Characteristics of dye Rhoeo spathacea in dye sensitizer solar cell (DSSC)

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Abstract. Dye-sensitized solar cell (DSSC) is a device that converts solar energy into electrical energy. The magnitude of the efficiency of DSSC is mainly based on the amount of dye absorbed by the surface of TiO2. In this work, used natural dye extracted from leaves Rhoeo spathacea. The dye partially used to immerse of TiO2 as working electrodes, and the rest are directly mixed TiO2 paste to obtain dye titanium dioxide. The paste TiO2 and dye titanium dioxide coated onto the fluorine-doped tin oxide (FTO) glass plate by spin coating method. The absorbance spectra of the dye, dye titanium dioxide, and TiO2 were obtained by UV-Vis spectroscopy. The conductivity of the dye, dye titanium dioxide, and TiO2 was measured by two point probe El-Kahfi 100. The DSSC based on dye titanium dioxide that stirring for 5 hours the highest efficiency of 0.0520 % whereas those based on TiO2 immersed for 36 hours showed achieved 0.0501 % obtained from I-V characterization.

1. Introduction
Dye-Sensitized Solar Cell (DSSC) is a device that converts solar radiation into electric energy. DSSC was devided of two section that consisting of nanopori TiO2 dye molecules are adsorbed on the surface of TiO and catalysts which are all deposited between two conductive glass [1,2]. When the light impinges the surface of the dye, the photon energy is absorbed by the electron dye thus get energy for the excited electron. Furthermore the excited dye injects electrons into the conduction band of the TiO2 nanoporous films and forwarded to the conductive electrode (anode). Electrons flow through an external load to reach the cathode (counter electrode). Electrons are transferred to the electrolyte in the cathode. Electrolyte containing I- / I3- which acts as an electron mediator so that it can produce in the cell cycle process. Thus, the dye is oxidized redox ions accept electrons from I- to replace the missing electron, and iodide molecules then oxidized to Tri-iodide ion (I3-) which compensate electron is missing from the counter electrode [3,6].

Dye-sensitizer is important in DSSC due to can absorbing sunlight and transforming it into electrical energy. One of the types the natural dyes has been used as a sensitizer is anthocyanin because can attach with TiO2 surface and exhibit broad region of the visible light spectrum [4,8]. Titanium dioxide (TiO2) is the most common used in DSSC especially the anatase phase because having better photo catalytic activity. TiO2 have superior properties, like non-toxic, inexpensive, good chemical stability, biocompatibility, etc[5,9].

In this work, we examined the influence of the process for fabrication DSSC using Rhoeo spathacea leaves. Rhoeo spathacea selected because they contain anthocyanins with a range of the
visible spectrum is quite wide[10]. The process of synthesis performed in this work is submersion of TiO₂ and the direct mixing to obtain dye titanium dioxide. The characterization of dye titanium dioxide and TiO₂ immersed using UV-Vis spectroscopy system (Lambda 25), two point probe El-Kahfi 10, and I-V characterization (Keithley 2602A meter). The purpose is to study the optical, conductivity and conversion efficiency from dye titanium dioxide and TiO₂ immersed using dye Rhoeo spathacea.

2. Experiment

2.1. Dye Extraction
In this work using dyes from anthocyanin extracted from the leaves Rhoeo spathacea. 10 g leaf Rhoeo spathacea is mixed in 50 ml ethanol. The mixture was kept for half an hour at temperature 60°C and kept for 24 hours. The extracted was filtered and used for the synthesis of natural dye mixed TiO₂ and submersion of TiO₂.

2.2. Synthesis of Dye Titanium Dioxide
Dye titanium dioxide obtained from direct mixing 8 ml dye and 1 ml TiO₂. Dye was added dropwise into TiO₂ under vigorous stirring at room temperature. After completing the dropwise addition of dye, the solution was stirred to obtain a homogeneous solution. For the paste of TiO₂ using 0.5 g the anatase phase TiO₂ is mixed 2.5 ml ethanol. The mixture was kept for an hour. The paste of TiO₂ and dye titanium dioxide was coated onto the FTO glass plate using the spin-coating method.

2.3. DSSC Fabrication
The DSSC is composed of two conductive glass, TiO₂ layer, molecules dye, electrolyte and carbon layer[11]. In this work, there are two ways to fabricate o DSSC:
   (i) TiO₂ paste with nanoparticle sizes was coated onto the FTO conductive glass with the spin-coating method and sintering at 500°C for 30 minutes. After cooling, the TiO2 electrode was immersed in a solution of dye for 3, 6, 22, 24, and 36 hours.
   (ii) The paste of dye titanium dioxide was coated onto the FTO glass with the spin-coating method and sintering at 60°C for 30 minutes.

To prepare the catalytic counter electrode, the surface of FTO glass is rubbed with carbon and then heated over a candle light until blackened. The DSSC are assembled injected with the electrolyte solution and then sealed using the clipboard. To obtain voltage and current of the DSSC used a Keithley 2602A meter (USA) under illumination by a lamp of 1000 W/m².

3. Results and Discussion

3.1. UV-Vis and Conductivity Analysis
The absorbance spectra were measured by UV-Vis spectroscopy system (Lambda 25). The absorption spectra of dye, dye titanium dioxide, and TiO₂ immersed in dye are given in Figure 1.
Figure 1. (a) Absorption spectra of TiO$_2$ submersion  
(b) Absorption spectra of dye Rhoeospathacea and dye titanium dioxide 

Figure 1 showed that the dye Rhoeo spathacea have a maximum absorption peak at 436 nm which is the visible region. After being mixed directly with TiO$_2$ and used to immersed, the absorption peak
is shifted. It shows that the TiO$_2$ needs a dye sensitizer to become a good solar cell photoanode material. It is because the pure of TiO$_2$ does not absorb the solar radiation above 320 nm, so that when the TiO$_2$ submersion or directly mixed with the dye, the dye binds to the surface of TiO$_2$. Consequently the number of electrons produced will be increased because the dye is able to absorb light in the visible region. The quality of bonding was influenced by a homogeneous solution. The directly mixed process, the homogeneity of the solution can be arranged through the length of the stirring. But the length of the stirring can make dye titanium dioxide drying due to the process stirring doing with temperature 60$^\circ$C and can lead to break the bond between the dye anthocyanin and TiO$_2$ compounds. While in the immersion process, the quality of bonding is done by prolonging the time immersed process. Hence, the directly mixed more efficiently than the submersion process and the quality of bonding is better. It is because the dye get suppressed when directly mixed with TiO$_2$.

The conductivity of the dye, dye titanium dioxide, and TiO$_2$ was measured by two point probe El-Kahfi 100 and are given in Figure 2.

**Table 1.** The conductivity of dye Rhoeo spathacea, dye titanium dioxide, and TiO$_2$

| Material                  | Dark of the conductivity ($\Omega^{-1}m^{-1}$) | Light of the conductivity ($\Omega^{-1}m^{-1}$) | $\Delta\sigma$ ($\Omega^{-1}m^{-1}$) |
|---------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------|
| Dye Rhoeo spathacea       | 0.002                                         | 0.003                                         | 0.001                               |
| Dye titanium dioxide      | 0.002                                         | 0.005                                         | 0.003                               |
| TiO$_2$                   | 0.001                                         | 0.002                                         | 0.001                               |

Table 1 shown that the difference value of between light and dark conductivity has the dye titanium dioxide is the highest, which means the dye titanium dioxide molecules has the smallest resistant. It was meant the dye titanium dioxide has the highest current and this comparable with the electrons flowed when the absorption of light energy.
3.2. Performance of DSSC

Characterization of the current-voltage (I-V) is a method for determining the ability of the DSSC to convert solar radiation into electrical energy. To obtain current-voltage characterization used a Keithley 2602A conducted in the dark and the light is under illumination by a lamp of 1000 W/m². The current-voltage of the dye titanium dioxide and TiO₂ has been immersed for 24 hours is shown in Figure 3.

![Figure 3](image)

**Figure 3.** (a) Current-voltage curves of TiO₂ with variation of time immersed (b) Current-voltage curves of dye titanium dioxide with variation of time stirring
Figure 3 showed that the dye titanium dioxide have a greater curve with the dark current than the TiO\textsubscript{2} has been immersed for 36 h. It means that the efficiency of the dye titanium dioxide is greater than the TiO\textsubscript{2} has been immersed for 36 h. The efficiency of the solar cell is a factor of the size quality of performance of DSSC. The higher of efficiency is mean a better performance. One of the reasons the curve are not neat was electrolytes used fast-drying, so need to inject electrolytes every characterization I-V. The value of efficiency for dye titanium dioxide and TiO\textsubscript{2} shown in Table 2.

Table 2. Efficiency of DSSC with Dye Rhoe spathacea as a Sensitizer

| Material | Dye Titanium Dioxide | TiO\textsubscript{2} has been immersed |
|----------|----------------------|----------------------------------------|
|          | 5h                   | 6h                                     | 6h | 22h | 36h |
| \(I_{\text{max}}\) (mA) | 0.0002 | 0.0001 | 0.0002 | 0.0004 | 0.0002 |
| \(V_{\text{max}}\) (mV) | 0.1000 | 0.3700 | 0.4150 | 0.4451 | 0.4751 |
| \(I_{\text{sc}}\) (mA) | 0.0003 | 0.0002 | 0.0002 | 0.0002 | 0.0001 |
| \(V_{\text{oc}}\) (mV) | 0.0700 | 0.0505 | 0.2200 | 0.2050 | 0.3400 |
| \(\eta\) (%) | 0.0020 | 0.0520 | 0.0423 | 0.0494 | 0.0501 |

The conversion of energy is related of the excitation of electrons that produced by the sample during the absorption of the light process. The electrons have been produced will be captured by the anode (TiO\textsubscript{2}) and the hole in the dye will be compesated by electrons from the electrolyte. Furthermore, electrons flow through an external load (I-V characterization) and obtained characteristics such as Figure 3. The next process is the travel back of electrons to solar cells that accepted by the counter electrode contained carbon layer. The carbon layer as a catalyst, which accelerates the flow of electrons, as well as to be able to accelerate the reaction in the electrolyte. The reaction redox of the electrolyte occurs repeatedly, which generates new electrons to replace the missing electron in the dye (hole).

4. Conclusion

The dye Rhoe spathacea has been used in DSSC as a sensitizer. To fabricate of DSSC using two ways, the TiO\textsubscript{2} electrode was immersed in a solution of dye and the directly mixed with TiO\textsubscript{2} nanoporous. From the result UV-Vis spectroscopy, two point probe El-Kahfi 100 and I-V characterization were obtain:

(i) The absorption peak of dye Rhoe spathacea is 436 nm. After being mixed directly with TiO\textsubscript{2} and used to immersed, the absorption peak is shifted.

(ii) The conductivity of dye Rhoe spathacea is 0,0010 \(\Omega^{-1}\)m\(^{-1}\), dye titanium dioxide 0,003 \(\Omega^{-1}\)m\(^{-1}\), and the TiO\textsubscript{2} 0,0012 \(\Omega^{-1}\)m\(^{-1}\).

(iii) The efficiency of the dye titanium dioxide that stirring for 5 hours 0,0520% and the TiO\textsubscript{2} was immersed for 36 hours in the dye 0,0501%

In this work shown that the directly mixed was a promising method for uniform dye absorption hence the conversion efficiency of the light to electron can be improved.

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