A Study on Efficiency Improvement of Dye Sensitized Solar Cell (DSSC) Organic Extracted from Mango Leaves and Ginger

Ade Ilham Tamara K, Paulus Lobo Gareso, Andi Anugrah Caezar T

Abstract — DSSC (Dye Sensitisize Solar Cell) or also called Bio solar cell serves to convert solar energy into electrical energy, The study literature on various DSSC using natural substances shows that average efficiency only really centered around zeroes percent, further research have been found to increase efficiency, can be done by expand the range of light absorption from dye Near Infrared (NIR) area, which is around 940 nm. To expand the area of light absorption this can be done by using combination of two dyes whose spectral properties support each other, which will be used as a method to expand the light absorption area of organic dye then be able to increase the efficiency of DSSC. Results from UV-Vis characterization revealed that the wavelength for ginger was 439 nm, mango leaves was 535 nm and the combination was obtained 645 nm. On other hand, the power conversion efficiency (η%) of natural yellow dye which extracted from ginger was obtained of 0.054% and for natural green dye extracted from mango leaves was 0.248% and maximum efficiency (η%) reached 1.431% by the combination of ginger and mango leaves. Therefore, the efficiency of combining the dyes is 26,5 times higher than that of the efficiency of a single dye.

Keywords — DSSC, Dyes, Efficiency, Ginger, Mango Leaves.

1 INTRODUCTION

1.1 Background

The intercession of the human race with nature has reached a level that demands an earnest re-assessment of possible energy supply techniques with a focus on sustainability, unless undesirable changes in atmosphere and environment are accepted. Mankind needs sustainable sources of energy. Employment of solar energy, biofuels, biomass, wind, geothermal, and hydro can be viewed as the best alternative to traditional energy [1]. Rapid development of sustainable energy and effectiveness, and technological miscellaneousness of energy sources, would bring energy security.

Solar energy is the most effectively exploitable. There are many kinds of photovoltaics system present in the market. As one of tropical country, Indonesia almost gets a maximum solar energy every single year, so it is very possible by making solar energy as the alternative energy producer one of them is DSSC, DSSC (Dye Sensitisize Solar Cell) is also called bio solar cell is a form of application of solar energy as a power plant.

• ***Ade Ilham Tamara K*** *is a student of Hasanuddin University, Departement of Physics he has been awardee as most outstanding student of his department, faculty and university in 2019, currently he has 2 years research experience on material and energy field.*
Email: ilham.tamara@gmail.com

• ***Paulus Lobo Gareso*** *completed his Ph.D from Australian National University He has more than 10 years of experience in teaching and research. His areas of research includes material and energy.*
Email: pgareso@gmail.com

• ***Andi Anugrah Caezar T*** *is a student of Hasanuddin University, Faculty of Mathematics and Natural Science, Departement of Physics, he is actively work as researcher at material and energy laboratory.*
Email: andianugrahcaezart@gmail.com

DSSC is a solar cell made from semiconductor materials coated with dyes that can increase the efficiency from solar energy into electrical energy [2]. Since their appearance in 1991 [3], [4]. DSSCs have drawn an extensive consideration from the scientific society because of their low fabrication cost and easy assembling process. DSSC has the ability to absorb more sunlight per surface area than traditional silicon-based solar cells. DSSCs can likewise work in low-light conditions, for instance, indirect sunlight and cloudy skies. easy to manufacture and built from inexhaustible and stable asset materials.

DSSC uses dye as a sensitizer (solar energy harvester) which is used as an electron donor on TiO_2 nanoparticles (semiconductor material) and uses electrolytes as an electron transport medium. TiO_2 is only able to absorb ultraviolet light (350-380 nm), so a layer of dye is needed as a sensitizer that will absorb visible light as much as possible. Usually DSSC uses a ruthenium complex as sensitizer, because the ability to absorb visible light and inject electrons into TiO_2 [5]. However, the ruthenium complex is difficult to find because the amount is limited in nature and toxic so that it can make a negative impact on health and the environment.

One Side knowledge about photosynthesis has developed rapidly where photosynthetic materials such as chlorophyll, beta-carotene, anthocyanin, tannins, curcumin are known as effective harvesters of photons from the sun. Therefore the development of DSSC using pigments as sensitizers is a promising choice because these pigments are available in abundant quantities in nature. [6]. Used dyes comes from combination of pigment extract from mango leaves and ginger which are the largest fruit and biopharmaca commodity in Indonesia. This mixture is expected be able to expand the peak absorbance of dye.

ISSN 2229-5518

1.2 The Latest Research

Based on study literature the obstacle of Organic DSSC implementation so far it is very low efficiency. One way to improve DSSC efficiency is by expanding the range of light absorption from dye become near the Near Infrared (NIR) area, which is around 940 nm. To expand the area of light absorption this can be done by using a combination of two dyes whose spectral properties support each other. Richhariya, et al [7] named this combination as "cocktail dye sensitizer", which will be used as a method to expand the light absorption area of organic dye then it is able to increase the efficiency of DSSC.

TABLE 1
Latest Research DSSC Organic

Ingredients	Material	Efficiency	References
Turmeric		0,378%	
Red spinach	TiO2	0,134%	[8]
Mixture		1,079%	
Bit		0,49%	
Spinach	TiO2	0,56%	[9]
Mixture		0,99%	

As a preliminary data, this hypothesis strengthened by looking the latest researches on organic DSSC, this method proven begin to be applied since introduced by Richariya [7] shown in (table 1) research conducted by Kabir [8] and Bashar [9], has proven by combining two types of pigments be able to increase the efficiency quite significantly.

2 MATERIALS AND METHOD

2.1 Tools and Materials

The used tools are lab glass, UV-Vis spectrometer, FTIR, XRD microwave, blender, hot plate magnetic stirrer, ultrasonic cleaner and digital multimeter. The used materials Are mango leaves, ginger, aquades, acetone, TiO2, polyethylene glycol (PEG 6000), 2B pencil, ITO conductive glass, ethanol, KI, I2, candle, detergent, insulation, aluminum foil, and Whatman filter paper 42.

2.2 Methods

Dye Extraction

Mango leaves and ginger were cleaned, dried, then mashed, a total of 8 grams was put into 80 mL of acetone then stirred for 1 hour at the temperature of 40°C with a rotation speed of 600 rpm using magnetic stirrer. The mixture were left for 24 hours until the residue and filtrate were completely separated and then filtered and put it in a dark bottle.

TiO2 Electrodes Preparation

FTO conductive glass was cut into the size of 2.5cm × 2.5cm. The glass was cleaned using an ultrasonic cleaner for 15 minutes, rinsed with distilled water and ethanol then dried. Next, the TiO_2 pasta was made by combining 1.5 grams of TiO_2, 0.5 grams of polyethylene glycol, and 8 ml ethanol. Then, the mixtures were stirred until a homogeneous paste was obtained. TiO_2 paste was deposited on the glass surface of the ITO using spin coating method. Finally, the samples were put into the oven for sintering process at 450°C for 60 min.

Working Electrode Preparation (Natural dye extract)

Working Electrodes was made by TiO_2 Electrodes, then extracted with ginger, mango leaves and mixture by dipping in the filtrated dye and left for 36 hours in dark conditions.

Counter Electrode Preparation

Counter electrodes were made by using conductive glass that coated by carbon. Graphite from pencil 2B was used as a carbon source to shade the glass evenly.

Electrolyte Preparation

10 mL of aquades was added into 0.8 grams of KI and stirred. Furthermore, 0.2 gram I_2 was restored for 30 minutes. Then, the solution was put into a dark bottle.

Cell Preparation

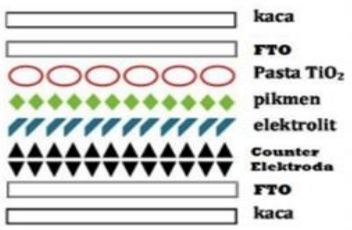


Fig. 1. DSSC Structure

The working electrode has made and the counter electrode is arranged with a sandwich structure as shown in Fig. 1. Photoanode and cathode then bonded together by paper binder clips and redox electrolyte solution was consisting of KI and I_2 injected into the cell.

Characterization and Measurement of The Photoelectric Parameters of DSSC

There are three characterizations carried out, namely XRD, FTIR and UV-VIS characterization, besides that the measurement of current, voltage and efficiency is carried out. In this measurement, the multimeter was using to measure the voltage produced by the DSSC. while the resulting currents (A) is determined using Ohm's Law approach, namely:

$$I = \frac{V}{R} \tag{1}$$

Then we can obtained the power values p by doing calculation using equation [10]:

$$p = \frac{VI}{A} \tag{2}$$

The Energy conversion efficiency is given below [10]:

$$\eta = \frac{p}{i} \times 100\% \tag{3}$$

Where, η = Efficiency (%), p is a power (Watt/cm^2), and i is light intensity (Watt/cm^2).

Photon energy or optical energy gap of the dye can be determined as follows [9]:

$$E = h\nu = \frac{hc}{\lambda} \tag{4}$$

Where, ν = frequency, h = Plank's constant (6.63 ×10^{-34} Js), c =light speed (3.0 ×10^{8} m/s), hc = 1240 eV nm and λ = wavelength (nm)

The absorption coefficient characterizes how far into a material, the light of a particular wavelength can penetrate before it is absorbed [11]. The absorption coefficient can be defined as follows [8]:

$$absorption\ coefficient = \frac{4\pi k}{\lambda} \tag{5}$$

Where, K = Boltzmann constant, K (8.316 $\times 10^{-5}$eV).

3 RESULTS AND DISCUSSION

3.1 X-RD Characterization

X-RD Characterization is used to determine the crystal structure of the working electrode. The X-RD measurements use Cu Kα radiation (λ = 1.5406 Å) where the current and voltage of X-RD measurements were kept constant at 30 mA and 40 kV, respectively as well as the speed rate of X-RD was 2°/min.

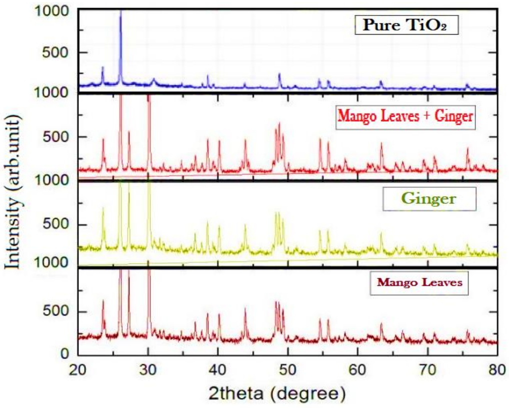


Fig. 2. The X-ray diffraction spectra of TiO2, mango leaves, Ginger and the combination of dyes.

As shown in Fig. 2, the dye particles have adhered well to the surface of TiO_2 by looking the difference of X-RD spectra in TiO^2 and two dyes and a single dye where there are two additional peak appearing at 26.9° and 30.5°. Also in Fig. 2, the intensity of the X-RD peak at the same angle of 2 Theta changes in absorption intensity (between glass that only coated by TiO_2 and glass that has been coated with dye) caused by the addition of dye particles attached to the surface of TiO_2. Based on the results of X-RD characterization, it can be assumed that the immersion of glass that has deposited TiO_2 to make a dye layer has been successful.

3.2 Optical Characterization

FTIR characterization are measured within spectral range of the wave band at 4000-500 cm^{-1} as shown in Fig. 3. For mango leaves at wave number 1023 cm^{-1} indicate C-O bond with strong intensity. at wave number 1641 cm^{-1} shows C=C bond type of alkene compound, at wave number 2923 cm^{-1} reveals alkane with C-H and O-H chemical bonds the wave number at 3418 cm^{-1} indicates a phenol compound.

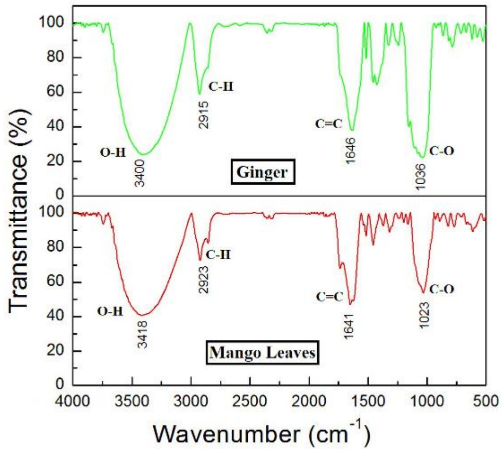


Fig. 3. FTIR spectra of mango leaves and ginger

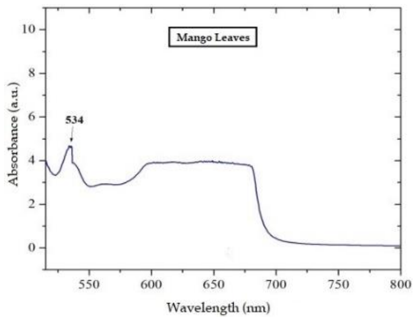
Afterwards is the characterization result of ginger, where at wave number 1023 cm^{-1} shows C-O bond with strong intensity, then at wave number 1641 cm^{-1} shows C=C bond type alkene compound, at wave number 2923 cm^{-1} reveals an alkane compound with C-H chemical bonds, and at wave number 3418 cm^{-1} shows phenol compounds with O-H chemical bonds.

The DSSC with extracted dye has a good efficiency when supported by chromophore groups that absorb light in the Visible area such as C=C bonds, beside the chromophore group, there are also ausochrome groups such as O-H bonds which cause absorption of light which previously was in the Visible area turned into Ultraviolet-Visible. Thereby, based FTIR characteristics it can be confirmed that mango leaf and ginger can be used as sensitizer into DSSC.

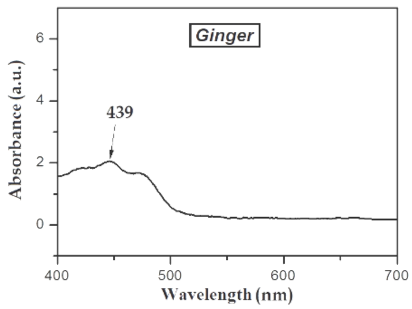
3.3 UV-Vis Characterization

Absorption Spectra

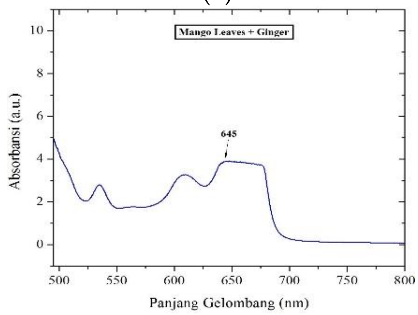
UV-Vis characterization was carried out to determine the wavelength absorption. Fig. 4 presents the absorption spectra of dyes that has been observed by UV–Vis spectrophotometer of mango leaves, ginger and the combination (mango leaves + ginger) in the spectral range within the wavelength of 400-800 nm respectively. It can be seen from the Fig. 4, the peak absorbance for mango leaves at 534 nm, ginger was obtained at 439 nm, and the combination dye materials at 645 nm.



(a)



(b)



(c)

Fig. 4. Results of UV-Vis Characterization

According to Richariya [7] "One way to improve DSSC efficiency is to expand the range of light absorption from dye Near the Infrared (IR) area which is around 940 nm, which can be done by combining two types of dye". Based on the UV-Vis results, it can be seen that, the value of the absorbance spectrum increases significantly after combining the two types of dye. Although the combination of these dyes increases the absorption spectra to about 645 nm which is still far from the infra-red absorption spectra, but the results are preliminary that the absorption spectra can be increased by mixing the dyes.

Band Gap Estimation and Absorption Coefficient of The Dyes

Energy band gap is the difference between conduction band and valence band. This optical energy band gap is used for analysing what portion of solar spectrum as absorbed by the DSSC. Table 2 demonstrates the energy band gap of dye. Mango leaves + ginger has the lowest band gap 1.92 eV compared to ginger band gap 2.82 eV. Similarly, Mango leaves + ginger has the lowest absorption coefficient 1.68 Km^{-1} compared to ginger absorption coefficient 2.47 Km^{-1}.

TABLE 2
Photon energy and absorption coefficient (α) of the dyes

Sample	Peak Absorbance (nm)	Absorption Range (nm)	Energy Band Gap (eV)	Absorption Coefficient (α) Km^{-1}
Mango Leaves	534	500-800	2.32	2.03
Ginger	439	400-700	2.82	2.47
Mango Leaves + Ginger	645	500-800	1.92	1.68

3.4 DSSC Performance

The DSSC prototype was performed outdoors using sunlight as a light source and measured using a digital multimeter by placing a positive pole on the working electrode and the negative pole on the counter electrode to determine the resulting voltage, the intensity of light measured using luxmeter, while the current (A) is calculated using Ohm's law approach on equation (1). The performance of DSSC is shown in Table 3 and 4.

TABLE 3
The measurements results of DSSC

Sample	Voltage (Volt)	Resistance (Ω)	Intensity (Watt/cm²)
Mango Leaves	$81,6\times10^{-3}$	40 Ω	$6,713\times10^{-2}$
Ginger	38×10^{-3}	40 Ω	$6,713\times10^{-2}$
Mango Leaves + Ginger	$196,1\times10^{-3}$	40 Ω	$6,713\times10^{-2}$

TABLE 4
The Calculation results of DSSC

Sample	Current (A)	Power (Watt/cm²)	Efficiency (%)
Mango Leaves	$2,04\times10^{-3}$	$166,46\times10^{-6}$	0,248
Ginger	$0,45\times10^{-3}$	$36,1\times10^{-6}$	0,054
Mango Leaves + Ginger	$4,9\times10^{-3}$	$960,89\times10^{-6}$	1,431

After measured the current, then will be calculated the power value P (Power generated by voltage and current), by doing calculation using equation (2), where mango leaves obtain power 166.46 × 10^{-6} Watt/cm², ginger equal to 36,1 × 10^{-6} Watt/cm² and mango leaves + ginger produce $960,89\times10^{-6}$ Watt/cm². Lastly, DSSC conversion efficiency used equation (3) The efficiency of using mango leaves as dye is 0.248%, ginger is 0.054% and the combination of dye (mango leaves + ginger) is 1.431%. These results indicate that the combination of dye result is higher than mango leaves and ginger as a single dye.

4 CONCLUSION

The Improvement of efficiency DSSC using ginger and mango leaves as a dye has been studied. The X-RD results show that there are two additions peak appear in the mango leaves and ginger compared to TiO_2 sample. The current and voltage characterization results show that by combining two types of dye, it can improve the efficiency significantly that is 26,5 times higher than that of a single dye. Therefore by using Cocktail dye Sensitizer method can become one way to improve the efficiency of organic DSSC.

ACKNOLEDGEMENT

The authors acknowledge the financial assistance from the higher education of Indonesia (RISTEKDIKTI) through the research scheme of competence based research (PRK) under contract number at 1740/UN4.21/PL.00.00/2019.

REFERENCES

[1] Sengupta, D, Das, P, Mondal, B & K. Mukherjee, Effects of doping, morphology and film-thickness of photo-anode materials for dye sensitized solar cell application–A review, Renew. Sustain. Energy Rev. 60 (2016) 356–376.

[2] Barnoy, EM. Conley, S. Gan, Y. Gafe, J. Lovell, K. Mann, A. Shuchatowitz and Tobin. 2011. The Potential of Natural, Photosynthetic Pigments to Improve the Efficiency of DSSC, PhD Thesis, University of Maryland, Maryland.

[3] Brian O'Regan, Michael Grätzel, A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films, Nature 353 (1991) 737–740.

[4] Gerischer, H, Michel-Beyerle, M.E, Rebentrost, F & H. Tributsch, Sensitization of charge injection into semiconductors with large band gap, Electrochimica Acta 13(6) (1968) 1509–1515,https://doi.org/10.1016/00134686(68)80076-3.

[5] Maddu, A., M. Zuhri, dan Irmansyah. 2009. Utilization of Extract Antosianin of Red Cabbage as Photosensitizer. Jurnal Teknologi Makara 11 (2): 78-84.

[6] Bahtiar, H., N. A. Wibowo, dan F. S. Rondonuwu. 2015. Bio Solar Cell Construction Using Chlorophyll-Carotenoid Combination as a Sensitizer. Jurnal Fisika dan Aplikasinya 11(1): 19-23.

[7] Richhariya, et.al. 2017, Natural Dyes for Dye Sensitized Solar Cell: a Review, Renewable and Sustainable Energy Review 69, Elsevier, 705-718.

[8] Kabir, F., et.al. 2019. Improvement of efficiency of Dye Sensitized Solar Cells by optimizing the combination ratio of Natural Red and Yellow dyes. International Journal for Light and Electron Optics. 179: 252-258.

[9] Bashar, H. 2019. Study on combination of natural Red and Green dyes to improve the power conversion efficiency of Dye Sensitized Solar Cells

[10] Tahir, D., P. Satriani, L. Garesso, dan B. Abdullah. 2018. Dye sensitized solar cell (DSSC) with natural dyes extracted from Jatropha leaves and purple Chrysanthemum flowers as sensitizer. The 2nd International Conference on Science (ICOS).

[11] R. Syafinar, N. Gomesh, M. Irwanto, M. Fareq, Y.M. Irwan, Chlorophyll Pigments as Nature Based Dye for Dye-Sensitized Solar Cell (DSSC), Energy Procedia. 79 (2015) 896–902, https://doi.org/10.1016/j.egypro.2015.11.584.

[12] Juwito, A. F., S. Pramonohadi, dan T. Haryono. 2012. Optimization of Renewable Energy as Power Plants Facing of Energy Independent Village in Margajaya. Jurnal Ilmiah Semesta Teknika 15 (1): 22-34.