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Electrical properties of dye sensitized solar cell with polyethylene glycol- based electrolyte and Senduduk fruit's extract as photosensitizer

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Abstract

The study determined the electrical performance of dye sensitized solar cell by using electrolyte hydrogels of Polyethylene Glycol 4000 and Polyethylene Glycol 6000. The experimental work consisted of Dye Sensitized Solar Cell (DSSC) structure arrangement, assembly of DSSC layers, and measurement of DSSC. The resistances of TCO glass were 1.1 kΩ and 14.9 kΩ. The concentration of the thickening agents in the electrolyte solution were 5%, 10%, and 15%, and a control sample without the addition of hydrogel. The parameters included total anthocyanin content of senduduk fruit, voltage and current values, output and input power values, fill factor, and DSSC efficiency. The best DSSC performance was DSSC with the addition of PEG 6000 at a concentration of 15%, and its electrical characteristics were I_{sc}: 0.0127 mA, V_{oc}: 0.721 mV, I_{max}: 0.0102 mA, V_{max}: 0.508 mV, P_{max}: 0.00518 mW, FF: 0.5659, and an efficiency of 0.018%.

Keywords: DSSC; PEG 4000; PEG 6000; Electrolyte; Efficiency

1. Introduction

Human survival is very dependent on energy resources. Currently, there is still a lot of non-renewable energy such as energy that comes from fossil fuels [1]; [2]. In this case, humans must find a substitute for alternative energy as the main source of energy for life. Thus, the use of alternative energy as the main renewable energy source for the environment needs to be implemented by utilizing solar energy or solar cells.

Indonesia is rich in sunshine; therefore, the use of conversion from sunlight to renewable energy is very appropriate. One of the technology is Dye Sensitized Solar Cell (DSSC). DSSC is a solar technology that can convert solar energy into electrical energy directly with the help of a photosensitizer. DSSC works based on photoelectrochemical principles with dye as a light absorber and a semiconductor as a charge separator (Carella et al., 2018).

The performance of the solar cell can affect the amount of electricity generated. Performance can be affected by the efficiency and fill factor of the solar cell. Fill factor and efficiency are influenced by solar cell construction and external factors such as light intensity, temperature, and other factors [4].

Natural dyes have many advantages, namely easy to obtain raw materials, low production prices, environmentally friendly, and do not use expensive chemical synthesis. Natural substances are used as alternative substances because natural substances have many advantages. In this case, the photosensitizers in DSSC that are often used come from natural dyes, such as chlorophyll, carotenoids, anthocyanins, flavonoids, cyanins and tannins [5]. The natural dye in this

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study was senduduk fruit that contained a substantial amount of anthocyanin; therefore, its extract can be used as a dye in DSSC [6]. Flavonoid compounds in senduduk fruit extract tend to absorb visible light in the range of 500 nm-700 nm, and these compounds are organic chemical compounds that can dissolve in polar solvents [7].

Anthocyanins are obtained from the extraction process of Senduduk fruit. The method used for the extraction process is the Ultrasonic Assisted Extraction (UAE) method. Ultrasonic-based sonication method by delivering ultrasonic waves that have a high frequency level of more than 20 kHz. Ultrasonic waves can cause a cavitation effect on the formation, growth, and breakdown of waves in a liquid due to heat which will produce continuous vibrations. The Ultrasonic Assisted Extraction (UAE) method aims to increase antioxidant levels in a short time during extraction [8]. This is an advantage of the ultrasonic-assisted extraction method because it is more effective than other extraction methods.

The DSSC component consists of counter electrode, sensitized dye, electrolyte solution, and working electrode. In this case, the electrolyte acts as a process for transferring the ions produced by the electrodes. The electrolyte in the solar cell on the DSSC plays an important role in the performance of the DSSC which functions as a source of excitation for the dye. Usually, the electrolyte is in the form of a liquid, but liquid electrolyte has weaknesses including that it is less practical, leaks easily, evaporates easily, corrodes easily, and is not durable. Therefore, to overcome the weaknesses of the liquid electrolyte, a gel electrolyte is used by adding a thickening agent in the form of Polyethylene Glycol so that the electric current goes well through the movement of ions on DSSC efficiency [9].

Polyethylene glycol is a synthetic flexible polymer that has different physical characteristics from one type to another. Polyethylene glycol (PEG) has the characteristic of being soluble in water, methanol, benzene, and dichloromethane. In addition, PEG also has a low toxic content (Majumdar et al., 2010). Based on the average molecular powder contained, the complex polymer in organic molecules is called Polyethylene glycol (PEG) with the classification name PEG 200-600 in the form of a liquid, PEG 1500 in the form of a semi-solid, and PEG 3000-20000 in the form of a solid crystal. The PEGs that are often used are PEG 4000 and PEG 6000 because the ingredients are easy to get and the price is cheap and the concentration of the thickener is good (Sing Liow et al., 2022).

The addition of Polyethylene glycol (PEG) to the electrolyte is carried out in order to increase efficiency in DSSC performance and DSSC performance will be stable and DSSC performance will run well. Based on this background, the authors will treat it with the addition of Polyethylene glycol 4000 and Polyethylene glycol 6000.

2. Materials and Methods

2.1. Dye extraction from senduduk's fruit

The extraction was performed by using ultrasonic assisted extraction. The ripe senduduk's fruits were selected. The flesh was weighed for 5 grams and transferred into a Beaker glass. An amount of 100 mL distilled water was poured into the Beaker glass, then it was put in the bath of ultrasonic processor. The processor was turned on at the frequency of 40 kHz for 30 minutes. The mixture was filter through a filter paper and the supernatant was collected as dye for sensitizer in DSSC.

2.2. Preparation of hydrogel electrolyte

The electrolyte solution was prepared with a mixture of 5 mL of iodine and various thickening agents from PEG 4000 and PEG 6000 with concentrations of 5%, 10% and 15% (w/v), respectively. The solution was stirred using a stirrer at medium speed at 60^{o}C for 20 minutes until it is homogeneous and forms a gel.

2.3. Preparation of a capacitive touch screen as a conductive substrate

The dimension of the capacitive touch screen used was 25 mm × 25 mm × 1.113 mm with the resistivity in the ranges of 0.73 to 9.6kΩ. The touch screen was then set for the active area for depositioning TiO_2 paste by a Scotch tape on the three sides of the touch screen (1.5 mm on the left and right; 3 mm on top of the touch screen).

2.4. Preparation of TiO_2 paste and counter electrode

Titanium (IV) oxide (TiO_2) (Sigma Aldrich) was weighed as amount of 0.5 g and placed in a 100 mL beaker glass. Acetic acid 0.25 N solution as amount of 1 mL was added and mixed homogeneously. Counter electrode from a capacitive touch screen is made by using a carbon catalyst from burning candles

2.5. DSSC assembly

The touch screens that had been deposited with TiO_2 paste was soaked with dye for an hour, and then was placed in an oven at 105°C for 15 minutes. The touch screen with TiO2 paste was sandwiched with the counter electrode and 1 mL of hydrogel electrolyte solution (iodine) was inserted between them using a binder clip.

2.6. Absorption spectra of dye

The absorption spectra of senduduk's dye were recorded using a UV-VIS spectrophotometer (Jenway 6305). The wavelength was in the range of 400 nm to 700 nm.

2.7. Electrical properties measurement

Open circuit voltage (V_{oc}) of the fabricated DSSC device was measured using Multimeter (DT-830B) for 10 minutes under light source, while the photocurrent voltage was measured under light illumination 94,000 lux. The fill factor (FF) and efficiency (η) of DSSC were calculated using equations as stated in equation (1) and (2).

$$FF = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{oc}} \quad (1)$$

$$\eta(\%) = \frac{P_{max}}{P_{in}} \times 100\% \quad (2)$$

2.8. Treatments of DSSC

DSSC A (as control, without addition of PEG), DSSC B (PEG4000, 5% w/v), DSSC C (PEG4000, 10% w/v), DSSC D (PEG4000, 15% w/v), DSSC E (PEG6000, 5% w/v), DSSC F (PEG6000, 10% w/v), DSSC G (PEG6000, 15% w/v).

3. Results and Discussion

3.1. Dye absorbance

The absorbance was analyzed using a UV-Vis spectrophotometer to determine the absorption area at the maximum wavelength of the dye extract to be used. Absorbance measurements can be seen in Figure 1. The absorbance peak of Senduduk fruit extract dye was at a wavelength of 540 nm with an absorbance value of 0.969. These results indicate that senduduk fruit extract dye has anthocyanin content. This is in line with research by [11] stated that in general the wavelength absorption areas of senduduk fruit are 500 nm- and 700 nm.

3.2. Anthocyanin content

The anthocyanin content of senduduk fruit was measured using the pH difference method. The solution used is KCl buffer solution pH 1.0 and sodium citrate buffer pH 4.5. Based on the results of the absorbance measurement, the value of the anthocyanin content of senduduk fruit was 0.648 mg/L.

3.3. Measurement of current-voltage

Current and voltage measurements are carried out using a digital multimeter and ammeter connected to the media project board. The DSSC structure that is ready to be measured and tested is connected using a jumper cable on the offset side area and measurements are carried out using a light source of a halogen lamp that has been turned on at 10 cm. This was in line with Andari (2020) who stated that the highest efficiency is at a distance of 10 cm because the closer the distance to the light source, the greater the light intensity so that the electrical values obtained based on current and voltage data produce electrical values, namely a) open circuit voltage values (V_{oc}), b) value of short circuit current (I_{sc}), c) value of maximum voltage (V_{max}), d) value of maximum current (I_{max}), e) fill factor (FF), f) efficiency (η), g) P_{output}. The data was presented in Table 1.

Table 1 shows that the addition of PEG into the electrolyte solution in the DSSC influenced the electrical characteristic. DSSC efficiency is influenced by the value of I_{sc}, V_{oc}, I_{max}, and V_{max}. Current and voltage affected the performance of DSSC due to the addition of thickening agents of PEG 4000 and PEG 6000. The addition of PEG 6000 has a better effect on the electrical performance of DSSC compared to the addition of PEG 4000. This was due to the higher molecular weight of

PEG. It had an impact on an easier forming gel in the electrolyte solution. In addition, the higher the concentration given to the electrolyte solution, the electrical value of the DSSC increases.

Table 1 Electrical properties of DSSC with hydrogel electrolyte and senduduk fruit extract as sensitizer

Treatment	**Experimental and calculated data**							
	V_{oc} (V)	**I_{sc} (mA)**	**V_{max} (V)**	**I_{max} (mA)**	**P_{input} (mW)**	**FF**	**P_{output} (mW)**	**Efficiency (%)**
DSSC A	0.295	0.0065	0.196	0.0045	26.15	0.4600	0.0009	0.003
DSSC B	0.362	0.0064	0.289	0.0039	26.80	0.4865	0.0011	0.004
DSSC C	0.412	0.0121	0.233	0.0077	26.91	0.3599	0.0018	0.007
DSSC D	0.637	0.0098	0.504	0.0067	27.12	0.5409	0.0034	0.013
DSSC E	0.513	0.0063	0.449	0.005	27.70	0.6946	0.0022	0.008
DSSC F	0.548	0.0107	0.415	0.0088	27.18	0.6228	0.0037	0.013
DSSC G	0.721	0.0127	0.508	0.0102	29.20	0.5659	0.0052	0.018

A thick hydrogel electrolyte functions to prevent evaporation of the electrolyte, therefore the electrical performance is better. DSSC without the addition of PEG was only able to perform its electrical properties for only 5 hours from its initial use at one drop of electrolyte. The electrolyte without PEG has a faster evaporation. Meanwhile, in this study, up to 3 days from the initial use, DSSC was still able to perform with high current stability. Evaporation of gel electrolytes takes longer than liquid electrolytes so not much iodine is lost due to evaporation (Hikmah and Prajitno, 2015).

3.4. DSSC A (as Control)

DSSC A is as a control which there was no addition of PEG in the electrolyte. The performance of its electrical properties for the curve of I-V can be seen in Figure 1.

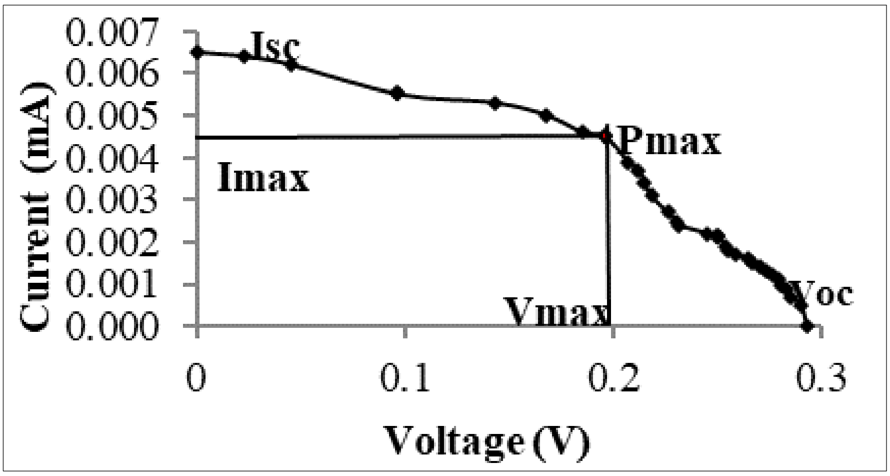

Figure 1 DSSC A as a control (I-V) curve

The voltage obtained when the circuit is open was equal to 0.295 V and the current value when the voltage is equal to zero, the obtained current was 0.0065 mA, and the maximum voltage was 0.196 V, the maximum current value was at 0.0045 mA, and the maximum power was 0.00082 mW. The level of curvature of the voltage and current curves is affected by the stability of the DSSC, where a small level of stability will result in a low fill factor area. Based on the measurement results in Figure 1, the curve (I-V) does not form a good square angle and the area of the fill factor is not too high so that the DSSC work is not very good. The value of fill factor that is near 100% indicating the DSSC performance is good. The Figure 1 shows that the voltage and current curves has low stability with a fill factor value of 0.4600.

3.5. DSSC with the addition of PEG in the electrolyte

The graphs of current-voltage (I-V) curves for the electrical properties' measurement of PEG addition into electrolyte are presented in Figure 2.

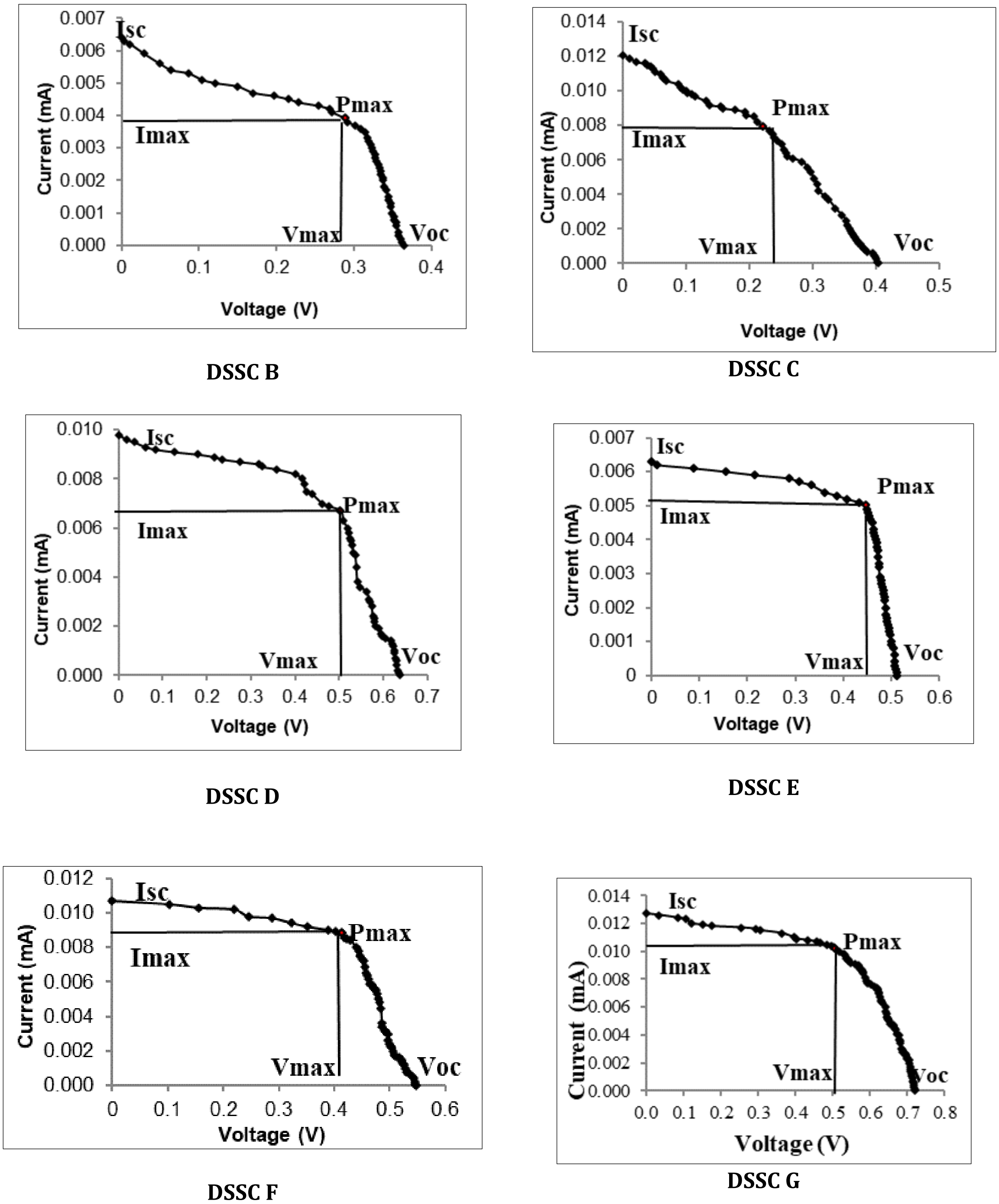

Figure 2 The I-V Curves of DSSC A to DSSC G

The higher the PEG concentration, the better the electrical stability in DSSC performance. Based on the results of calculated P_{input}, the highest P_{input} is in the DSSC G sample with the addition of a thickener in the form of PEG 6000 with a concentration of 15% in the electrolyte solution, which is equal to 29.20 mW. The lowest P_{input} is in sample DSSC A (control) without the addition thickener in the electrolyte that is equal to 26.15 mW. The value of P_{input} is obtained based on the product of the light intensity with the active surface area, the value of the light intensity is obtained from a halogen lamp with 10 cm from the DSSC samples. The results of calculated P_{input} of each DSSC sample can be seen in Figure 3.

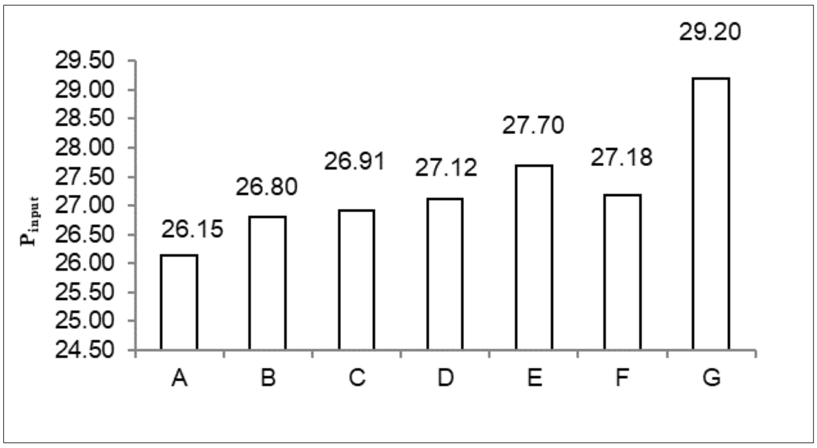

Figure 3 P_{input} of DSSC A to DSSC G

Based on the results of the calculated P_{input}, the highest P_{input} is in the DSSC G sample with the addition of a thickener in the form of PEG 6000 with a concentration of 15% in the electrolyte solution, which is equal to 29.20 mW, while the lowest input power value is in the control DSSC A sample without the addition of thickener to the electrolyte is equal to 26.15 mW. The value of the P_{input} is obtained based on the product of the light intensity with the active surface area. The P_{ouput} is obtained based on the value of the open circuit voltage, short circuit, and the fill factor value. The P_{ouput} affects the efficiency. The P_{ouput} of all samples can be seen in Figure 4.

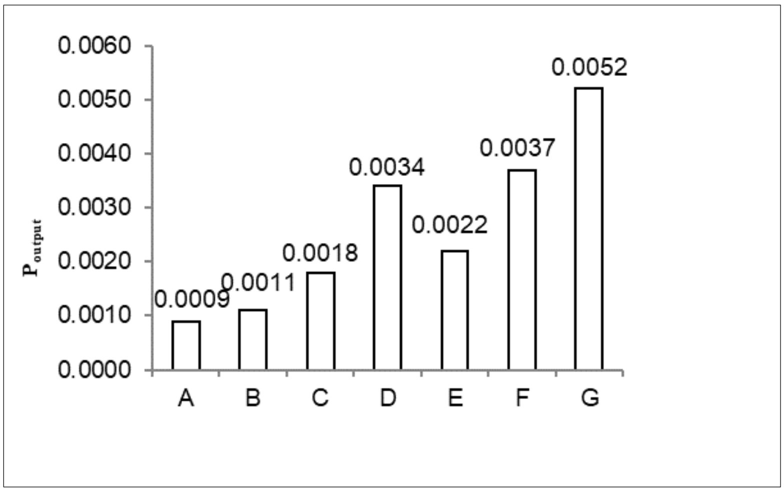

Figure 4 P_{ouput} of DSSC A to DSSC G

The data in Figure 4 indicated that the P_{ouput} increased along with the addition of concentration in each sample. The highest P_{ouput} was obtained at DSSC G, which was 0.0052 mW, this was directly proportional to the highest efficiency produced, which was 0.018%. Meanwhile, the lowest P_{ouput} was obtained in the control sample DSSC A, which was 0.0009 mW with the lowest efficiency, which was 0.003%.

3.6. Calculation of Fill Factor (FF)

Fill factor is influenced by the value of maximum current, maximum voltage, short circuit current and open circuit voltage. The fill factor of all samples was presented in Figure 5.

The fill factor can affect the power obtained. In addition, the level of stability of DSSC measurements also affects the degree of curvature of the voltage and current curves. The curve value was reflected by the stability of the curve (I-V), if the curve shows an ideal curve, then the fill factor is high, and vice versa.

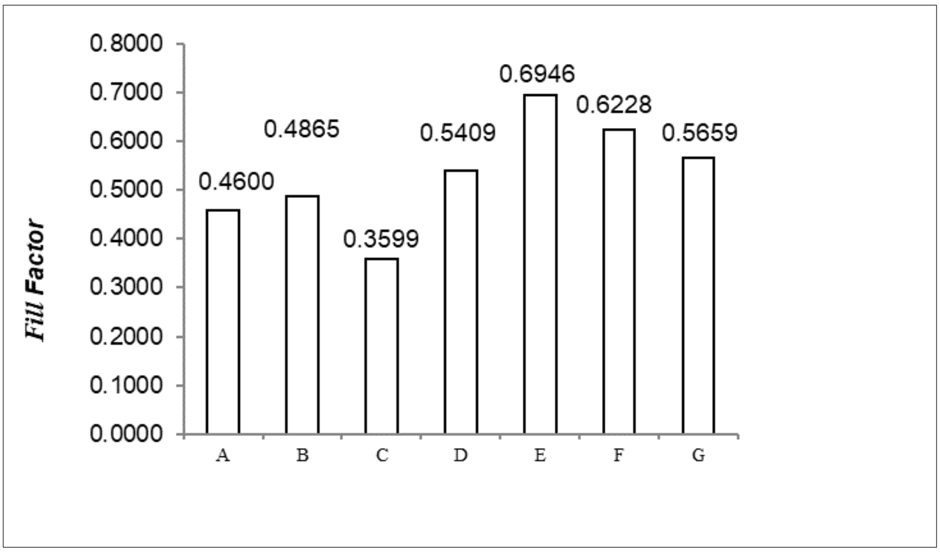

Figure 5 Fill factor of DSSC A to DSSC G

3.7. Calculation of DSSC Efficiency

Efficiency is obtained from the DSSC P_{output} divided by P_{input}. This study shows that each addition of PEG into the electrolyte solution had an impact on the efficiency of the DSSC. The addition of PEG 4000 and PEG 6000 increased the DSSC efficiency. This is in line with (Hikmah and Prajitno, 2015) which stated that the addition of a thickening agent to the electrolyte affected stability and performance in DSSC. The calculated the efficiency of each sample was shown in Figure 6.

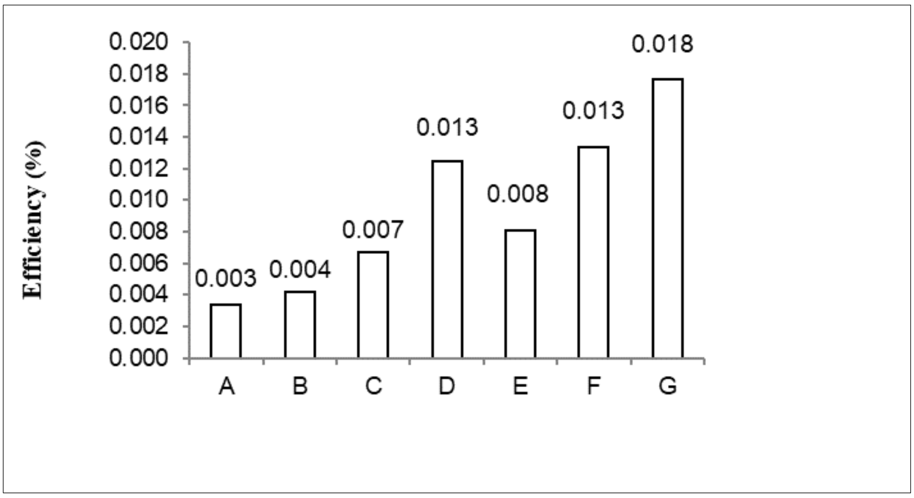

Figure 6 Efficiency of DSSC A to DSSC G

The DSSC sample with the highest efficiency was found in sample G with the addition of 15% PEG 6000 into the electrolyte solution of 0.01% and the lowest DSSC efficiency was found in DSSC A as a control without the addition of PEG, which was only 0.003%. The addition of PEG into electrolyte resulted in better efficiency in DSSC. Polyethylene Glycol (PEG) is a flexible polymer that is soluble in water, methanol, and benzene.

Electrolyte with an addition of PEG4000 tends to be liquid compared to electrolyte with PEG 6000 and PEG 8000. The electrolyte with the addition of PEG 8000 which is thicker than the electrolyte with the addition of PEG 6000 should have better results because the possibility of lost iodine is very small, but in this study the electrolyte with the addition of PEG 6000 produced better efficiency. This is because the electrolyte with the addition of PEG 8000 reduces the performance of iodine due to being too thick or dense so that the performance of iodine is hampered.

4. Conclusions

The addition of PEG into the electrolyte solution resulted in better performance than that of without PEG. The addition of PEG 6000 at a concentration of 15% produced a higher efficiency of 0.018%, while the highest fill factor is produced by PEG 6000 at a concentration of 5% with a value of 0.6946.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

References

[1] H. H. Al-Kayiem and S. T. Mohammad, "Potential of renewable energy resources with an emphasis on solar power in Iraq: An outlook," Resources, vol. 8, no. 1, p. 42, 2019.

[2] N. Kannan and D. Vakeesan, "Solar energy for future world:-A review," Renewable and sustainable energy reviews, vol. 62, pp. 1092–1105, 2016.

[3] A. Carella, F. Borbone, and R. Centore, "Research progress on photosensitizers for DSSC," Front Chem, vol. 6, p. 481, 2018.

[4] M. Giannouli, K. Govatsi, G. Syrrokostas, S. N. Yannopoulos, and G. Leftheriotis, "Factors affecting the power conversion efficiency in ZnO DSSCs: Nanowire vs. nanoparticles," Materials, vol. 11, no. 3, p. 411, 2018.

[5] S. Hao, J. Wu, Y. Huang, and J. Lin, "Natural dyes as photosensitizers for dye-sensitized solar cell," Solar energy, vol. 80, no. 2, pp. 209–214, 2006.

[6] A. Z. M. Rus, N. M. Abdullah, and M. F. L. Abdullah, "Characterization and treatment of titanium dioxide via ultrasonic process with melastoma malabathricum as sustainable sensitizer for photovoltaic solar cell," J Chem, vol. 2013, 2013.

[7] S. Danladi et al., "Phytochemical screening, total phenolic and total flavonoid content, and antioxidant activity of different parts of Melastoma malabathricum," J Teknol, vol. 77, no. 2, 2015.

[8] M. Chen, Y. Zhao, and S. Yu, "Optimisation of ultrasonic-assisted extraction of phenolic compounds, antioxidants, and anthocyanins from sugar beet molasses," Food Chem, vol. 172, pp. 543–550, 2015.

[9] M. S. Akhtar, J.-M. Chun, and O.-B. Yang, "Advanced composite gel electrolytes prepared with titania nanotube fillers in polyethylene glycol for the solid-state dye-sensitized solar cell," Electrochem commun, vol. 9, no. 12, pp. 2833–2837, 2007.

[10] K. Sing Liow, C. S. Sipaut, R. Fran Mansa, M. Ching Ung, and S. Ebrahimi, "Effect of PEG Molecular Weight on the Polyurethane-Based Quasi-Solid-State Electrolyte for Dye-Sensitized Solar Cells," Polymers (Basel), vol. 14, no. 17, p. 3603, 2022.

[11] M. Megawati, N. K. C. Mulyani, and E. A. Alvionita, "Pengaruh Perbedaan Pelarut Asam Pada Ekstraksi Antosianin Bunga Dadap Merah (Erythrina Crista-Galli) Dengan Metode Microwave Assisted Extraction," Journal of Chemical Process Engineering, vol. 5, no. 1, pp. 33–39, 2020.

[12] I. Hikmah and G. Prajitno, "Pengaruh Penggunaan Gel-Electrolyte pada Prototipe Dye Sensitized Solar Cell (DSSC) berbasis TiO2 Nanopartikel dengan Ekstrak Murbei (Morus) sebagai Dye Sensitizer pada Substrat Kaca ITO," Jurnal Sains dan Seni ITS, vol. 4, no. 1, pp. B5–B10, 2015.