Effect of Mixing Dyes and Solvent in Electrolyte Toward Characterization of Dye Sensitized Solar Cell Using Natural Dyes as The Sensitizer

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Abstract. Dye Sensitized Solar Cell (DSSC) using natural dyes (chlorophyll, curcumin from turmeric extract, and anthocyanin from mangosteen extract) have been successfully fabricated for determining the effect of variation natural dyes, mixing dyes and acetonitrile in electrolyte toward characterization of DSSC. DSSC consists of five parts namely ITO (Indium Tin Oxide) as a substrate; TiO₂ as semiconductor materials; natural dyes as an electron donor; electrolyte as electron transfer; and carbon as a catalyst that can convert light energy into electric energy. Two types of gel electrolyte based on PEG that mixed with liquid electrolyte have utilized for analyzing the lifetime of DSSC. Type I used distilled water as a solvent whilst type II used acetonitrile as a solvent with addition of concentration of KI and iodine. The main purpose of study was to investigate influence of solvent in electrolyte, variation of natural dyes and mixing dyes toward an efficiency that resulted by DSSC. The result showed that electrolyte type II is generally better than type I with efficiency 0.0556 and 0.0456 %, respectively. An efficiency values which resulted from a variation of mixed three natural dyes showed the greatest efficiency compared to mixed two natural dyes and one dye, with an efficiency value can be achieved at 0.0194 % for chlorophyll; 0.111 % for turmeric; 0.0105 % for mangosteen; 0.0244 % (mangosteen and chlorophyll); 0.0117 % (turmeric and mangosteen); 0.0158 % (turmeric and chlorophyll); and 0.0566 % (mixed three natural dyes).

1. Introduction
Solar energy makes comfortable for humans and the environment and has been widely used as energy source in solar cells. The solar cell is a device that can convert light energy into electrical energy [1]. The use of solar cells as a source of electrical energy is still limited due to constraints of the high cost of the main ingredient of the cell, namely silicon. However, after passing through the times, solar cell technology also developed. These developments have come to the solar cells developed by Gratzel. These cells are often also called Gratzel cells or Dye-Sensitized Solar Cells (DSSC) [2]. The Dye Sensitized Solar Cell is a photoelectrochemical solar cell, it uses a liquid electrolyte or other ion-conducting phase as a charge transport medium [3]. DSSC usually consists of five parts namely TiO₂ as semiconductor materials for photoanode; ITO (Indium Tin Oxide) as a substrate; dyes as an electron donor; carbon as a catalyst that can convert light energy into electric energy; and electrolyte as electron transfer. The electrolyte is one of the key components of DSSC that provide internal electric ion conductivity that spreads in the mesoporous TiO₂ layer and an important factor for
determining the performance of the cells [4]. Therefore, various attempts have been made to study the various types of electrolytes. In liquid electrolytes, ionic conductivity is generated is high. However, in use in a DSSC, leakage and evaporation of the solvent liquid cannot be avoided so that the stability of the low electrolyte which causes low efficiency [5]. To overcome these problems, gel electrolyte have been a good candidate for the application of DSSC. In the gel electrolyte, polymer is used as a container to trap liquid solvents, organic solvents and inorganic salts such as propylene, ethylene carbonate and iodide salts of lithium, sodium and potassium. In the resulting gel electrolyte stability and conductivity high enough when compared with liquid electrolyte. Therefore, it will do further research on the influence of the electrolyte material such as a polymer or solvent of the electrolyte gel material used in DSSC

2. Experimental

2.1 Materials

The materials used in this research: Alfalfa chlorophyll (K-Link), curcumin from turmeric extract, and anthocyanin from mangosteen extract as the dyes solution, graphite carbon (from pencil), ITO (Indium Tin Oxide) that has been cleaned by ultrasonic cleaner, ethanol, HCl (Merck), TiCl3 (Merck), NH2OH (Merck), HNO3 (Merck), Triton X-100 (Merck), aquades, PEG (polyethylene glycol), chloroform, iodine (Merck), acetonitrile (VWR), and KI (Potassium Iodide).

2.2 Synthesis of TiO2 Nanoparticles

The precursor solution to synthesize of nanocrystalline TiO2 anatase containing a mixture of 50 mL aquades, 20 mL HCl (Merck) 2M 37% and 20 mL TiCl3 (Merck) was magnetically stirred for half hour at room temperature. Furthermore, a solution of 50 mL of NH2OH (Merck) 25% was added dropwise to the precursor solution and was then stirred again for 60 minutes and precipitated for 1 day at room temperature and sealed. After the filtering the sediment then dried using a furnace with a temperature at 400 °C for 3 hours [6].

2.3 Preparation of Dye Sensitized Solar Cell

The paste of TiO2 made from 1 ml distilled water, 0,7 ml of acetic acid ((Merck) and 0,7 ml of Triton X-100 (Merck) and PEG 1000 [7]. TiO2 layer is deposited on the ITO glass by Doctor-Blade method for DSSC photoanode (working electrode). These photoanode are soaked in natural dyes solution for 24 hours at room temperature and was then taken out from the dye solution and rinsed in 70% ethanol. The counter electrode made of a ITO (Indium Tin Oxide) glass coated with graphite. Two types of the gel electrolyte fabricated by adding a polymer in a liquid electrolyte. Type I consists of a mixture of 7 g PEG (Merck), 25 mL chloroform (Merck), and liquid electrolyte (liquid electrolyte : 0.8 g KI dissolved in 10 ml of aquades and 5 drops of iodine solution (Merck)). The precursor solution was magnetically stirred for one hour at 80°C until homogenous and become a gel [8]. Type II consists of a mixture of 7 g PEG (Merck), 25 mL chloroform (Merck), and liquid electrolyte (liquid electrolyte: 3 g KI dissolved in 10 mL acetonitrile and 3 mL iodine solution (Merck)). The precursor solution was magnetically stirred for one hour at 80°C until homogenous and become a gel. The counter electrode made of a ITO glass coated with graphite. Subsequently, the working electrode, electrolyte, and counter electrode arranged in the sandwich for fabricating of DSSC.

2.4 Measurements

The synthesized anatase TiO2 nanoparticles were characterized by XRD (X-Ray Diffraction) whereas the absorbance spectrum of extracted natural dyes were characterized by using UV-Vis Spectrophotometer 110 (Ocean Optics). The result of characterization was done by measuring dyes’ absorbance to visible light spectrum with the wavelength ranging from 300 – 700 nm. The performance of DSSC (Dye Sensitized Solar Cell) was tested by characterizing the current and voltage
(I-V) with the power density 125 W/m². Fill factor of DSSC was determined according to equation (1) and the energy conversion was determined according to equation (2) [3]:

\[
FF = \frac{V_{MPP}I_{MPP}}{V_{OC}I_{SC}}
\]  

(1)

Where \( FF \) is the fill factor (value should be between 0 and 1), \( V_{MPP} \) is the voltage maximum power point (V), \( I_{MPP} \) is The current maximum power point (Ampere)

\[
\eta = \frac{P_{max}}{P_{light}} \times 100\%
\]  

(2)

Where \( \eta \) is efficiency (%), \( P_{max} \) is the maximum power (Watt)

3. Result and Discussion

3.1 Characterization of Dye Absorbance

The characterization of dye sensitizer has been done by using the dye absorbance UV-Vis Spectrophotometer (UV-Vis 1100 Spectrophotometer, Ocean Optics). The result of UV-Vis absorption spectra of Chlorophyll Sensitizer is shown in Figure 1. Based on the results of UV-Vis absorption in Figure 1, All of natural dyes has the absorbance spectrum 300 – 700 nm. The absorbance peak of chlorophyll sensitizer located at 400 nm. The absorbance peak of turmeric sensitizer located at 435 nm. The absorbance peak of mangosteen sensitizer located at 429 nm. The absorbance peak of mangosteen-chlorophyll sensitizer located at 300 nm and 418 nm. The absorbance peak of turmeric-mangosteen sensitizer located at 300 nm and 410 nm. The absorbance peak of turmeric-chlorophyll sensitizer located at 300 nm and 422 nm. The absorbance peak of mixing dyes (chlorophyll-turmeric-mangosteen) sensitizer located at 300 nm and 432 nm.

![Figure 1. Absorption spectrum of natural dyes.](image)

3.2 Characterization of I-V Curves

The characterization of current and voltage need to be done to determine the performance of all types of DSSC samples that have been fabricated in this paper. In DSSC type I (using gel electrolyte type I) are summarized in Table 1. It can be concluded from Table 1 that the highest maximum power and
The highest efficiency were achieved for the DSSC using mixing dyes (chlorophyll-turmeric-mangosteen) with the values obtained at 8548,8 nW and 0,0456%, respectively. Meanwhile, the performance of the DSSC using electrolyte type II are summarized in Table 2. The best result was achieved for the DSSC using mixing dyes (chlorophyll-turmeric-mangosteen) with the highest efficiency at 0,0566%.

Table 1. Photochemical parameters of the DSSC by natural dyes using electrolyte type I

| Nama Sel               | $V_{sc}$ (mV) | $I_{sc}$ (µA) | $P_{max}$ (nW) | FF (%) | η (%) |
|------------------------|---------------|---------------|----------------|--------|-------|
| Chlorophyll            | 426           | 20            | 1720,5         | 20,193 | 0,0092|
| Turmeric               | 460           | 18,9          | 1780           | 20,474 | 0,0095|
| Mangosteen             | 377           | 27,4          | 2811,9         | 27,221 | 0,0150|
| Mangosteen-Chlorophyll | 376           | 53            | 4360,5         | 21,881 | 0,0232|
| Turmeric-Mangosteen    | 504           | 62,2          | 5795,5         | 18,487 | 0,0309|
| Turmeric-Chlorophyll   | 563           | 64            | 7046           | 19,555 | 0,0376|
| Chlorophyll-Turmeric-Mangosteen | 574 | 69 | 8548,8 | 21,586 | 0,0456|

Table 2. Photochemical parameters of the DSSC by natural dyes using electrolyte type II

| Cell Name               | $V_{sc}$ (mV) | $I_{sc}$ (µA) | $P_{max}$ (nW) | FF (%) | η (%) |
|------------------------|---------------|---------------|----------------|--------|-------|
| Chlorophyll            | 295           | 43            | 3634           | 28,648 | 0,0194|
| Turmeric               | 320           | 24            | 2076           | 27,031 | 0,0111|
| Mangosteen             | 450           | 30            | 1958,8         | 14,510 | 0,0105|
| Mangosteen-Chlorophyll | 530           | 44            | 4488           | 19,245 | 0,0244|
| Turmeric-Mangosteen    | 340           | 20            | 2200,5         | 32,360 | 0,0117|
| Turmeric-Chlorophyll   | 387           | 30            | 2964           | 25,529 | 0,0158|
| Chlorophyll-Turmeric-Mangosteen | 496 | 60 | 10605 | 35,635 | 0,0566|

The results of the characterization of the current and voltage are obtained, it is known that when the light illuminated DSSC, TiO$_2$ nanoparticles that have been created, capable of generating current and voltage response was quite good. It is proved that the dyes used in this study has a good potential for DSSC application. The voltage generated at the DSSC is affected by the conditions of material arranged at DSSC, namely semiconductors and electrolytes. In theory, the voltage arising from the difference, or the difference between the Fermi energy level of the semiconductor and the potential energy of the redox electrolyte [9]. The resulting current in DSSC is influenced by the quantity and activity of electrons located in the cell. The more electrons, the greater the current generated. In the first type of this DSSC, the current generated from single DSSC dye is smaller than the current generated from a two mixing dyes and three mixing dyes. According to UV-Vis data, absorbance values on a single dye bigger than two mixing dyes and three mixing dyes but the mixing dyes produce wide wavelength range than single dye. This is consistent with research of A.Z Abidin et al and Bandara, which in their study that the results DSSC written by a mixing of more than one dye can improve the efficiency of the solar cells [10-11]. Where the dye is meant to capture photons from the light source has the ability to absorb light of a wavelength range that is generated between each dye was done mixing. So that more photons are absorbed by the dye and cause electrons generated more and more. However, the current results obtained in this study is the first type DSSC, the results obtained current is small, so the optimization was done by replacing the type of electrolyte. In this second type of DSSC, optimization is done by adding the KI and iodine concentration in the gel electrolyte and also replace the previous solvent distilled into acetonitrile. Acetonitrile as a solvent increase the efficiency of DSSC because acetonitrile is an organic solvent.
which has many advantages compared to distilled water, such as low viscosity and rapid diffusion of ions. With this second optimization, the voltage generated is not much different, but as a whole, the current generated has risen 20 – 60 μA. This is due to the addition concentration of KI and Iodine. With the addition of this concentration, the ion - ion produced was also growing. Given that the ions in the electrolyte serves as an electron transfer from the carbon electrode to the dye was oxidized on the working electrode. The more ions contained in the electrolyte, the faster the electrons recombine [12]. The Characterization of current and voltage DSSC type I shown in Figure 2. The Characterization of current and voltage DSSC type I shown in Figure 3.

![Figure 2](image.png)

**Figure 2.** The Characterization of Current-Voltage DSSC type I.

![Figure 3](image.png)

**Figure 3.** The Characterization of Current-Voltage DSSC type II.

**4. Conclusion**

The features of the DSSC have successfully been fabricated with natural dyes sensitzers containing chlorophyll, turmeric, mangosteen, chlorophyll-mangosteen, chlorophyll-turmeric, turmeric-mangosteen and chlorophyll-mangosteen-turmeric. DSSC with all natural dyes were optimized using two types of gel electrolyte. DSSC type I and type II with mixing three dyes generate greater efficiency compared to sensitizer single dye and mixing two dyes. Meanwhile, DSSC type II using acetonitrile solvent generate greater than DSSC type I using aquades solvent.
5. **References**

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