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Green Synthesis of TiO_2 Using Aloe Vera for Photodegradation in Sasirangan Waste

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Abstract

Green synthesis of TiO_2 has been successfully carried out using aloe vera. Aloe vera extract was mixed with $TiCl_4$ while heated to obtain TiO_2 powder. The FTIR spectrum showed a peak at 487.67 cm^{-1} corresponding to the Ti-O-Ti functional group, which indicates the formation of TiO_2 particles. The XRD results showed that the TiO_2 crystals were in the anatase phase. SEM images show that the particles tend to be spherical in shape as in the anatase phase. With the Scherer equation, the size of the TiO_2 crystal yielded was around 2.3 nm in diameter. The UV-vis spectrophotometer results showed the blue shift of absorption peak at 368 nm or band gap energy of 3.37 eV. A thin layer of TiO_2 was made by using the slip casting method. These thin films were applied to methylene blue and sasirangan waste samples for photodegradation tests. The exposure times used were 15, 30, 45, 60, and 75 minutes. The results showed photodegradation of 38.9 % and 4.5 %, respectively, for methylene blue and sasirangan waste.

Introduction

Sasirangan is the traditional fabric from South Kalimantan which has special colours and patterns [1]. The sasirangan colours are influenced by the type of the dye used. Sasirangan's natural dyes are now being replaced by synthetic dyes that are easier to obtain and produce attractive colours. Synthetic dyes produce dangerous waste which is accountable for water pollution [2]. Sasirangan waste has a concentrated colour and contains hazardous chemicals that are often discharged into the river without any prior waste treatment [3]. In addition, this waste is difficult to decompose, has a pungent odor, and pollutes the environment if disposed of carelessly, so waste treatment is needed to overcome this problem.

There are many methods to treat sasirangan waste, such as membranes [3], coagulation [4], adsorption [5], and a combination of filtration and phytoremediation methods [6]. However, these methods are expensive, difficult to implement, produce sludge, and are less effective against some color wastes. Photocatalyst is one of the simple and economical methods, that is effective for treating waste and parsing organic compounds such as methylene blue [7]. This method is economical and environmentally friendly because it can use UV light or sun in the reaction [8]. Photocatalysts can convert light energy into chemical energy that will produce hydroxyl radicals. Then it interacts redox with pollutants in liquid waste [9]. One of the materials that has a photocatalytic effect is TiO_2 [10][7][11]. TiO_2 is a white dioxide compound that is a stable and effective catalyst for water and air purification, destroying microorganisms, degrading dyes and toxic chemicals [12].

Titanium dioxide (TiO_2) could be greenly synthesized from natural extracts [13]. Green synthesis utilizes plants to synthesize particles [14] and is superior because it is environmentally friendly, cheap, and energy efficient. Several researchers used aloe vera to synthesize TiO_2 [15][16][17]. According to Okto [8], aloe vera is a good reducer in the synthesis of TiO_2 because aloe vera gave smaller TiO_2 particles size compared to other plants such as lemon (*Citrus limon*), lime (*Citrus limett*), Indian gooseberry (*Phyllanthus Emblica),* pala indigo (*Wrightia tinctoria*), and purging nut (*Jatropha curcas L*). The previous research which used aloe vera in TiO_2 synthesis were used in several applications such as: drug delivery [18] or catalyst [19].

Thus, in this study, TiO_2 would be synthesized by using aloe vera and used as a photocatalyst in an attempt to degrade sasirangan waste in Banjarmasin. In Rao's research [15], the neutral pH was used, while in this research, several pH variations (acid, neutral, and base) in synthesizing TiO_2 would be investigated. Moreover, the produced TiO_2 will be made into thin films by using the slip-casting method, because the thin films are more suitable for use as catalysts [20]. Therefore, the purpose of this study is to synthesize TiO_2 by using aloe vera extract, identify the characteristics of TiO_2 produced, produce TiO_2 thin film, and the investigate photodegradation of methylene blue and sasirangan waste.

Experimental Method

Synthesis of TiO_2

The aloe vera leaves ware cleaned using water. Then the leaves were cut, and the gel was taken out. 100 gram aloe vera gel was mixed with 100 ml distilled water, then heated for 2 hours at 90°C. The extract was cooled and filtered using whatman filter paper with a pore diameter of 15-20 μm. Next, The aloe vera extract was mixed with 100 mL of 1 N $TiCl_4$ solution [15]. Then the 17.5% NaOH was added slowly until it reached acid, neutral, and base conditions while stirring at 600 rpm for 4 hours. Then, the mixed solution was precipitated and filtered. The formed precipitate, which is TiO_2 powder, was rinsed with distilled water and then dried in an oven for at least 12 hours. The TiO_2 powder, then, was heated in a furnace at 500°C for 4 hours. The TiO_2 powder was characterized using UV-Vis spectrophotometer (LGS 53), FTIR (Bruker), and X-Ray Diffraction (XRD Bruker Eco D8 Advance).

The deposition of TiO_2 thin film

The TiO_2 films were deposited by the slip casting method because the method is simple and possible in doing in Indonesia. The size of slide glass as substrate is presented in Figure 1.

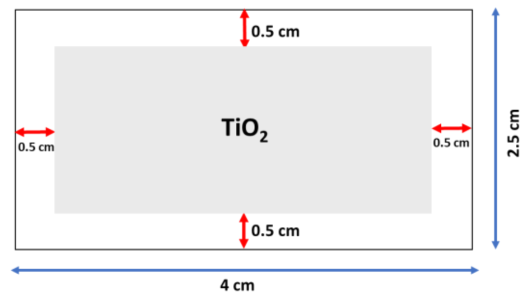


Figure 1. Size of substrate and TiO_2 thin film

The substrate was cleaned with detergent, followed by distilled water and acetone. The substrate's side was given a barrier by attaching a 0.5 cm wide tape. TiO_2 paste is produced through the mixture of TiO_2 powder and 96% ethanol, which was applied on the substrate. TiO_2 paste was allowed to dry. The tape had to be removed before the thin film was calcined for 2 hours at temperature of 650 °C [10]. After the calcination, the thin film was stored in desiccator to cooling down.

Thin films were evaluated by physical tests such as water resistance, moisture content, shape, color, and odor. Water resistance was investigated by immersing the thin film in methylene blue solution for 24 hours to evaluate its resistance to the solution [2]. Moisture content was done by placing the sample in a porcelain cup and heated in the oven at 105°C for 30 minutes. Then, cooling down in a desiccator before the cup was weighed. Moisture content was calculated using the equation [21] below:

$$\% \text{ Moisture content} = \frac{B-C}{B-A} \times 100\% \qquad (1)$$

Where:

A: Weight of empty cup (g)

B: Weight of cup + thin film (g)

C: Weight of cup + thin film after drying (g)

Photocatalyst activity of TiO_2

The photocatalyst activity was observed by placing the TiO_2 thin film into 50 mL of methylene blue and sasirangan waste solution. The samples were placed in a box sized 35x34x35 cm equipped with a 25-watt Spotlight UV Anti-Bacterial LED lamp, as shown in Figure 2.

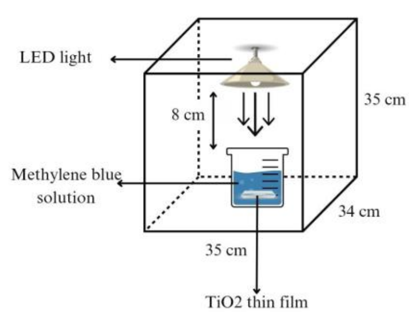


Figure 2. Photocatalyst Reactor in a Box

Then irradiated for 15, 30, 45, 60, and 75 minutes. For each irradiated time, the absorption spectra of methylene blue and sasirangan waste were measured by UV-Vis spectrophotometer to determine their photodegradation. The degradation results were calculated using the Equation (2).

$$\%\text{Degradation} = \frac{C_0 - C_t}{C_0} \times 100\% \quad (2)$$

Using the same photocatalytic activity method, the percentage of degradation by commercial TiO_2 was observed and compared with the synthesized TiO_2 to determine the difference in the level of degradation effectiveness. The size of TiO_2 particles was calculated using the Debye and Scherrer equation as shown in Equation (3) [22].

$$D = \frac{k\,\lambda}{\text{Cos}\,(\theta)\text{WFHM}} \quad (3)$$

Result and Discussion

Synthesis and characterization of TiO_2 particles

Titanium dioxide (TiO_2) was synthesized by using sol-gel method in 3 pH variations (acidic, neutral and base). The weight of TiO_2 particles obtained is shown in Table 1.

Table 1. pH variations of TiO_2 synthesis

No	pH	TiO_2 results (g)
1	3	0.4451
2	7	0.044
3	9	0.686
4	10	1.4264

From Table 1., it seems that pH of TiO_2 synthesis affected the weight of TiO_2 particles obtained. As can be seen, the base condition gave the most of TiO_2 result in weight. In addition, based on the research of [16] green synthesis of aloe vera with a pH variation of 9 produces a smaller particle size and has the purest crystal phase among other variations.

FTIR spectra describes the relationship of transmittance (%) with wavenumber (cm^{-1}), where the absorption peak indicates the location of the functional group in the infrared region. In this study, FTIR was used to measure the transmission of the aloe vera extract, the mixed solutions and the resulting powders in the range of 500-3500 cm^{-1} to determine the present of TiO_2. Figure 3 shows the FTIR spectra of the aloe vera extract, the mixed solutions and the resulting TiO_2 powders.

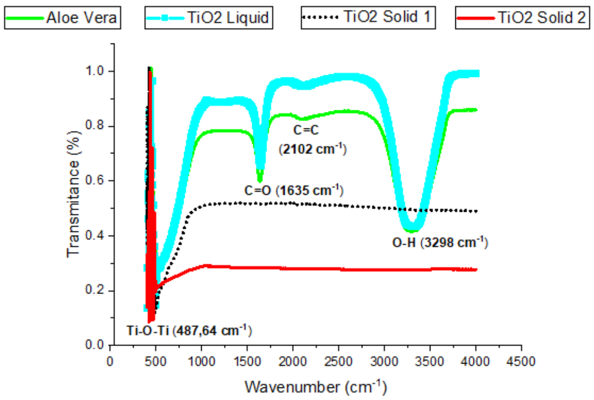


Figure 3. TiO_2 Particle and Aloe Vera FTIR Spectrum

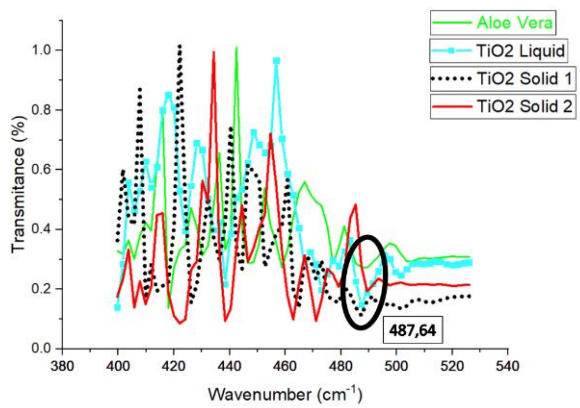


Figure 4. TiO_2 Particle and Aloe Vera FTIR Spectrum (Wavelength 380 - 530 nm)

There is a peak at 3298 cm^{-1} which indicating hydroxyl (O-H) functional group and/or phenolic hydroxyl (O-H) functional group vibrations in aloe vera extract [23]. This shows that there is absorption of water molecules as a result of the use of distilled water in the synthesis of aloe vera extract and TiO_2 [24]. At the absorption peak of 1636.45 cm^{-1}, there is a C = O group which is a bond of the carbonyl group. This indicates that organic compounds such as phenolics, anthraquinones, flavonoids, and terpenoids found in aloe vera play an important role in stabilizing the process of forming TiO_2 particles [25]. The peak of 2100 cm^{-1} indicates the C=C vibration of the aromatic ring by aloe vera [17]. When heated, peaks of organic compounds have been cleaned [26]. Then, the absorption region below 950 cm^{-1} reflects the typical vibrational bonding of TiO_2. The peak at 487.64 cm^{-1} shows absorption for Ti-O-Ti bonds, as shown in Figure 4.

According to [27], the band gap energy value plays a key role in the performance of semiconductors, because it determines the energy required to move electrons in the process of excitation and hole. The band gap energy can also be determined based on the particle size, whether nanoparticle or bulk-sized, and is determined based on the shift in the absorption peak [28]. Therefore, the absorption peak of TiO_2 solution was observed by UV-Vis spectrophotometer. The resulting spectra of UV-Vis spectrophotometer was converted to energy and plotted using Originlab 2018 software (see Figure 5.). The band gap energy of TiO_2 was determined by Gaussian fitting method.

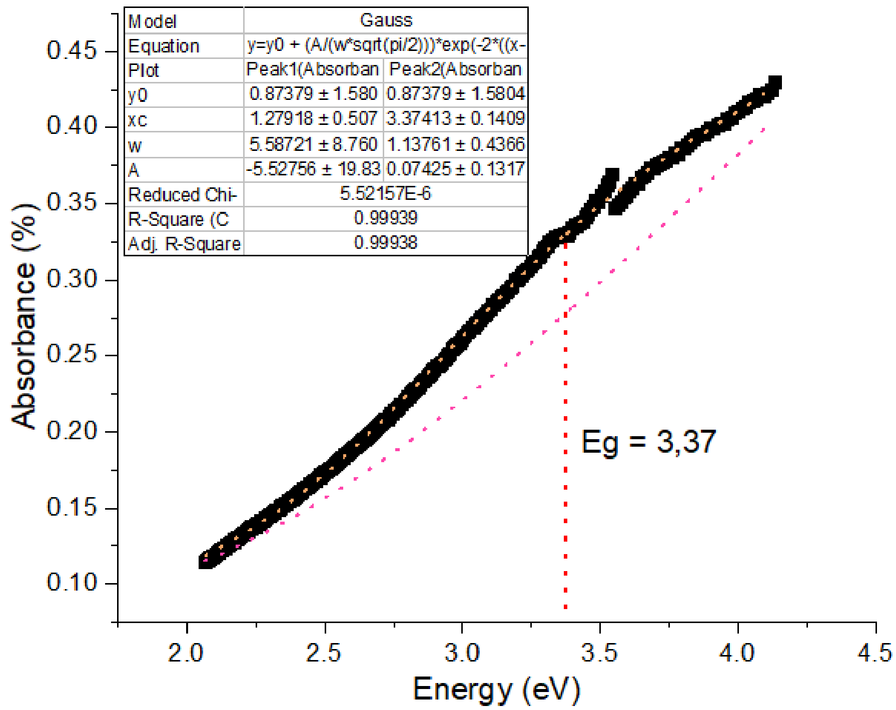


Figure 5. The energy band gap of TiO_2 based on UV-vis spectrophotometer spectra

Figure 5. shows that the band gap energy for the variation of TiO_2 solution with pH 10 is 3.37 eV. This is in line with research by [29]. TiO_2 has a band gap energy ranging from 3.2-3.9 eV. After calculating using the Planck equation, the absorption peak of TiO_2 was found to be at 368 nm. This TiO_2 energy gap indicates the particles are in nano-sized. Research by [2] states that the energy gap of TiO_2 would increase with decreasing particle size. The bulk TiO_2 energy gap is about 3.2 eV. This increase is also related to the phase, namely the anatase phase has a band gap greater than the rutile, which has an impact on the effectiveness of photocatalytic greater [30].

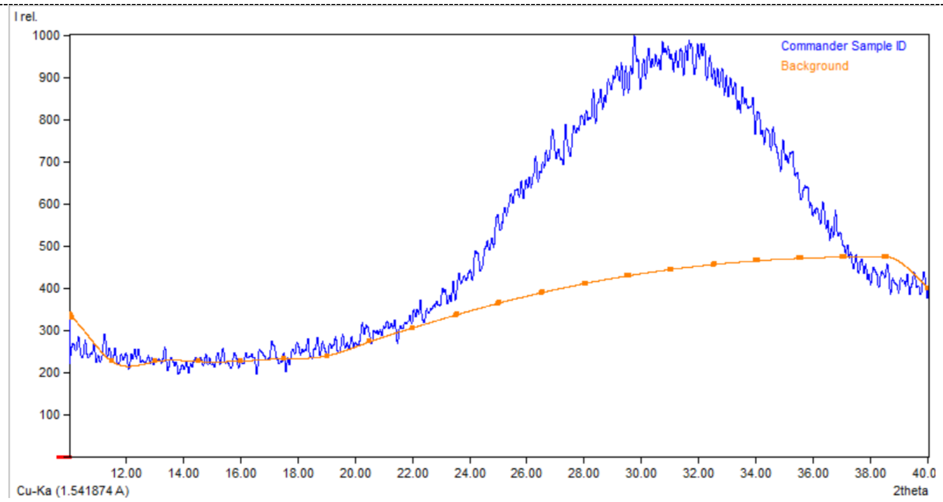


Figure 6. XRD spectra of TiO_2 and inset (XRD TiO_2– Anatase from [31])

Figure 6. shows that the XRD spectra has a peak around 2θ = 30°. The inset shows that the anatase phase of TiO_2 appears at 2θ = 30° as found in research by [31]. This means the TiO_2 obtained in this study was also in the anatase phase (in base condition). This is in line with some research that pH solution would affect the phase that would be formed. Base pH forms the anatase phase, and acidic pH tends to form the rutile phase [32]. The anatase phase on TiO_2 is the most appropriate phase in its application as a photocatalyst [33]. TiO_2 with an anatase phase has advantages such as having a large surface area and smaller particle size. This can support the increase in photocatalyst activity in degrading pollutants and dyes [11]. However, the graph displayed is not sharp, indicating that amorphous particles dominate. This may be due to the addition of aloe vera as an organic material containing complex compounds. The Scherrer equation (Equation (3)) can be used to calculate the particle size of TiO_2 [34], which yielded 2.3 nm in size.

Deposition of TiO_2 thin films and its characterizations

The thin films of TiO_2 were rectangular in shape, white in color, and had no odor (see Figure 7.). Water resistance and moisture content would affect the photocatalyst process. High water resistance and low moisture content would maintain its structure as an effective, stable and long-lasting photocatalyst. Each thin film of TiO_2 has 100% water resistance (not soluble in water) with moisture content between 0.43% to 0.48%.

(a)

(b)

Figure 7. Thin film of TiO_2 Synthesized **(a)** and TiO_2 Commercial **(b)**

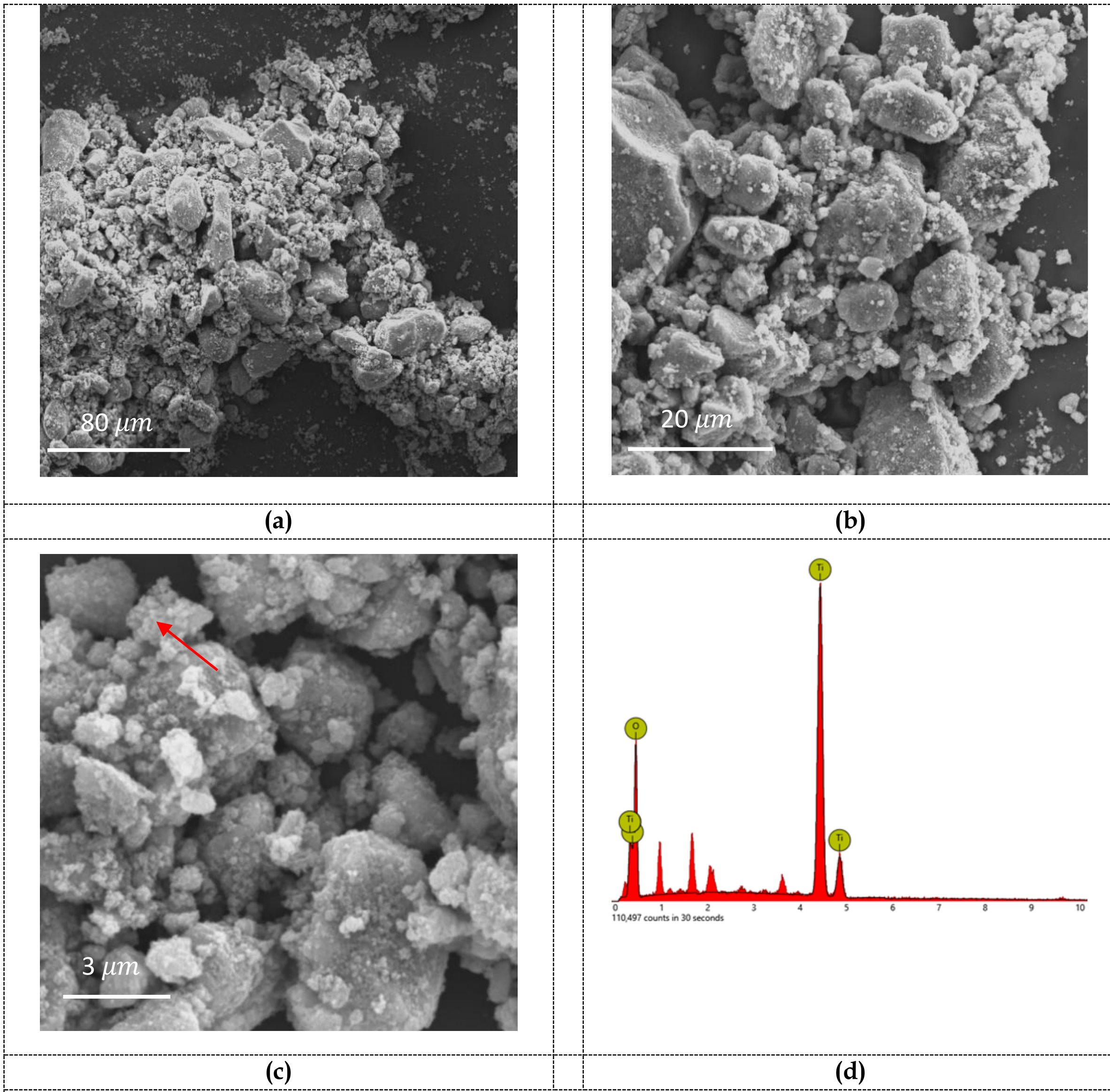


Figure 8. SEM results of TiO_2 with magnification 1000x **(a)**, 5000x **(b)**, 20.000x **(c)**, and EDX of TiO_2 **(d)**

Scanning Electron Microscope (SEM Phenom ProX) measurement was conducted to examine the morphology, size, and composition of the TiO_2 samples. According to research by [26], TiO_2 can have a spherical or irregular shape depending on the plant used during the synthesis process. As can be seen in Figure 8., the particles of the synthesized TiO_2 have large irregular chunks (Figure 8. (a) and (b)) and a small portion of particles in spherical shape (Figure 8. (c). It is assumed that the large irregular chunks are caused by the addition of aloe vera extract to the sample, so that the particle size becomes large due to clumping and aggregate formation. As a stabilizer, the aloe vera extract would experience a decrease in performance due to the presence of particles whose size increases and is not uniform [17]. The large chunks may also be due to particle distribution in the form of a single particle or a group of non-uniform particles. However, after further examination, very small round particles could be seen (Figure 8. (c)), which were identified as TiO_2 nanoparticles with anatase phases that form sponge-like aggregates [35]. This finding is in line with previous research, which shows that TiO_2 particles in the anatase phase tend to be round. This is in line with the previous result of XRD measurement, which yielded that the TiO_2 sample has a particle size of about 2.3 nm and is in anatase phase.

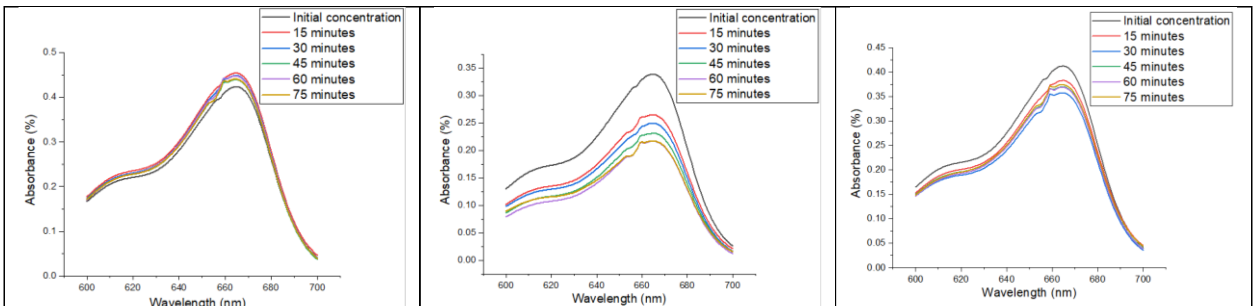
EDX results indicate the presence of Ti and O elements in TiO_2 thin film samples (Figure 8. (d)). The percentage and atomic weight of Ti and O elements in TiO_2 thin film samples were presented in Table 2.

Table 2. Sample Spectrum TiO_2

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
22	Ti	Titanium	25.94	51.17
8	O	Oxygen	74.06	48.83

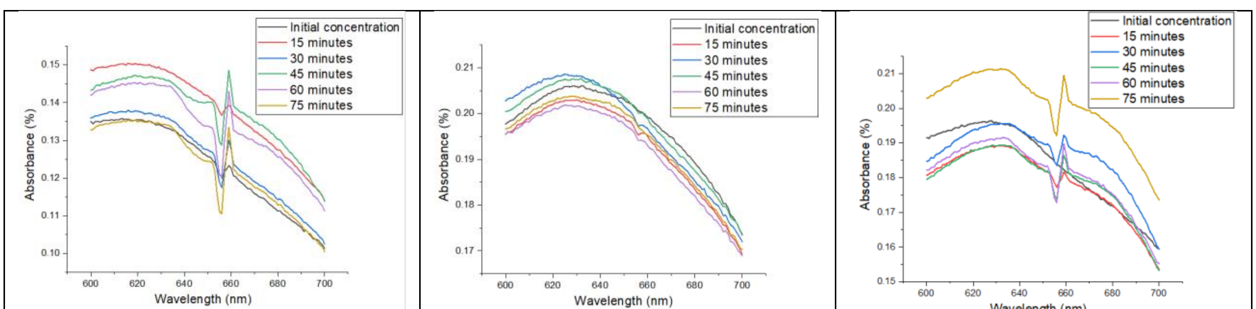
The EDX result shows that the TiO_2 was successfully synthesized. This is confirmed by rhe results of FTIR and UV-vis spectrophotometer which show the peak formation of TiO_2 and absorption blueshift.

Photocatalyst activity TiO_2



(a) (b) (c)

Figure 9. Absorption spectra of methylene blue with blank (a), synthesized **(b)**, and commercial **(c)** TiO_2



(a) (b) (c)

Figure 10. Absorption spectra of sasirangan waste with blank (a), synthesized **(b)**, and commercial **(c)** TiO_2

Figure 9. and 10. shows the absorbance peaks at 665 nm (methylene blue) and 656 nm (sasirangan waste). The iradiation of UV light on methylene blue and sasirangan waste

without TiO_2 thin films was shown in Figure 9. (a) and Figure 10 (a). Both of them show an irregular pattern. The absorbance peaks for both methylene blue and sasirangan waste were up and down unpredicted in accordance with the irradiation times. In the presence of TiO_2 films, the absorbance decreased with the length of the irradiation times, indicating the photocatalyst activity of TiO_2, respectively, for methylene blue (Figure 9. (b)) and sasirangan waste (Figure 10. (b)). The irregular absorbance peaks of methylene blue are also likely due to the concentration of methylene blue (4 ppm) being too low for UV-Vis spectrophotometry device. This is by [36] that UV-Vis spectrophotometry uses lower energy, so it cannot be too accurate for too dilute concentrations. This also shows the superiority of aloe vera in TiO2 synthesis (stable curve Figure 9. (b)). In sasirangan waste, the irregular adsorption graph is likely caused by the complex waste content. Similar research by [37] with ZnO as a photocatalyst also showed a decrease in absorbance over time. TiO_2 thin films have good and stable photocatalyst activity, allowing electron excitation that causes holes to react with H_2O to form hydroxyl radicals that degrade organic compounds [38]. We suspect that this is the cause of the pH of the sasirangan waste also changing from 9 to 7 after 24 hours.
In order to see much clearer differences in photocatalyst activity, the photodegradation of methylene blue and sasirangan waste were calculated by using Equation (2) based on the decrease in the absorbance curve of UV-Vis spectrophotometer. Furthermore, the photodegradation of the synthesized TiO_2 tended to increase linearly until 75 minutes (see Figure 11.).

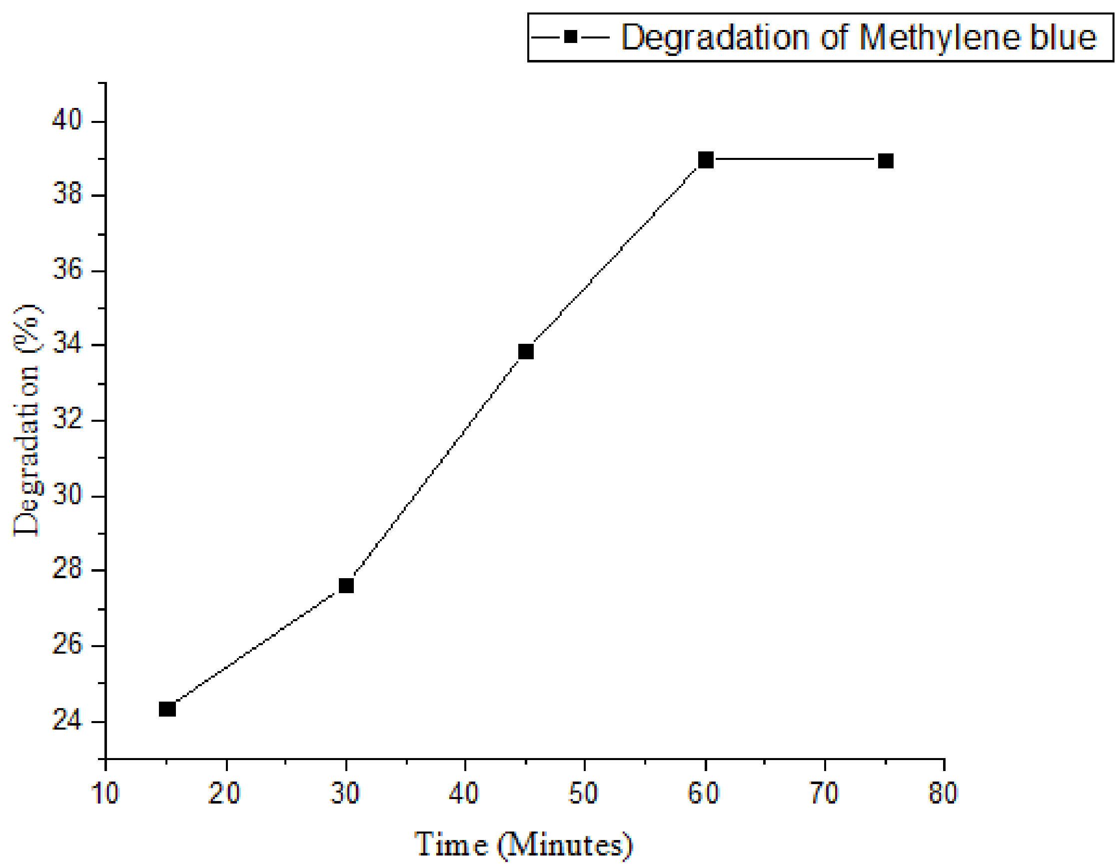


Figure 11. Percentage Degradation of TiO_2

Therefore, photocatalyst activity of green synthesis TiO_2 using $TiCl_4$ and aloe vera extract were more effective in degrading methylene blue compared to commercial TiO_2. This difference may be related to the unique characteristics of green synthesis photocatalysts, such as particle size [39] and the presence of bioactive compounds from aloe vera that can stabilize the TiO_2 particle formation process [40][25].

Conclusion

TiO_2 has been successfully greenly synthesized using aloe vera. The formation of TiO_2 was confirmed by FTIR measurement, while the results of UV-Vis spectrophotometer showed that the resulting TiO_2 has optical properties suitable for photocatalyst applications. XRD and SEM characterizations show that the use of aloe vera extract did not affect the formation of the desired TiO_2 phase, namely anatase. In base conditions, more TiO_2 was produced than under acidic or neutral conditions. The TiO_2 thin film showed significant photodegradation of 38.9% and 4.5%, respectively, for methylene blue and sasirangan waste. Unfortunately, the photodegradation of sasirangan waste is not directly proportional to the duration of exposure. Further investigation into the components of sasirangan waste is needed to explain the irregular pattern.

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References

[1] E. Y. Nugraheni and M. Maryanto, "Motif Variety Of Sasirangan On Martapura Riverbank Communities," *2nd Int. Conf. Art Cult. (ICONARC 2018). pp*, vol. 271, no. Iconarc 2018, pp. 25–28, 2019, doi: 10.2991/iconarc-18.2019.60.

[2] A. S. Almu'minin, "Sintesis dan Karakterisasi Film Lapis Tipis TiO2 Sebagai Pendegradasi Pewarna Tekstil Procion Red MX-8B," Universitas Jember, 2015.

[3] R. S. Khalis, Margareta, Hasbullah, E. Suarso, S. Fitriana, and U. Farisa, "Development Of Sasirangan Liquid Waste Treatment System Using Ozonization Method Using Composite Ceramic Filter Media Based On Water Chestnut (Eleocharis Dulcis)," *J. Phys. Its Appl.*, vol. 6, no. 1, pp. 31–37, 2023.

[4] A. Khair, "Larutan Tawas dan Skala Warna Air Limbah Industri Sasirangan," *J. Skala Kesehat.*, vol. 8, no. 1, pp. 2–31, 2017.

[5] L. Marisa, A. Mukarramah, and A. I. Fatya, "Pengaruh Variasi Aktivator ZnCl 2 dan NaOH terhadap Efisiensi Adsorpsi Karbon Aktif dari Kayu Cempedak (Artocarpus Champeden) sebagai Adsorben dalam Limbah Sasirangan," *Al Kawnu Sci. Local Wisdom J.*, vol. 3, no. 2, pp. 26–35, 2024, doi: 10.18592/ak.v3i2.12671.

[6] U. Santoso *et al.*, "Pengolahan Limbah Cair Sasirangan Melalui Kombinasi Metode Filtrasi dan Fitoremidiasi Sistem Lahan Basah Buatan Menggunakan Tumbuhan Air

yang Berbeda," *EnviroScienteae*, vol. 10, no. 3, pp. 157–170, 2014, [Online]. Available: https://ppjp.ulm.ac.id/journal/index.php/es/article/view/1978

[7] H. Aliah and Y. Karlina, "Semikonduktor TiO2 Sebagai Material Fotokatalis Berulang," *J. ISTEK*, vol. IX, no. 1, pp. 185–203, 2015.

[8] H. S. Okto and Munasir, "Review: Green Synthesis Nanopartikel TiO2 Sebagai Material Fotokatalis," *J. Inov. Fis. Indones.*, vol. 12, no. 2, pp. 82–91, 2023.

[9] T. N. Sucahya, N. Permatasari, and A. B. D. Nandiyanto, "Review: Fotokatalis Untuk Pengolahan Limbah Cair," *J. Integritas Proses*, vol. 6, no. 1, pp. 1–15, 2016.

[10] S. U. Ramadhani, L. Destiarti, and I. Syahbanu, "Degradasi Bahan Organik Pada Air Gambut Dengan Fotokatalis TiO2 Lapis Tipis," *J. Kim. Khatulistiwa*, vol. 6, no. 1, pp. 50–56, 2017.

[11] M. Hikmah and N. Wahyuni, "Sintesis Fotokatalis TiO2 Untuk Degradasi Zat Warna Sintetis Metilen Biru Dengan Bantuan Sinar Tampak," *J. Teknol. Lingkung. Lahan Basah*, vol. 11, no. 3, p. 878, 2023, doi: 10.26418/jtllb.v11i3.70903.

[12] W. D. Prastiwi, K. D. Maulana, E. A. P. Wibowo, N. R. Aji, and A. Setyani, "Sintesis dan Karakteristik TiO2 dan SiO2 Serta Aplikasinya Terhadap Kadar Fe Dalam Air Sumur," *J. Ilm. Sains*, vol. 17, no. 1, pp. 30–34, 2017.

[13] M. Santiago, D. Rivera, and A. Torres, "Green Synthesis of Titanium Oxide Nanoparticles Using Natural Extracts," *J. Mater. Sci. Chem. Eng.*, vol. 11, no. 02, pp. 29–40, 2023, doi: 10.4236/msce.2023.112003.

[14] T. M. I. Kojong, H. Aritonang, and H. Kolengan, "Green Syntesis Nanopartikel Perak (Ag) Menggunakan Larutan Daun Rumput Macan (Lantana Camara L .)," *Chem. Prog*, vol. 11, no. 2, pp. 46–51, 2018.

[15] K. G. Rao, C. H. Ashok, K. V. Rao, and C. H. S. Chakra, "Green Synthesis Of TiO2 Nanoparticles Using Aloe Vera Extract Green Synthesis Of TiO 2 Nanoparticles Using Aloe Vera Extract," *J. Adv. Res. Phys. Sci.*, vol. 2, no. 1, pp. 28–34, 2015.

[16] M. S. Hanafy, D. A. A. Fadeel, M. A. Elywa, and N. A. Kelany, "Green Synthesis and Characterization of TiO2 Nanoparticles Using Aloe Vera Extract At Different pH Value," *Sci. J. King Faisal Univ.*, vol. 21, no. 1, pp. 103–110, 2020, doi: 10.37575/b/sci/2020.

[17] D. V. Wellia *et al.*, "Rind Of Aloe Vera (L.) Burm. f Extract For The Synthesis Of Titanium Dioxide Nanoparticles: Properties and Application In Model Dye Pollutant Degradation," *Case Stud. Chem. Environ. Eng.*, vol. 9, no. January, pp. 1–9, 2024, doi: 10.1016/j.cscee.2024.100627.

[18] D. A. Abdel Fadeel, M. S. Hanafy, N. A. Kelany, and M. A. Elywa, "Novel greenly synthesized titanium dioxide nanoparticles compared to liposomes in drug delivery: in vivo investigation on Ehrlich solid tumor model," *Heliyon*, vol. 7, no. 6, p. e07370, 2021, doi: 10.1016/j.heliyon.2021.e07370.

[19] B. Bulgar, G. Ozkan, O. S. Angi, and G. Ozkan, "Green Synthesis of TiO2 Nanoparticles Using Aloe Vera Extract as Catalyst Support Material and Studies of Their Catalytic Activity In Dehydrogenation of Ethylenediamine Bisborane," *Int. J. Hydrogen Energy*, vol. 75, pp. 466–474, 2024.

[20] M. Ohring, *Materials Science Of Thin Films: Depositions and Structure. Edisi ke-1*. Cambridge: Academic Press, 2022.

[21] N. R. Putri, D. Nofiandi, and K. Khotimah, "Pembuatan dan Karakterisasi Edible Film Dari Pati Bonggol Pisang Kepok (Musa balbisiana Colla)," *J. Katalisator*, vol. 6, no. 2, pp. 211–222, 2021.

[22] M. Uyun, "Synthesis Of TiO2 Nanoparticles Rutile Using TiCl3 Precursors (Hydrolysis and mineralization Process) and TiCl4 Precursors," Institut Teknologi Sepuluh Nopember, 2015.

[23] D. P. Mohapatra *et al.*, "Photocatalytic Degradation Of Carbamazepine In Wastewater By Using A New Class Of Whey-Stabilized Nanocrystalline TiO2 and ZnO," *Sci. Total Environ.*, vol. 485–486, no. 1, pp. 263–269, 2014, doi: 10.1016/j.scitotenv.2014.03.089.

[24] F. Deswardani, Nelson, Nurhidayah, Helga Dwi, and M. F. Afrianto, "Analisis Gugus Fungsi Pada TiO2/Biochar Dengan Spektroskopi FTIR (Fourier Transform Infrared)," *J. Online Phys.*, vol. 5, no. 2, pp. 54–58, 2020, doi: 10.22437/jop.v5i2.9397.

[25] E. T. Bekele, B. A. Gonfa, O. A. Zelekew, H. H. Belay, and F. K. Sabir, "Synthesis Of Titanium Oxide Nanoparticles Using Root Extract Of Kniphofia Foliosa As A Template," in *Characterization, and Its Application on Drug Resistance Bacteria*, 2020, pp. 1–10.

[26] S. Srujana *et al.*, "A Comprehensive Study On The Synthesis and Characterization Of TiO2 Nanoparticles Using Aloe vera Plant Extract and Their Photocatalytic Activity against MB Dye," *Adsorpt. Sci. Technol.*, vol. 2022, pp. 1–9, 2022, doi: 10.1155/2022/7244006.

[27] M. Julita, M. Shiddiq, and M. Khair, "Penentuan Energi Celah Pita (Band Gap) Nanopartikel ZnO/Au Hasil Ablasi Laser dalam Cairan," *Periodic*, vol. 12, no. 2, p. 71, 2023, doi: 10.24036/periodic.v12i2.118243.

[28] Suryajaya, Habibah, S. Husain, and N. H. Haryanti, "Synthesize Of CdS Nanoparticles Using Liquid-Gas Method," *J. Phys. Conf. Ser.*, vol. 1816, no. 1, 2021, doi: 10.1088/1742-6596/1816/1/012112.

[29] D. Indriani, H. D. Fahyuan, and N. Ngatijo, "Uji UV-Vis Lapisan TiO2/N2 Untuk Menentukan Band Gap Energi," *J. Online Phys.*, vol. 3, no. 2, pp. 6–10, 2018, doi: 10.22437/jop.v3i2.5142.

[30] S. Wardiyati, F. Adel, and Yusuf Saeful, "Sintesis Nanokatalis TiO2 Anatase Dalam Larutan Elektrolit Dengan Metode Sol Gel," *J. Sains Mater. Indones. Akreditasi*, no. April 2012, p. 44, 2018.

[31] D. Wojcieszak *et al.*, "Effect Of The Structure On Biological and Photocatalytic Activity Of Transparent Titania Thin-Film Coatings," *Mater. Sci. Pol.*, vol. 34, no. 4, pp. 856–862, 2016, doi: 10.1515/msp-2016-0100.

[32] N. I. AS, V. Zharvan, D. Rizqa, S. Hadi, Y. Gatut, and Darminto, "Pengaruh pH pada Pembentukan Nano-powder TiO2 Fase Anatase dan Sifat Fotokatalisnya," *J. Fis. dan Apl.*, vol. 11, no. 2, p. 60, 2015, doi: 10.12962/j24604682.v11i2.1056.

[33] S. Ramalingam, "Synthesis of Nanosized Titanium Dioxide (Tio2) By Sol-Gel Method," *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. S2S, pp. 732–735, 2020, doi:

10.35940/ijitee.B1174.1292S219.

[34] D. Fatmawati and A. B. Aritonang, "Sintesis dan Karakterisasi TiO2-Kaolin Menggunakan Metode Sol-Gel," *J. Kim. Khatulistiwa*, vol. 8, no. 2, pp. 15–21, 2019, [Online]. Available: https://jurnal.untan.ac.id/index.php/jkkmipa/article/view/36559

[35] P. Praveen, G. Viruthagiri, S. Mugundan, and N. Shanmugam, "Structural, Optical and Morphological Analyses Of Pristine Titanium Di-Oxide Nanoparticles - Synthesized Via Sol-Gel Route," *Spectrochim. Acta - Part A Mol. Biomol. Spectrosc.*, vol. 117, no. 2017, pp. 622–629, 2014, doi: 10.1016/j.saa.2013.09.037.

[36] Agilent, "The Basics of UV-Vis Spectofotometry," USA, 2021, pp. 1–36.

[37] T. C. Raganata, H. Aritonang, and E. Suryanto, "Sintesis Fotokatalis Nanopartikel ZnO Untuk Mendegradasi Zat Warna Methylene Blue," *Chem. Prog*, vol. 12, no. 2, pp. 54–58, 2019.

[38] R. Tussa'adah and Astuti, "Sintesis Material Fotokatalis TiO2 Untuk Penjernihan Limbah Tekstil," *J. Fis. Unand*, vol. 4, no. 1, pp. 91–96, 2015.

[39] D. Li *et al.*, "Pengaruh Ukuran Partikel Terhadap Struktur dan Kinerja Fotokatalik TiO2 yang Diperlakukan Dengan Alkali," *Nanomater.*, vol. 10, no. 3, p. 546, 2020, doi: 10.3390/nano10030546.

[40] J. Rajkumari *et al.*, "Synthesis Of Titanium Oxide Nanoparticles Using Aloe Barbadensis Mill and Evaluation Of Its Antibiofilm Potential Against Pseudomonas Aeruginosa PAO1," *J. Photochem. Photobiol. B Biol.*, vol. 201, no. May, p. 111667, 2019, doi: 10.1016/j.jphotobiol.2019.111667.