



Increasing Efficiency of Dye-Sensitized Solar Cell (DSSC) Originating from Yellow Sweet Potato Extract as Dye Sensitizer: Effect of Acetic Acid, Polyethylene Glycol, and Polyvinyl Alcohol as TiO₂ binders



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Abstract

This study aimed to obtain the most efficient Dye-Sensitized Solar Cell (DSSC) using yellow sweet potato extract (*Ipomoea Batatas* L.) as a dye sensitizer, with acetic acid, polyethyleneglycol (PEG), and polyvinylalcohol (PVA) as TiO₂ binding solution. This research includes the preparation of TiO₂ paste with variations: 4 g TiO₂ plus 2 M acetic acid (Paste-1), 3.5 g TiO₂ plus 15 mL PEG-400 (Paste-2), and 0.5 g TiO₂ plus 0.75 mL PVA (Paste-3). Anthocyanin dye from yellow sweet potato was prepared and used to soak the TiO₂ photoelectrode for 24 hours. UV-vis and FTIR spectra of dye solution from yellow sweet potato extract showed anthocyanin content at a maximum wavelength of 283 nm and were strengthened by the appearance of hydroxyl groups in the infrared spectra. The highest DSSC efficiency of 0.302% was obtained from PVA as a TiO₂ binder, with an electric current of 0.0204 mA and an electric voltage of 338 mv.

1. Introduction

Energy demand continues to increase along with population growth and development progress in technology, industry, and information. The need for energy, which has been relying on fossil fuels, has resulted in reduced fossil resources, particularly petroleum. Fossil energy sources are non-renewable energy sources because the formation process takes a long time, so alternative energy is vital. Energy conservation that utilizes renewable energy resources can be used as a solution as an alternative energy source, such as wind energy, solar energy, water energy, biomass, and geothermal.

Indonesia, which is located on the equator, has considerable renewable energy potential, especially solar energy. Solar energy is possible to be used as a substitute solution for fossil energy resources. Solar radiation can be directly converted into electrical energy through a conversion device called solar cells. Current solar cell technology has entered the development stage of the

third generation, namely dye-sensitized solar cells after previously there were conventional semiconductor-based solar cells made of silicon (single and multi-crystalline) and thin layer type solar cells [1, 2].

Research on solar cells' efficiency of various types continues and has increased from year to year [3]. Monocrystalline solar panel optimization is designed with the help of Reflector Scanning Technology to grow solar radiation exposure to solar panels. The lowest power produced by solar panels is at 08.00, and the highest is at 13.00 [4]. The factors that affect the performance of solar energy are the temperature of the photovoltaic and shadow panels. These two factors significantly influence the photovoltaic (PV) system's behavior to greatly affect system efficiency and energy output [5].

Michael Grätzel is the first researcher to develop Dye-Sensitized Solar Cell (DSSC) into a third-generation solar cell. DSSC consists of a pair of glass electrodes, a working electrode, and a counter electrode that sandwiches the electrolyte [6, 7]. The working electrode is TCO (Transparent Conducting Oxide) glass coated with

a wide-slit semiconductor such as TiO_2 , which is then immersed in dye as a photosensitizer, a charge carrier. Meanwhile, the opposite electrode is TCO coated with carbon, which functions as a catalyst to accelerate the redox reaction with electrolytes [8].

Anthocyanin compounds as dye sensitizers from various types of plants have been carried out, including using anthocyanin compounds from mangosteen fruit, which produce a maximum efficiency value of $2.2 \times 10^{-3}\%$ [9]. The use of roselle flower extract resulting in an efficiency of 0.01883% has also been reported [10]. Monzir *et al.* [11] used PEG as a TiO_2 binder with various natural dyes and obtained the highest efficiency of 0.56%. Meanwhile, the study, which used acetic acid as a TiO_2 binding solution and dragon fruit as a dye sensitizer, obtained an efficiency of 0.0006% [12]. The use of polyvinyl alcohol in the mixture of TiO_2 paste with synthetic dye N719 resulted in an efficiency of 2.05% [13].

Based on the above references, innovation is still needed for the optimization of the DSSC fabrication. In this research, we tried to use yellow sweet potato as a dye sensitizer. One of the flavonoid compounds in yellow sweet potato is anthocyanin. Anthocyanins can be used as a dye in DSSC as an electron donor [14]. The dye layer functions as a sensitizer to absorb photons from sunlight [15].

Apart from the dye, another factor that influences the efficiency of DSSC is the TiO_2 paste used. TiO_2 in DSSC is an anode, which will multiply the electrons flowing from the conduction band to the valence band so that the photocatalyst reaction space and dye adsorption will be more. In other words, the absorption spectrum becomes wide. The purpose of this study was to determine the effect of acetic acid, polyethylene glycol, or polyvinyl alcohol as a TiO_2 binder in producing the highest efficiency (current and voltage) values in DSSC, using anthocyanin sensitizer from yellow sweet potato extract.

2. Methodology

2.1. Materials and equipment

The equipment used in this study were the Multimeter DT-9205A and DT-830B made in China, Hot plate, Luxmeter Light Meters UNI-T UT383 made in China, Spectrophotometer UV-1800 Shimadzu and UV-2600 made in Japan, and Thermo Scientific Nicolet iS10 FTIR. Spectrometer made in the United States of America (USA). Meanwhile, the materials used included Titanium Dioxide (TiO_2), acetic acid, PEG-400, PVA, ethanol, acetonitrile, potassium iodide (KI), and iodine (I_2) produced by Merck Germany, Fluorine Doped Tin Oxide Coated Glass. (FTO) made in China, and Yellow Sweet Potatoes.

2.2. TiO_2 Paste Preparation

TiO_2 paste was prepared by mixing TiO_2 powder and various binder solutions. The binder solutions used were acetic acid, polyethylene glycol (PEG), and polyvinyl alcohol (PVA).

1. Paste-1. 4 g TiO_2 was dissolved in distilled water then stirred until homogeneous. Then to the mixture, 2 M

acetic acid was added dropwise until a paste was obtained.

2. Paste-2. 3.5 g TiO_2 and 15 mL PEG-400 were mixed with a magnetic stirrer until evenly distributed.
3. Paste-3. 0.5 g of PVA was added with 4.5 mL of distilled water. The mixture is then stirred with a magnetic stirrer at a temperature of 80°C for approximately 30 minutes until the solution thickens and is homogeneous. The solution that has been made was added to 0.5 g of TiO_2 powder, with a ratio of 2 spoons of TiO_2 spatula mixed with 15 drops or 0.75 mL of PVA solution to form a TiO_2 paste.

2.3. Preparation of Yellow Sweet Potato Dye Solution

The yellow sweet potato was extracted by drying in an oven at 105°C for 24 hours and mashed in a blender. The powder was then crushed again in a porcelain cup, filtered using Whatman filter paper to take 50 grams. Yellow sweet potato powder was dissolved in 100 mL distilled water and 21 mL ethanol. The mixture was stirred for 20 minutes, then filtered and stored in a dark bottle.

2.4. Electrolyte Solution Preparation

The electrolyte solution used in this study was the redox pair iodine, and iodide (I^-/I_3^-) gel made [16]. 0.83 grams of Potassium iodide was mixed into 1 mL of distilled water, then added 9 mL of acetonitrile or 10 mL of PEG 400 solution. 0.127 grams of iodine (I_2) was added to the solution and then stirred using a magnetic stirrer. The solution was stored in a dark bottle and tightly closed.

2.5. Preparation of reference electrode

The reference electrode was made of carbon-coated FTO glass. Carbon coating on FTO glass was by evenly scratching a 6B pencil on the FTO glass's conductive part, then heating it over a candle flame to form a black layer [17].

2.6. Assembly of Dye-Sensitized Solar Cell (DSSC)

An area of 2.5×2.5 cm FTO glass was formed where TiO_2 was deposited with tape on the conductive part of the glass so that a size of 2×2.5 cm was formed as shown in Figure 1. Paste-1 was deposited over the area made on the conductive glass with the help of a stir stick (doctor blading method) to spread the paste. The layers were dried for about 15 minutes and heated in a furnace at a temperature of about 450°C for 30 minutes.

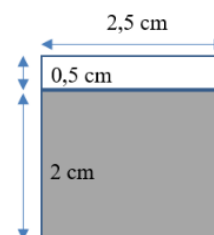


Figure 1. Schematic of TiO_2 paste deposition area on FTO glass

The TiO_2 layer was then immersed in a dye solution of yellow sweet potato extract for 24 hours so that the TiO_2 layer turned brownish-yellow. The anthocyanin

adsorption occurred on the TiO₂ surface. The TiO₂ layer soaked in dye was rinsed first with distilled water, with ethanol, then dried with a tissue paper. Polymer gel electrolyte was dropped on the TiO₂ surface and covered with a reference electrode to form a sandwich structure [18]. The cell structure was clamped with paper clips on both sides to secure the two electrodes, as shown in Figure 2. The DSSC cells were regenerated using Paste-2 and Paste-3, starting from the paste deposition step on the FTO glass to assembling the sandwich structure to obtain three DSSC cell structures.



Figure 2. Construction of the solar cell electrode

2.7. Testing and Characterization

2.7.1. Tests for dye absorption

Before being used as a sensitizer, the yellow sweet potato extract was characterized using a UV-Vis Spectrophotometer. This characterization was carried out to determine the absorption of light by anthocyanin pigments from yellow sweet potato. The absorbance spectrum was measured over the wavelength range of 400–800 nm.

2.7.2. Determination of Functional Groups

A functional group measurement was carried out to determine whether the extracted compound was an anthocyanin. The determination of functional groups was carried out using FTIR Spectrophotometry by looking at the specific peaks showing the types of functional groups possessed by anthocyanin compounds in yellow sweet potatoes. Dye samples from pure yellow sweet potato extract and dye samples from isolated yellow sweet potato extract added with TiO₂ crystals were measured for their functional groups.

2.7.3. Measurement of Electric Voltage and Current

The performance of TiO₂ - DSSC thin layer solar cells was carried out by measuring current and voltage. The DSSC cell measurements were carried out with a multimeter and sunlight as a light source [19], as shown in Figure 3.



Figure 3. DSSC current and voltage measurement

3. Results and Discussion

3.1. Absorption of Dyes

Titanium dioxide semiconductors are only able to absorb ultraviolet light with a wavelength of 350–380 nm. A dye that absorbs visible light is needed to increase the spectral absorption of titanium dioxide in the visible area. Before being used as a dye sensitizer, the yellow sweet potato extract was characterized using a UV-Vis spectrophotometer instrument. This characterization was carried out to determine the absorption of light by the anthocyanin pigments from yellow sweet potato. UV-vis spectrophotometry works to measure the light absorption of a compound in the ultraviolet (200–350 nm) and visible (350–800 nm) regions.

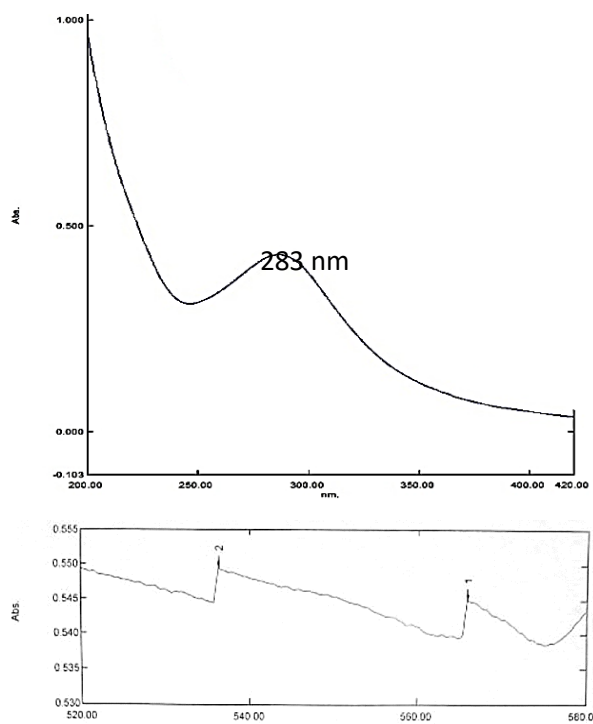


Figure 4. Absorbance spectrum of dye from Yellow Sweet Potato Extract

Figure 4 shows the spectrum of the UV-1800 Shimadzu Spectrophotometer measurement results on

yellow sweet potato extract. The spectra show absorption at a maximum wavelength (λ_{max}) of 283 nm. Meanwhile, in the Spectrophotometer UV-2600 Shimadzu, the maximum wavelength is at 536 nm. Anthocyanins in yellow sweet potato have a wide absorption in the ultraviolet light region around 250–330 nm. There are aromatic compounds as the center of the chromophore group of the phalnoind group compounds, the -OH group substituted for benzene, and the C=O group. The absorbance results showed that the yellow sweet potato extract was good enough to be used as a dye source in DSSC. The molecules in yellow sweet potato extract as DSSC sensitizers are expected to have (1) panchromatic properties, namely being able to absorb all visible colors of light at 500–580 nm [8], (2) to have functional groups that allow it to be bound to the conduction band of wide-slit material (titanium dioxide), (3) to have an appropriate level of excitation energy and (4) to have chemical and physical stability, especially heat stability. Yellow sweet potato extract produces high absorption power, which means that the ability of yellow sweet potato dye to absorb photons emitted by sunlight is also large to excite the electrons contained in the TiO₂ semiconductor from the conduction band and improve the performance of solar cells.

3.2. Functional Groups

Furthermore, to determine the functional groups contained in the yellow sweet potato extract was carried out by FTIR analysis. The condition for an electric current in the DSSC circuit is the bonding of the anthocyanin dye molecule with TiO₂. Anthocyanin dye molecules that bind to TiO₂ in the presence of light cause excitation of electrons to the TiO₂ semiconductor conduction band through the glass conducting. These electrons cause an electric current. The bond that occurs in the anthocyanin dye with TiO₂ can occur through a chelate bond. This bond can occur between the hydroxyl group of the anthocyanin and the Ti⁴⁺ group on TiO₂.

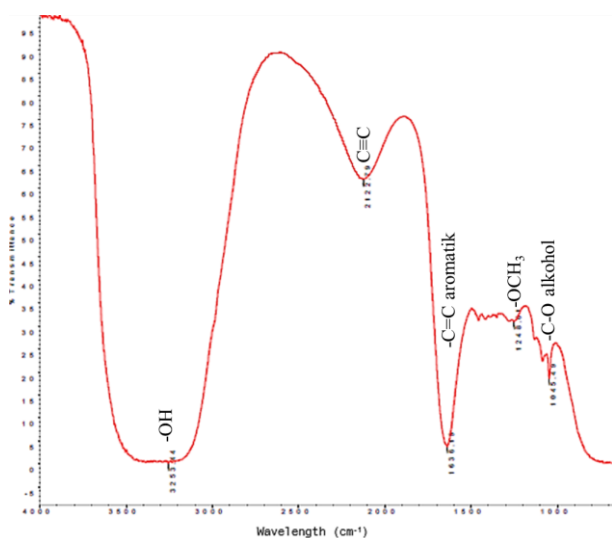


Figure 5. FTIR Spectrum of Yellow Sweet Potato Extract dye

Spectra measurements were carried out at a wavenumber of 4000–600 cm⁻¹. The FTIR spectra results

are presented in Figure 5. The dye's FTIR spectra showed absorption at a wavenumber of 3253.44 cm⁻¹ derived from a hydroxyl group, which can form a hydrogen bond. Also, the absorption at the wave number 1045.49 cm⁻¹ appears from the -C-O bond of the alcohol. This OH group's presence indicates the presence of a phenol OH group in anthocyanin compounds or alcohol compounds in the dye solution. The alcohol compound in the solution comes from one of the anthocyanin solvent constituents, which is ethanol. Alcohol can also be formed from the hydrolysis of glucosides found in anthocyanins to become alcohols called aglycones and sugar molecules. The double bond absorption -C=C- aromatic is shown by the sharp absorption at the wave number 1636.18 cm⁻¹. The peak at 2122.79 cm⁻¹ originated from the -C≡C- group's stretching vibration, while the peak at 1248.61 cm⁻¹ came from the stretching vibration of the aromatic ether group. Based on the FTIR spectrum results, it can be concluded that the extracted compound is anthocyanin. Another study using purple sweet potato as dye sensitizer produced almost the same FTIR spectra, which were at a wavenumber of 3348.88 cm⁻¹ (-OH group), 1641.17 cm⁻¹ (-C=C-aromatic group), 1015.70 cm⁻¹ (-CO alcohol group), and 675.43 cm⁻¹ (bent -CH group) [8].

When the light in the form of photons hits the DSSC cells, the energy from these photons is absorbed by the yellow sweet potato dye extract. The difference in the energy level of the absorbed photons depends on the dye used. The absorption of the photon energy causes the electrons in the dye to get excited. The presence of microparticle titanium dioxide semiconductors causes the dye to adhere to during the dyeing process. The more dye adheres, the more photoelectrons are produced. The excited electrons are then injected into the titanium dioxide conduction band so that the titanium dioxide acts as an n-type semiconductor. The injected photoelectrons move along the nanoparticles towards the top conduction band (anode). After reaching the anode, the photoelectrons move through the electrical circuit, and the excess energy is converted into electrical energy by the device in the circuit (load). The number of electrons flowing through the load per second is read as current, and the energy possessed by each electron is the voltage or electric potential.

3.3. Current and Voltage

In the DSSC made with various TiO₂ binder solutions - including acetic acid, polyethylene glycol, and polyvinyl chloride -, the current and voltage tests were carried out using a digital multimeter (Figure 3). The light source used was direct sunlight during bright lighting, which was at 12.00 noon.

Table 1. Current and Voltage Measurement Results

day	Acetic acid		PEG		PVA	
	I (µA)	V (mV)	I (µA)	V (mV)	I (µA)	V (mV)
1	8.1	218	1.3	381	20.4	338
2	7.9	322	3.6	461	16	320
3	10.5	359	1.9	407	18.9	295
4	10.5	358	3.6	448	13.6	264
5	10.8	339	3.1	442	18.7	243
6	12.7	338	3.7	436	7.6	216
20	12.7	332	2.6	238	9.7	221
40	12.9	331	4.7	230	10.2	222
50	7.1	264	3.1	213	12.4	179
60	9.9	240	1.6	172	7.4	165
70	8.9	234	1.3	157	13.5	169
80	6.9	193	2	166	11.2	125

The results of measurements with multimeters are presented in Table 1, then a graph of the relationship between current and time (days) is made and is shown in Figure 6. The voltage and current generated by the DSSC, although fluctuating from day 1 to day 2, tended to decrease from day 4 to day 80 in each TiO₂ binder solution.

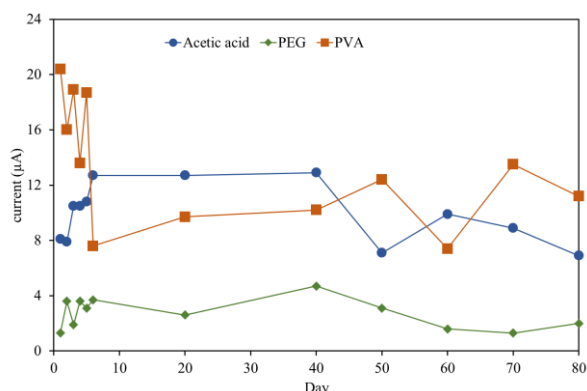


Figure 6. Correlation of current (µA) to time (days) with variations of TiO₂ binder solution

Figure 7 shows the stress of the DSSC with yellow sweet potato as a dye sensitizer with a variation of the three TiO₂ binder solutions experiencing a decreasing trend from day 3 to day 80. PVA produces a higher current and voltage value than acetic acid and PEG as TiO₂ binder in DSSC.

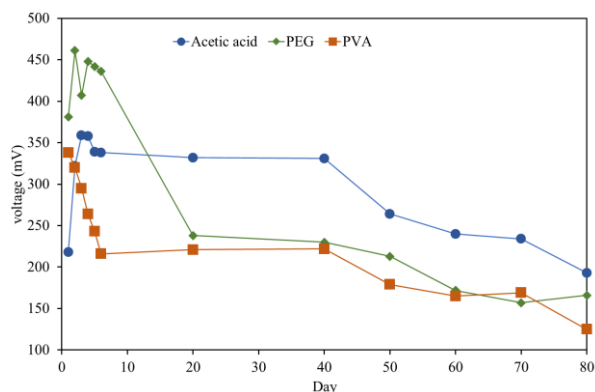


Figure 7. Correlation of voltage (mV) against time (days) with variations in TiO₂ binder solution

The amount of DSSC efficiency can be calculated using the equation: $\eta = \frac{P_{max}}{P_{in}} \times 100\%$ [20], where P_{max} is the maximum power produced by DSSC, P_{in} is the power from the light source used. The pin comes from the sun in Palembang’s city with a light intensity of around 457 mW/cm². The maximum power is given by the relationship: P_{max} = V_{max} · I_{max}. The maximum voltage generated is V_{max} and the maximum current produced is I_{max}. The resulting current and voltage measurements and the calculation of the DSSC efficiency of each TiO₂ binder solution are presented in Table 2.

Table 2. DSSC efficiency with variations of TiO₂ binder solution

No.	Binder solution	V _{max} (mV)	I _{max} (mA)	P _{max} (mW/cm ²)	P _{input} (mW/cm ²)	η (%)
1.	Acetic acid	359	0.0129	0.926	457	0.203
2.	PEG 400	461	0.0047	0.433	457	0.095
3.	PVA	338	0.0204	1.379	457	0.302

The efficiency value obtained in each type of TiO₂ binder solution on the DSSC is still below the efficiency value of solar cells with silicon-based materials. This is due to the immense value of the constraints contained in the DSSC itself. The easy evaporation process of liquid electrolytes can also degrade DSSC performance. Iodine, a redox component in a liquid electrolyte solution, has low stability because it is easily oxidized by air. This oxidation process is also accelerated by the heat received by the DSSC from the sun. Another factor that also affects the decline in the stability and performance of DSSC is the lack of strength of yellow sweet potato, which is an organic substance as a dye sensitizer.

The maximum efficiency of converting solar energy into electrical energy is obtained in PVA as a TiO₂ binding solution, with a value of 0.302%. Efficiency is calculated from the maximum voltage value of 338 mV and the maximum current value of 0.0204 mA. The initial analysis of why PVA is the most optimal as a TiO₂ binder solution to the efficiency of DSSC is because PVA has a high-density value, which is 1.19–1.31 g/cm³, and a boiling point of 228°C.

The second-largest efficiency value was obtained when using acetic acid as a TiO₂ binder. Acetic acid has physical properties with a density of 1.049 g / cm and a low pH, producing good results in maintaining TiO₂ resistance. PEG, a synthetic polymer widely used in industry, is not efficient enough as a TiO₂ binder solution in DSSC. Selection of the type of TiO₂ binder solution is one of the methods used in research to increase the stability of TiO₂. The more stable the TiO₂ binder solution is used, the better the electron flow, which, on the whole, determines the resulting efficiency of the solar cell.

4. Conclusions

From the results of this study, the Uv-Vis spectra obtained from the Shimadzu UV-1800 and UV-2600 Shimadzu Spectrophotometers show that yellow sweet potato contains anthocyanins, which can be used as a dye sensitizer in DSSC. Meanwhile, FTIR analysis revealed that TiO₂ had formed chelate bonds with anthocyanin compounds. The choice of TiO₂ binder solution used was

able to increase the efficiency of DSSC, where TiO₂, which was bound with PVA, produced higher efficiency than using acetic acid and PEG. DSSC characteristics can be seen from the resulting current and voltage. The efficiency values of each variation of the titanium dioxide binder solution used were acetic acid of 0.203%, PEG of 0.095%, and polyvinyl alcohol of 0.302%.

References

- [1] S. Abid, A. E. Baraka, H. Ennaceri, A. Khaldoun, Properties of TiO₂ and Dye in Enhancement of Dye-Sensitized Solar Cells' Efficiency, *2017 International Renewable and Sustainable Energy Conference (IRSEC)*, 2017 <https://doi.org/10.1109/IRSEC.2017.8477272>
- [2] Arif Rahman, Fabrikasi dan Karakterisasi Nanopartikel ZnO Untuk Aplikasi Dye Sensitized-Solar Cell, *Master Thesis, Metallurgy and Materials Study Program, Universitas Indonesia, Depok*, 2011
- [3] Mowafak Al-Jassim, in, *National Renewable Energy Laboratory (NREL)*, 2020
- [4] Fiqri Al Faruqi, R. D. Kusumanto, Abu Hasan, Optimization of Monocrystalline Solar Panels Using Reflector Scanning Technology, *Journal of Physics: Conference Series*, 1167, (2019), 012024 <http://dx.doi.org/10.1088/1742-6596/1167/1/012024>
- [5] Hendra Kusuma Negara, R. D. Kusumanto, Abu Hasan, Effects of Direct Window Film Installation on Photovoltaic Solar Panel, *Journal of Physics: Conference Series*, 1167, (2019), 012029 <http://dx.doi.org/10.1088/1742-6596/1167/1/012029>
- [6] M. Grätzel, A. J. McEvoy, Principles and applications of dye sensitized nanocrystalline solar cells (DSC), *Asian Journal on Energy and Environment*, 5, 3, (2004), 197–210
- [7] Halil İbrahim Yavuz, Design of high-efficiency dye-sensitized nanocrystalline solar cells, *Master Thesis, Graduate School of Natural and Applied Sciences, Orta Doğu Teknik Üniversitesi, Ankara*, 2014
- [8] Retno Damayanti, Hardeli Hardeli, Hary Sanjaya, Preparasi Dye Sensitized Solar Cell (DSSC) Menggunakan Ekstrak Antosianin Ubi Jalar Ungu (*Ipomoea Batatas L.*), *Sainstek: Jurnal Sains dan Teknologi*, 6, 2, (2016), 148–157
- [9] Joko Suryadi, Gunawan Gunawan, Abdul Haris, Pembuatan dan Penentuan Nilai Efisiensi Sel Surya Berwarna Tersensitisasi dengan Senyawa Antosianin dari Buah Manggis (*Garcinia mangostana L.*) sebagai Pewarna Pensensitisasi, *Jurnal Kimia Sains dan Aplikasi*, 13, 3, (2010), 88–94 <https://doi.org/10.14710/jksa.13.3.88-94>
- [10] Mustaqim Mustaqim, Abdul Haris, Gunawan Gunawan, Fabrikasi Dye-Sensitized Solar Cell Menggunakan Fotosensitizer Ekstrak Bunga Rosela (*Hibiscus sabdariffa L*) dan Elektrolit Padat Berbasis PEG (Polyethylene Glycol), *Jurnal Kimia Sains dan Aplikasi*, 20, 2, (2017), 62–67 <https://doi.org/10.14710/jksa.20.2.62-67>
- [11] S. Monzir, M. A. Abuiriban, N. A. Dahoudi, Dye-sensitized solar cells using fifteen natural dyes as sensitizers of nanocrystalline TiO₂, *Science Technology and Development*, 34, 3, (2017), 135–139
- [12] Danang Mohamat Yuri, W. S. Brams Dwandaru, Uji Beda Kestabilan Tegangan dan Arus antara Dye Sensitized Solar Cell (DSSC) yang Menggunakan Counter Electrode Jelaga Lilin dan Grafit Pensil, *E-Journal Fisika*, 5, 5, (2016), 318–327
- [13] P. Nijisha, N. M. Bhabhina, S. Sindhu, Application of gel electrolyte in dye sensitized solar cells, *Nanosystems: Physics, Chemistry, Mathematics*, 7, 4, (2016), 752–754
- [14] Sukardi Sukardi, S. M. Kiswaya, D. Pranowo, Extract anthocyanin of dried purple sweet potato as electron donors in dye sensitized solar cell (DSSC), *Industria: Jurnal Teknologi dan Manajemen Agroindustri*, 7, 3, (2018), 133–142 <http://dx.doi.org/10.21776/ub.industria.2018.007.03.1s>
- [15] Sri Handayani, Gunawan Gunawan, Abdul Haris, Pengaruh Pasta ZnO dengan Penambahan Dish Detergent dan PVA pada Kaca Konduktif terhadap Efisiensi Dye Sensitized Solar Cell dari Ekstrak Bunga Rosela (*Hibiscus sabdariffa L.*), *Jurnal Kimia Sains dan Aplikasi*, 16, 3, (2013), 90–96 <https://doi.org/10.14710/jksa.16.3.90-96>
- [16] Shihan Zhang, Jingsha Jin, Dan Li, Zhiqiang Fu, Shufang Gao, Shubo Cheng, Xiangxiang Yu, Yan Xiong, Increased power conversion efficiency of dye-sensitized solar cells with counter electrodes based on carbon materials, *RSC advances*, 9, 38, (2019), 22092–22100 <https://doi.org/10.1039/C9RA03344K>
- [17] Khoiruz Zaidit Taqwa, Studi Eksperimental Pengaruh Intensitas Cahaya terhadap Performa DSSC (Dye Sensitized Solar Cell) dengan Ekstrak Buah dan Sayur Sebagai Dye Sensitizer, *undergraduate thesis, Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Surabaya*, 2015
- [18] Laila Ika Anggraini, Abdul Haris, Didik Setiyo Widodo, Pembuatan Dye-Sensitized Solar Cell dengan Memanfaatkan Fotosensitizer Ekstrak Kol Merah (*Brassica oleracea var. capitata f. Rubra*), *Jurnal Kimia Sains dan Aplikasi*, 13, 3, (2010), 101–108 <https://doi.org/10.14710/jksa.13.3.101-108>
- [19] Devi Maryani, Gunawan Gunawan, Khabibi Khabibi, Penentuan Efisiensi DSSC (Dye-Sensitized Solar Cell) yang Dibuat dari Semikonduktor ZnO yang diemban Fe³⁺ Melalui Metode Presipitasi, *Jurnal Kimia Sains dan Aplikasi*, 15, 1, (2012), 29–35 <https://doi.org/10.14710/jksa.15.1.29-35>
- [20] Sahat M. R. Nadaek, Diah Susanti, Variasi temperatur dan waktu tahan kalsinasi terhadap unjuk kerja semikonduktor TiO₂ sebagai dye sensitized solar cell (DSSC) dengan dye dari ekstrak buah naga merah, *Jurnal Teknik ITS*, 1, 1, (2012), F81–F86