27] |
| $Fe_3O_4$/ $Fe_2O_3$ | - | Co-precipitation | 90 | [36] |
| Ag-$Fe_3O_4$ | 10 | Co-precipitation | 86,81 | In this study |

## CONCLUSION

The co-precipitation method was successfully applied for the synthesis of $Fe_3O_4$ and Ag-$Fe_3O_4$ photocatalytic materials. XRD characterization results confirmed that the material consisted of the $Fe_3O_4$ phase and the addition of Ag metal, indicating that the synthesis process produced Ag-$Fe_3O_4$ nanocomposites. SEM-EDX mapping results showed that pure $Fe_3O_4$ had an irregular morphology and tended to agglomerate. Meanwhile, the addition of Ag controls crystal growth and prevents particle agglomeration, resulting in a smoother surface and more evenly distributed particles. In addition, the presence of Ag metal successfully enhances absorption in the visible light region. The photocatalytic activity of $Fe_3O_4$ towards the degradation of methylene blue solution reached 33,44% and was degraded within 120 minutes. Meanwhile, the Ag-$Fe_3O_4$ nanocomposite was able to degrade up to 86,81% within 120 minutes of irradiation. The addition of a sacrificial agent to the Ag-$Fe_3O_4$ photocatalyst plays a role in increasing degradation because SA acts as a hole scavenger during irradiation, thereby inhibiting recombination and increasing the number of active radicals to accelerate the degradation process of the dye.

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## AUTHOR CONTRIBUTIONS

Frisellya Dirgantari: Conceptualization, Methodology, Writing – Original Draft; Nasikhudin: Methodology, Formal Analysis, and Resources; Herlin Pujiarti; Methodology, Formal Analysis and Resources, Serguei Savilov: Validation and Project Administration, and Markus Diantoro: Data Curation, Project Administration, and Writing – Review & Editing.

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