International Journal for Research in Applied Sciences and Biotechnology

ISSN: 2349-8889
Volume-9, Issue-3 (May 2022)

www.ijrasb.com

https://doi.org/10.31033/ijrasb.9.3.10

Performance of Photovoltaic of Solar Cell Based on Natural and Synthetic Dye

Ibnu Hazar Al Haitami[1], Sri Mulijani[2] and Komar Sutriah[3]
[1]Department of Chemistry, Bogor Agriculture University, INDONESIA.
[2]Department of Chemistry, Bogor Agriculture University, INDONESIA.
[3]Department of Chemistry, Bogor Agriculture University, INDONESIA.

[2]Corresponding Author: srimulijani@apps.ipb.ac.id

ABSTRACT

Dye-sensitized photovoltaic solar cells were developed to obtain high efficiency by replacing the sensitizer, semiconductor, and modifying it with polymer electrolyte. In this study, an evaluation of natural dyes derived from sappan wood (*Caesalpinia sappan L.*) and synthetic dyes strawberry red was carried out to increase the efficiency of DSSC performance with the addition of anatase TiO2 nanoparticles as a semiconductor. The DSSC assembly uses natural and synthetic dyes for the applied counter electrode to obtain maximum energy conversion efficiency. The value of efficiency and other electrical parameters as photovoltaic performance is obtained by measuring the performance of the cell by considering the photoelectrochemical output and measuring current and voltage. FTIR and UV-Vis were used to determine the compounds contained in natural and synthetic dyes. Testing the crystallinity of TiO_2 anatase was measured using X-Ray Diffraction, while an atomic force microscope was used to test the surface topography of the counter-electrode plate containing dye. The result of UV-vis measurement of natural dyes shows that two maximum wavelengths of synthetic dyes are 488 nm (Brazilin), 540 nm (Brazillein), and synthetic dyes containing anthocyanins (510 nm). The XRD diffractogram revealed that TiO_2 was formed with the standard anatase phase (JCPDS) 21-1272. The surface topography of the PVSC plate shows that the dye in TiO_2 is evenly distributed. The energy efficiency conversion of synthetic dye exhibited more greater than natural dye. Thus, it can be concluded that strawberry red dye have potential as good dye sensitizers for DSSC.

Keywords- dye sensitizer, natural dye, photovoltaic, sappan wood, synthetic dye.

I. INTRODUCTION

Nowadays, solar energy is a source of renewable energy that can be converted into electrical energy. Conversion of solar energy to electrical energy is an alternative solution for future energy needs. DSSC is the current generation of solar cell technology developed by Michael Gratzel that utilizes dyes as solar energy absorbers and converts them into electrical energy. DSSC consists of five important components: conductive glass, dye, electrolyte solution, counter electrode, and titanium oxide (TiO_2) semiconductor [1]. TiO_2 nanocrystals have three different forms, namely rutile, anatase, and brookite. The most often used as semiconductors is anatase TiO_2 crystals due to photoactive compared to rutile and brookite TiO_2 [2]. The dye used as a sensitizer is in the form of natural or synthetic dyes. Natural dyes usually come from plant extracts, such as leaf, flower, and fruit extracts. Ruthenium (Ru) is an inorganic dye that is best used as a dye in the DSSC and produces high energy conversion efficiency. Unfortunately, it is not environmentally friendly and expensive. On the other hand, natural dyes have the advantage of being cheap, environmentally friendly, and abundant in nature [3]. *Caesalpinia sappan L.* is a type of medicinal plant that can be used as a natural dye because it contains brazillin causing a red dye. Brazilin ($C_{16}H_{14}O_5$) is a compound that is used as a natural dye and belongs to the group of flavonoid compounds [4] .

The sensitizer variation on the PVSC will affect the efficiency value. Previous study, the efficiency of PVSC based on Hibiscus Sabdariffa and Rosa Damascena extracts were 0.28% and 0.11%, respectively [5]. The aims of study was to evaluate the use of natural dyes which was extracted from sappan wood and synthetic strawberry dyes to increase efficiency in DSSC devices.

II. METHODOLOGY

Ten grams of mashed dried sappan wood purchased from traditional market in Bogor was extracted using 60 mL of ethanol as a solvent. The ethanol was purchased from Brataco Chemical store. Furthermore, the extraction results were filtered using Whatman 42 filter paper. Then, strawberry red synthetic dye as an additive material for food was dissolved using ethanol in a 100 mL flask. The obtained filtrate was then stored in a dark container and used as a dye in DSSC.

The conductive glass ITO from Solaronic with size (1.5×1.5) cm^2 was cleaned using acetone and dried. Furthermore, the conductive glass is measured its resistance using a digital multimeter on the conductive side. TiO_2 paste was made by weighing 3.5 g of TiO_2 and 15 mL of ethanol and then stirring using a magnetic

ISSN: 2349-8889
Volume-9, Issue-3 (May 2022)

https://doi.org/10.31033/ijrasb.9.3.10

stirrer for 30 minutes. Furthermore, five drops of triton X-100 were added and stirred again for 30 minutes until homogeneous to form a paste. The TiO_2 paste was deposited on the conductive side of the glass using a stir bar, then dried and heated at 350°C for ±30 minutes. After that, the TiO_2-coated conductive glass was immersed in the dye extract for one hour, then dried using tissue paper.

The reference electrode is made by coating the conductive side of the conductive glass using a carbon layer. The conductive glass is cleaned using acetone and then dried. Next, the resistance is measured using a digital multimeter. On the side of the conductive glass, scratched in the direction of the 8B pencil evenly. After that, the conductive part of the glass is heated over a candle flame to obtain a carbon layer. The iodide/triiodide electrolyte solution was prepared by dissolving 0.8 g of potassium iodide (KI) into 10 mL of 1 N methanol and then stirring until homogeneous. Then 0.127 g of iodine (I_2) was added to the solution and stirred again until homogeneous. The solution is then stored in dark-colored bottles or bottles lined with aluminum foil. All DSSC components are combined into a DSSC circuit. The working electrode is placed above the reference electrode, which has been dripped with electrolyte. The coating method between electrodes is called the sandwich method [6],[7]. In this study, the characterizations used were UV-VIS, FT-IR, XRD, and AFM spectrophotometers. UV-vis spectrum testing is used to determine the wavelength of sappan woods dye with a wavelength range of 255-750 nm and a scanning interval of 2 nm. The Fourier Transform Infrared (FTIR) was employed to determine the function group contained in natural and synthetic dyes. X-Ray Diffraction (XRD) testing was carried out to determine the level of crystallinity, particle size, phase percentage of material of TiO_2. Atomic Force Microscopy (AFM) was used to evaluate the surface topography and distribution of the TiO_2 phase coated into dye. Potentiostat E-DAQ and e-corder 410 are used to observe the presence of current (I) and voltage (V) of the DSSC. Curve IV can be used to determine the efficiency of DSSC energy conversion which converts sunlight into electrical energy[8],[9].

III. RESULT AND DISCUSSION

The four basic steps involved in the working principle of DSSC are dye as a sensitizer absorbing light, followed by the injection of electrons into the conduction band and the last carrier transport is current collection. One of the requirements of dye for DSSC is luminescent dye form [10], [11]. Figure 1(a) shows the dried *Caesalpinia sappan L* and Figure 1(b) shows the extracted of *Caesalpinia sappan L*. The extracted dye appears luminescent red, this dye has good potential to be used as a dye sensitizer for DSSC.

Figure 1. *Caesalpinia sappan L*. material (a), extracted dye (b)

Absorption spectra of extracted dye presence in ultraviolet-visible region. As shown in Figure 2a. is extracted dye revealed in 480 nm and 540 nm and it indicates brazillin and brazilein compound which are the major coloring pigments in *Caesalpinia sappan L*.

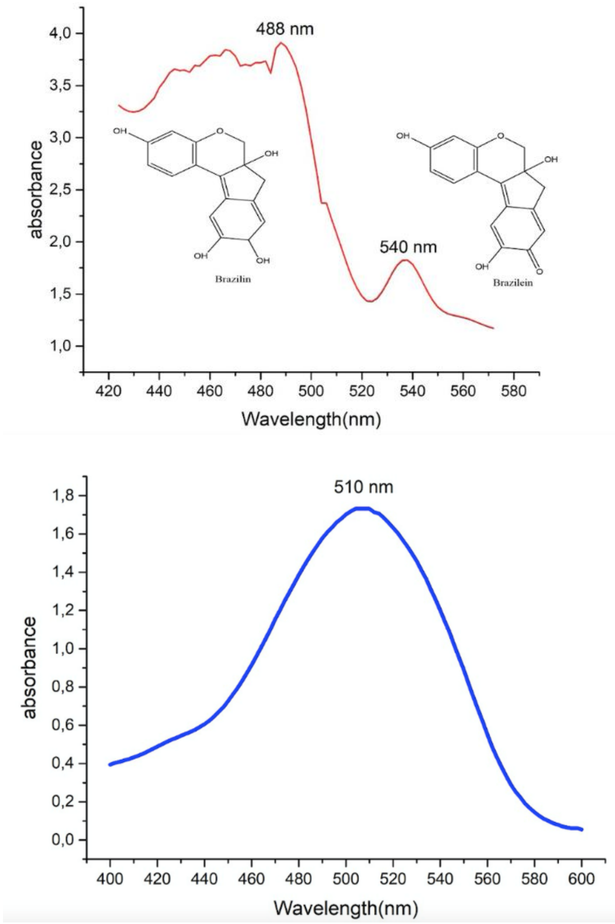

Figure 2. The UV-vis spectra of dye extraction of *Caesalpinia sappan L*. (a) and synthetic dye strawberry red (b)

International Journal for Research in Applied Sciences and Biotechnology
www.ijrasb.com

ISSN: 2349-8889
Volume-9, Issue-3 (May 2022)
https://doi.org/10.31033/ijrasb.9.3.10

Brazilin is the main active ingredient in Sappan wood extract. These compounds are heterotetracyclic organic compounds and are classified as neoflavonoids. The presence of a hydroxyl group in Brazilin is very easily oxidized to form a carbonyl. This structural transformation causes braziline to easily form brazilein compounds. Brazilin which was originally yellow, will turn red and dissolve in water if oxidized. The yellow color of brazilin, which changes to reddish brazilein, is due to an increase in electron delocalization due to the presence of a carbonyl group [12][13]. Figure 2b. shows absorption edge at 510 nm in the case of synthetic dye of strawberry red. Anthocyanins are the main pigments in synthetic dye strawberry red. The dye tends to facilitate the rapid movement of electrons to the conduction band of TiO_2 because it has a small band gap. Most of these dyes exhibit appreciable shifts at the absorption edge towards longer wavelengths when coated on TiO_2. The light-harvesting capacity and hence the photocurrent of the cell will increase as a result of the shift towards longer wavelengths. It also shows the partial chemical bonding of the dye with Ti^{4+} from TiO_2, bring out to the formation of the dye-TiO_2 complex.

Figure 3. reveals several active groups in the content of sappan wood. At wave numbers 3401cm^{-1} indicates the presence of an OH functional group, while at wave numbers 1615 cm^{-1} and 1502 cm^{-1} there is absorption due to the presence of a C=C alkene group, 1259 cm^{-1} and 1040 cm^{-1} have a CO group cm^{-1}, and the wavenumber of 857 cm^{-1} indicates the CH region. These characteristics show that the compound contained in the sappan wood compound is brazilin. In Figure 3b, there is an OH functional group at the absorption wave number 3205 cm^{-1}, then the absorption at wave numbers 1636 cm^{-1}, 1492 cm^{-1}, and 1423 cm^{-1} indicates the presence of a C=C alkene functional group. Furthermore, it is seen that there is absorption at wave number 1048 cm-1 which indicates the presence of C-O groups, while the C-H functional group is seen by absorption at wave number 978cm^{1}.

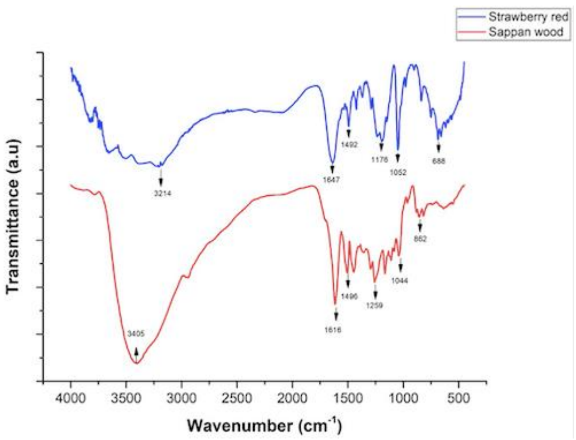

Figure 3. FTIR spectra of dye extraction of *Caesalpinia sappan L*. and synthetic dye strawberry red.

Figures 4 show the results of the crystal phase analysis using XRD. The peaks formed on TiO_2 were compared with the TiO_2 anatase standard joint committee on powder diffraction standards (JCPDS) 21-1272 [14]. The number of peaks formed was similar to that of the anatase phase XRD. Based on the comparison of the results of the characterization of 4a TiO_2 and the standard, the results of the TiO_2 peaks are classified in the crystalline form of the anatase phase.

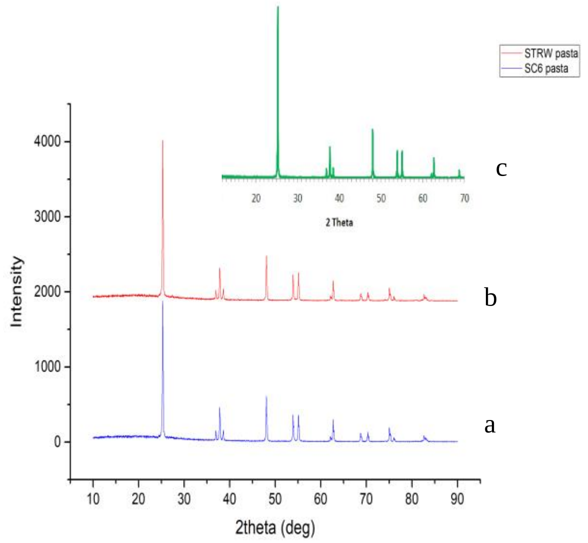

Figure 4. Difractogram of TiO_2

Performance of DSSC by electrochemical analysis

Figures 6 and 7 are curves of current strength against the voltage of the dyestuffs of sappan wood extract and strawberry red. DSSC performance can be improved by modifying some of its constituent components because each component has an important role in the DSSC work process. The following are several stages of the DSSC

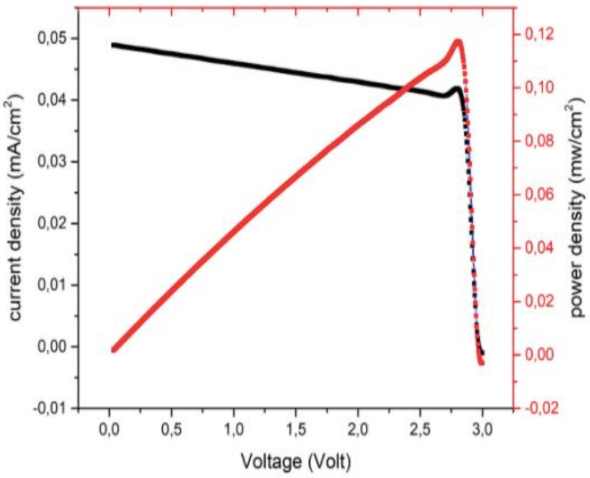

Figure 5: I-V curve of natural dye sappan wood extract

ISSN: 2349-8889
Volume-9, Issue-3 (May 2022)

www.ijrasb.com

https://doi.org/10.31033/ijrasb.9.3.10

Figures 5 shows curves of current density against the voltage of the dyestuffs of sappan wood extract. DSSC performance can be improved by modifying some of its constituent components because each component has an important role in the DSSC work process. The following are several stages of the DSSC work process. The DSSC work process follows several stages. Stage 1 occurs in the process of light absorption and excitation. The dye that is in the ground state will absorb photons from the light so that the electrons will move from the ground state / HOMO (Highest Occupied Molecular Orbital) to the excited state / LUMO (lowest unoccupied molecular orbital). Stage 2 occurs in the electron injection process. The dye in the excited state will undergo an oxidation reaction, thereby releasing electrons. The electrons will be transferred to the conduction band of the semiconductor TiO2 (titanium dioxide). Then the electrons diffuse to the current collecting section of the anode to produce an electric current. Stage 3 is the process of regeneration of the dye. The oxidized dye will regenerate. The regeneration that occurs is assisted by the transfer of electrons from the iodide in the electrolyte solution. Stage 4 occurs the reduction process at the cathode. Iodide in the electrolyte solution will undergo reduction assisted by triiodide at the cathode [10], [15].

The I-V DSSC curve was obtained from analysis with a potentiostat using the E-Chem V.2.1.6 software. Fill factor calculation using the formula: FF= Pmax/ ISC x VOC and efficiency measurement using the formula = $p_m/(p_{in})$ X 100%. = Light conversion efficiency (%), Pmax = Maximum power obtained (W/cm2), Pin = Power intensity of light irradiated on the DSSC (W/cm2). The light used comes from an LED lamp with a capacity of 33 watts, namely a pin of 146.7 mW/cm2. Figures 6 and 7 show the I-V curves of DSSC derived from sappan wood extract dye and strawberry red, semi-conductors used TiO2 nanoparticles. Figure 6 shows the Pmax value of 0.664 mW/cm2 and the highest Jsc value of 0.7374 mA/cm2. Figure 7 It can be said that the higher the value of Jsc, the more photons that are adsorbed [16]. So that the efficiency value (η) of the DSSC obtained is 0.3%

PVSC Electrode Surface Topography

The surface topography of the DSSC working electrode was analyzed using Atomic Force Morphology (AFM). AFM is a technique for analyzing surface morphology/topography at the nanoscale. In this study, AFM was used to observe the surface layer of the TiO2 semiconductor and extract the sappan dye. Figure 6 shows a hollow indicating that the surface layer has not been filled with dye, while Figure 6b shows that the semiconductor has been filled with dye. It can be seen that the addition of dye to TiO2 has evenly covered the pores of the semiconductor, so that it can increase the absorption of photons. TiO2 nanoparticles are able to increase the surface area and thus it would assist increase the efficiency of the DSSC.

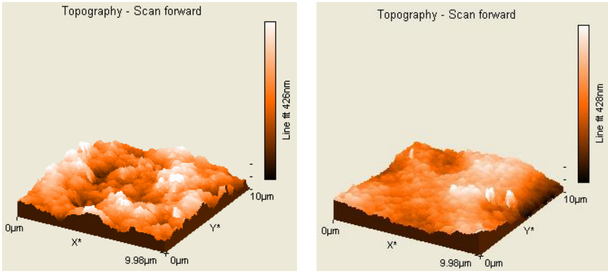

Figure 6: Topography morphology of PVSC before (a) after (b) testing

IV. CONCLUSION

Based on UV Vis and FTIR measurements, the dye extracted from sappan wood contains brazilin and brazilein compounds. TiO_2 anatase nanoparticles can improve the performance of DSSC of efficiency 0.09%. it can be concluded, that dye of sappan wood extract shows the potential as a sensitizer for DSSC.

REFERENCES

[1] L. B. Patle and A. L. Chaudhari, “Performance of DSSC with Cu Doped TiO2 Electrode Prepared by Dip Coating Technique,” *International Journal of Scientific and Engineering Research*, vol. 7, no. 8, pp. 1004–1009, 2016.

[2] R. Sastrawan, “Photovoltaic modules of dye solar cells: Ronald Sastrawan,” *Solar Energy Materials and Solar Cells*, 2006, [Online].

[3] M. R. Narayan, “Review: Dye sensitized solar cells based on natural photosensitizers,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 208–215, 2012, doi: 10.1016/j.rser.2011.07.148.

[4] A. Kowsar *et al.*, “Progress in major thin-film solar cells: Growth technologies, layer materials and efficiencies,” *International Journal of Renewable Energy Research*, vol. 9, no. 2, pp. 579–597, 2019.

[5] R. D. Flowers, S. A. Taya, T. M. El-agez, and H. A. Al-mogiar, “Solar Cells Sensitized with the Extracts of Hibiscus,” vol. 6, no. 2, 2016.

[6] G. Xing *et al.*, “Effect of cerium ion modifications on the photoelectrochemical properties of TiO2-based dye-sensitized solar cells,” *Optical Materials*, vol. 75, pp. 102–108, 2018, doi: 10.1016/j.optmat.2017.10.006.

[7] J. Suryadi, G. Gunawan, and A. Haris, “Pembuatan dan Penentuan Nilai Efisiensi Sel Surya Berpewarna Tersensitisasi dengan Senyawa Antosianin dari Buah Manggis (Garcinia mangostana L.) sebagai Pewarna Pensensitisasi,” *Jurnal Kimia Sains dan Aplikasi*, vol. 13, no. 3, pp. 88–94, 2010, doi: 10.14710/jksa.13.3.88-94.

[8] M. I. Khan, “A Study on the Optimization of Dye-Sensitized Solar Cells,” no. January, 2013.

[9] S. Agarkar, “Dye sensitized solar cell : Optimizing materials , methods and optoelectronic effects,” *AcSIR*, pp. 1–234, 2014.

[10] M. Alhamed, A. Issa, and A. Doubal, “Studying of natural dyes properties as photo-sensitizer for dye sensitized solar cells (DSSC),” *Journal of Electron Devices*, vol. 16, pp. 1370–1383, 2012, [Online]. Available: http://www.jeldev.org/16_Mounir.pdf.

[11] H. Hug, M. Bader, P. Mair, and T. Glatzel, “Biophotovoltaics: Natural pigments in dye-sensitized solar cells,” *Applied Energy*, vol. 115, no. February, pp. 216–225, 2014, doi: 10.1016/j.apenergy.2013.10.055.

[12] S. Mulyanto, “Pengaruh Temperatur Ekstraksi dan Heating Timeterhadap Spectrum Absorbansi pada Zat Warna Alam dari Kayu Secang,” *JTT (Jurnal Teknologi Terpadu)*, vol. 4, no. 1, pp. 7–11, 2016, doi: 10.32487/jtt.v4i1.122.

[13] HaijuanDuJu, ChengMinghuan, WangMengchao, TianXiaoming, YangQingWang. Red dye extracted sappan wood waste derived activated carbons characterization and dye adsorption properties

[14] T. Theivasanthi and M. Alagar, “Titanium dioxide (TiO2) Nanoparticles XRD Analyses: An Insight,” 2013, [Online]. Available: http://arxiv.org/abs/1307.1091.

[15] O. Adedokun, K. Titilope, and A. O. Awodugba, “Review on Natural Dye-Sensitized Solar Cells (DSSCs),” *International Journal of Engineering Technologies*, *IJET*, vol. 2, no. 2, p. 34, 2016, doi: 10.19072/ijet.96456.

[16] Sholihun, “Tesis komputasi parameter internal sel surya organik dan penentuan pola keterkaitannya terhadap intensitas menggunakan metode,” 2009.