Variation of *Indigofera tinctoria*’s Immersion Time on Dye Solution and its effect on DSSC efficiency

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**ABSTRACT**

The utilization of *Indigo tinctoria* as a DSSC sensitizer has been done to study the effect of *I. tinctoria*’s immersion time on DSSC efficiency. One of the most essential components in DSSC is a sensitizer or dye. In this work, the dye has been used in DSSC is the natural indigo dye from *I. tinctoria* leaves. The extraction was done by dissolving 50 grams of *I. tinctoria* leaves in 500 milliliters aquades and soaking in various time: 12, 24, 36, and 48 hours. The optical properties of dye solution was characterized by UV-Vis spectrophotometer and the current-voltage of DSSC was characterized by Keithley I-V Meter. The highest absorbance is 2.7 of 48h dye solution, but the best efficiency of DSSC is $5.39 \times 10^{-3} \%$ that owned 24 h cell.  

Keywords: DSSC, *Indigofera tinctoria*.

**INTRODUCTION**

One of the renewable energies in the world is solar energy. Dye Sensitized Solar Cell (DSSC) is a device that can convert light energy into electrical energy with photosensitizer based \[^1-3\]. The advantages of DSSC are economical, simple to fabricate, easily obtained the materials, and have excellent conversion efficiencies \[^4\]. DSSC is composed of three main components namely working electrode, counter electrode and electrolyte solution \[^5,6\]. The working electrode is composed of transparent conductive glass, such as Fluorine-doped Tin Oxide (FTO), TiO$_2$ nanocrystalline semiconductor layer and dye active layer. Dye serves as a sensitizer in which the transfer of electrons to the TiO$_2$ semiconductor occurs. Dyes are basically divided into two kinds: organic dyes and synthetic dyes. Organic dyes or natural dyes are dyes that are ingredients derived from nature, whereas synthetic dyes are dyes that material derived from chemical compounds. Natural dyes unlimited availability, environmentally friendly, cheap and the process of making it very simple. While the synthetic dyes are very limited, can cause environmental pollution, using some expensive metals and complicated manufacturing processes \[^7,8\].

In this study, indigo pigment was used as a sensitizer from *Indigo tinctoria* leaves. The indigo plant (*Indigofera* sp.), which is one of the oldest natural dye in the world and has been used since the ancient periods. This plant has many species, but the most commonly species are *I. arrecta* and *I. tinctoria* \[^9\]. *I. tinctoria* is widespread across tropical regions around the world. The plant has been cultivated and highly valued for centuries as a main source of indigo dye. Commonly called as ‘true indigo’, *I. tinctoria* is a primary source of natural dye among the indigo plants as shown in Figure 1.
Figure 1. Organic Dye *Indigofera tinctoria* (Private document)

Indigo blue colour comes from indican substances contained in Indigofera leaves. After soaking the leaves in water, hydrolysis reaction will bring indoxyl (white colour) and glucose. The indoxyl is transformed into blue colour after aeration is performed. If the fabric is dipped in a mixture of fermentation solution containing indoxyl and dried in the fresh air, it will generate insoluble indigo and change into blue colour. Indigo precipitates in the form of cis isomerization and turns into trans isomer that will change into blue color [10]. Indigo is a group of carbonyl compound and one of the oldest known dyes in terms of natural dyes. According to a derivative of a group of organic compounds that are colourless glucoside from a form of "enol" from an indoxyl, for example indican. Indigo is formed from indican because the fermentation process of Indigofera species plant is followed by oxidation by free air of indoxyl [11-13]. Figure 2 shows the reaction illustrates the extraction of indigo colour.

![Indican to Indigo Diagram](image)

Figure 2. Reaction to produce natural dye indigo [14].

**METHOD**

DSSC structure was used in this research is sandwich structure, that consists of working electrode, counter electrode, dye as photosensitizer, and electrolyte as redox mediators. The extraction dye was done by cut and take the leaves of *I. tinctoria* (better before sunrise). 50 grams *I. tinctoria* leaves are dissolved in 500 milliliters aquades. We make sure all the leaves are soaked; and they’re soaked in various time: 12, 24, 36, and 48 hours. The FTO glass (2 cm x 2 cm) was washed by aquades, acetone, and alcohols every 10 minutes, respectively, using the ultrasonic bath. The TiO$_2$ paste is made from 3 grams of transparent TiO$_2$ with 3 ml of ethanol and they’re stirred using a magnetic stirrer for ±4 hours at 300 rpm so that both materials become homogeneous solutions. The TiO$_2$ paste deposition on the substrat by using a spin coating method with a rotation speed of 1000 rpm for 1 minute. Then TiO$_2$ is annealed using furnace with temperature of 550°C for 60 minutes with heating rates 15. After that, the working electrode is soaked in dye solution for 24 hours. For the counter electrode used platinum dissolved in ethanol. The platinum solution is applied to a FTO glass over a hot plate of 250°C by brush method. The scotch tape is used on the FTO glass to avoid contact between the working electrode and the counter electrode. Electrolyte is applied to the counter electrode. Working electrodes and counter electrodes are combined using a binder clip.
The absorption spectra of indigo dye solutions were recorded using a UV-Visible spectrophotometer *Lambda 25*. The absorption analysis was conducted in the wavelength range from 400 to 800 nm. The *I-V* characteristic curves under simulated sunlight 1000 W/m² were conducted using *Keithley I-V* meter. Based on *I-V* curve, the fill factor (*FF*) can be calculated as:

\[
FF = \frac{I_m V_m}{I_{sc} V_{oc}}
\]

(1)

where *Iₘ* and *Vₘ* are the photocurrent and photovoltage for maximum power output (*Pₘ*), *Iₙₐₜ* and *Vₙₜₜ* are the short-circuit photocurrent and open-circuit photovolta, respectively. The overall energy conversion efficiency (*η*) is defined as

\[
\eta = \frac{FF I_{sc} V_{oc}}{P_{in}} \times 100 \%
\]

(2)

where *Pₐₘ* is the power of incident light.

**RESULT AND DISCUSSION**

**Absorption Spectra of Dye Solutions with Immersion Time Variation**

Figure 3 shows that the absorbance peak of the indigo dye solution occurs at a wavelength of 600 nm. The highest absorbance is 2.7 of 48 h solution. The wave peak occurs from dye 36 h solution. The dye solution with immersion time for 12 hours (12h) shows only straight line because the solution is still clear and the leaves have not been perfectly fermented. Clear solutions show a low absorbance rate because more light is transmitted so that no absorbance peak occurs. The longer the immersion time so the solution color is getting older, so that the absorbance is higher. The highest absorbance is owned 48 hours (48h) immersion time of dye solution.

**I-V Characterization**

Characterization of Current and Voltage is done using *Keithley I-V* meter. The measured DSSC performance can be seen in Table 1.
Table 1. I-V Characteristics of DSSC

| Sample  | $I_{max}$ (A) | $V_{max}$ (V) | $P_{max}$ (W) | $P_{in}$ (W) | Efficiency (%) |
|---------|---------------|---------------|---------------|--------------|----------------|
| 12 h Cell | $5.60 \times 10^{-6}$ | 0.03 | $1.70 \times 10^{-1}$ | 0.05 | $3.40 \times 10^{-4}$ |
| 24 h Cell | $2.54 \times 10^{-5}$ | 0.10 | $2.69 \times 10^{-6}$ | 0.05 | $5.39 \times 10^{-3}$ |
| 36 h Cell | $9.40 \times 10^{-6}$ | 0.12 | $1.14 \times 10^{-6}$ | 0.05 | $2.28 \times 10^{-3}$ |
| 48 h Cell | $8.10 \times 10^{-6}$ | 0.08 | $7.29 \times 10^{-7}$ | 0.05 | $1.46 \times 10^{-3}$ |

Figure 4 is a graph of $I$-$V$ characterization showing different voltage and current outputs due to immersion time. The efficiency of 36h and 48h cells actually decreased so that the greatest efficiency is owned by the 24h cell, that is $5.39 \times 10^{-3}$ %. Although the highest absorbance is owned 48h solution, but the 24h dye solution produces the highest DSSC output when the dye was binding with TiO$_2$. It is possibly due to the fermentation time with an interval of 24 hours shows the condition of bacteria (an aerobic) that achieve optimum condition because of the temperature, time and pH were met by nutrients.

CONCLUSION

The highest absorbance of dye solution is 2.7 of 48 h solution but the best efficiency of DSSC is $5.39 \times 10^{-3}$ % that owned 24 h cell. It is possibly due to the fermentation time with an interval of 24 hours shows the condition of bacteria (an aerobic) that achieve optimum condition.

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