Fabrication of Dye Sensitized Solar Cell from Buni Fruit (Antidesma bunius L.)

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Abstract. Energy crisis is what being faced by every country today. Many efforts have been devoted to overcome the problems. One of several offered solutions is to develop solar cells since solar energy is abundant and free to use. Especially in a tropical country like Indonesia, solar energy is available a whole year with quite high power 450 mWcm⁻². Several types of solar cells, silicon-based solar cell has high efficiency yet has high price. Dye sensitized solar cells (DSSC) are a new breakthrough in solar cells with the cheaper cost than conventional solar cells. The natural ingredients could be utilized as dyes for DSSC. In this research, buni fruit extract was employed as the dye for TiO₂-based DSSC. Factor levels for this research are determined by Taguchi Method. The highest voltage average of dye sensitized solar cell is 0.5 volt with the levels of influencing factor are 5: 1 for ratio of TiO₂: ethyl cellulose, 5: 1 for buni fruit extract ratio: ethanol, 1.5 g for Carbon amount, and 0.3 ml for amount of electrolyte solution. The simple calculation of the price is Rp 2.371 per 5 x 5 cm a piece of dye sensitized solar cell.

Keywords: Buni Fruit, Dye Sensitized Solar Cell, Solar Energy, Taguchi Method

1. Introduction

Nowadays energy crisis is a big issue for every country in the world. Based on the national energy management blueprint 2006-2025, Indonesia's main energy supply in 2010 was still dominated by oil, which amounted to 54.78%, followed by natural gas 22.24%, coal 16.77%, hydro power 3, 72%, and geothermal 2.48% [1]. Fossil fuel is still an idol because of its relatively low price, ease in the usage and availability. However since the reserves are decreasing, alternative energy resources especially which are eco-friendly and inexpensive are urged to be explored and utilized [2].

Solar energy is expected to be a primary energy source especially in a tropical country like Indonesia which is available a whole year with quite high power 450 mWcm⁻² [3]. Solar cell (SC) is one of several ways to convert solar energy into electrical energy. Silicon-based SCs have been mass-produced and applied in many applications with quite high efficiency of 15-25% [4]. However they have some drawbacks including high cost and requirement of wide area to place the solar panel.

Many efforts have been devoted to overcome the problems. Gratzel and O'Regan in 1991 introduced an attractive and low cost third-generation solar cell technology namely Dye Sensitized Solar Cell (DSSC) which based on TiO₂ material [5]. DSSC consists an anode of conductive glass coated with a conductor noble metal which acts as a counter electrode and photocatalyst, a cathode of semiconductor materials, a conductive glass substrate contained a monolayer of dyes and an electrolyte of certain organic solvent containing a redox couple [6]. TiO₂ is a semiconductor having three polymorphisms including tetragonal rutile, tetragonal anatase and orthorhombic brookite. Rutile structure is the most thermodynamically stable phase, while the other two are metastable [7].

Besides semiconductor material, dye also plays an important role in enhancing DSSC performance since it should be able to harvest the sunlight and transfer it into electrical energy. Many researches have been conducted on DSSC using different types of dyes including natural and synthetic dyes [8]. The main characteristic of the dye is its ability in absorbing the visible light spectrum from red to blue so that it can sensitize the wide band gap semiconductor material. Ruthenium polypyridyl...
complex has been employed as a dye for DSSC and resulted in a quite high power efficiency of 5.63% [9]. However this transition metal coordination compound is expensive. Therefore people are interested to utilize inexpensive dye ingredients based on natural products such as fruits and vegetables having flavonoid (natural pigment) which contains anthocyanin.

One of the fruits that contain anthocyanin and abundant in Indonesia is buni (Antidesma bunius L.) [10]. Buni is a wild berry species in Australia, China, India, Indonesia, Myanmar, Philippines, Sri Lanka, Thailand and Vietnam [6]. In Java, this plant grows wild in the forest or is planted in the yard and can be found from the lowlands up to 1,400 m. Single leaf, short stem, round egg shape to lanceolate, 9-25 cm long, flat edges slightly flat, pointed tip, and base of blunt [11]. The buni tree has a height of 15-30 m. The fruit is small about 1 cm long, green elliptical shape.[12]. Medium trunked trees are spread in Southeast Asia and Australia, in Java grow wild in the forest or planted in the yard and can be found from lowlands up to 1400 m dpi. However, buni fruit has not been cultivated due to some considerations such as yet utilized in the world of industry and consumer demand is low. Often in some areas, this fruit is also referred to as snake food.

The content of anthocyanin in buni fruits and the abundant presence of these fruits in Indonesia are the main reason to use buni as a raw material of DSSC in this research. A set of experiments is conducted to extract anthocyanin of buni then its utilization in DSSC technology is observed. It is expected that a deeper understanding of using natural ingredients in DSSC technology could enhance the overall solar cell conversion efficiencies which current efficiency of (IPCE) over 10% has been achieved [13].

2. Methodology
2.1 The Structure of Solar Cell

The structure of the solar cells made in this study as shown in Figure 1.

![Solar Cell Structure](image)

**Figure 1.** DSSC solar cell structure

The manufacture of solar cells based on buni fruit dye is divided into 5 important items:

1). Conductive Glass
   Preparation of conductive glass using the main material glass preparations and the addition of tin chloride (SnCl2.H2O), ammonium fluoride (NH4F) and water (H2O).

2). Pasta TiO2
   Preparation of buni fruit absorbent paste is using TiO2, ethyl cellulose, and ethanol to be sintered on a conductive glass surface with a temperature of 450 °C so that the TiO2 paste is anatase phase.

3). Substance
   The fruits of buni are extracted using alcohol. The anthocyanin found in the buni fruits acts as a solar photon catcher that will be passed on as an electron producer. Transparent conductive glass with TiO2 on its surface is stuck on the buni fruit extract for ± 2 hours.
4). Counter electrode
The electrode counter is made by coating the carbon on a transparent conductive glass surface. Carbon acts as an electron holder to keep it around the conductive glass of TiO2 that has been made.

5). Electrolyte solution
The electrolyte solution using iodine (I2) is placed between the TiO2 paste and the electrode counter. This solution serves as the activation of the flow of electrons in the solar cell when exposed to sunlight.

6). Testing
The solar cell efficiency test is using a multimeter as a measure of solar cell voltage when exposed to sunlight. Testing is done 3 times every 1 hour to get the average voltage generated.

2.2. Application of the Taguchi Method

In this research, improvement process has done using Taguchi method by examining the factors that influence the quality of solar cell product. Here are the steps of applying Taguchi method in this research.

2.2.1. Determination of Quality Characteristics
For the determination of the quality characteristics, the result of solar cell voltage test is processed by the response of taguchi method using minitab 18 software. The optimum quality is obtained by using base of Higher is Better with formula:

\[ \text{Response:} \ -10 \times \log_{10} \left( \frac{1}{n} \sum_{1}^{n} Y^2 \right) \]

Where:
N = number of tests in trial (trial)
Y = experimental value

2.2.2. Determination of Factor and Influential Level
Determination of factor and level of influential factors obtained from the results of research that has been done. Here are the factors that affect the solar cell production process.

1). The ratio of TiO2: Ethanol
According to Asep Purwanto (2012), TiO2 is very influential in the absorption of banana anthocyanins and ethyl cellulose as adhesive molecules of TiO2 in order to remain anatase structure, therefore the optimal percentage of TiO2 and ethyl cellulose is important to know. For this study, the ratio between TiO2: ethyl cellulose is 1: 1, 5: 1, and 10: 1.

2). The ratio of Buni Extract: Ethanol
The anthocyanin in the buni fruit is the main substance used as a photon capture of the sun. Therefore, the concentration of optimal buni extract greatly affects the efficiency of solar cells. The ratio of buni extract: ethanol used is 1: 1, 5: 1, and 10: 1.

3). Total Carbon Counter Electrode
Variable counter electrode used is 0.5 g, 1 g, and 1.5 g.

4). Number of Electrolyte Solutions
Variables of electrolyte solution (iodine) used were 0.2 ml, 0.4 ml, and 0.6 ml.
After analyzing the factors that will be used later, factor level for this experiment are determined by Taguchi Method. The factor level used in the experiment will be presented in Table 1.

**Table 1. Level of Influential Factors**

| Factor Influential          | Factor Level |
|-----------------------------|--------------|
|                             | 1 | 2 | 3 |
| The ratio of TiO2: ethyl cellulose | 1:1 | 5:1 | 10:1 |
| The ratio of buni extract: ethanol | 1:1 | 5:1 | 10:1 |
| The amount of carbon        | 0.5 g | 1 g | 1.5 g |
| Amount of electrolyte solution | 0.2 ml | 0.3 ml | 0.4 ml |

2.2.3. Orthogonal Array Determination

To obtain an appropriate orthogonal array design, it is necessary to obtain a degree of freedom on the factors to be used in the experiment. Once the degree of freedom of the factor is known, the degree of freedom orthogonal array used is at least equal to that degree of freedom. In Table 2 is a degree of freedom calculation for controlled factors in this study.

**Table 2. Calculation of Degree of Freedom**

| Factor Code | DF Code | Explanation |
|-------------|---------|-------------|
| A           | (3-1)   | Ratio of TiO2: ethyl cellulose |
| B           | (3-1)   | The ratio of buni extract: ethanol |
| C           | (3-1)   | The amount of carbon |
| D           | (3-1)   | Amount of electrolyte solution |
| Total       |         | 8           |

In Table 2, it is known that the degree of freedom of the factor in this study is eight (8). To know the degree of freedom the orthogonal array is obtained by multiplying the degrees of freedom per column by the number of columns. Based on the description in table 2 above, then in this research should be run with orthogonal array L8 = 34, but because in Taguchi experiment did not recognize the existence of orthogonal array L8 = 34, so for the purposes of this study the number of orthogonal arrays used should be increased to L9 = 34 So that this research can be carried out in accordance with Taguchi’s research principles.

3. Result and Discussion

Table 3 shows the experimental results of solar cell voltage test 3 times based on time every 1 hour using Taguchi method.

**Table 3. Solar Cell Voltage Results**

| Ex | Control Factor | Result (volt) | Average |
|----|----------------|---------------|---------|
|    | A   | B   | C   | D   | I   | II  | III  |       |
| 1  | 1   | 1   | 1   | 1   | 0.4 | 0.38| 0.37 | 0.38  |
| 2  | 1   | 2   | 2   | 2   | 0.43| 0.41| 0.4  | 0.41  |
| 3  | 1   | 3   | 3   | 3   | 0.41| 0.4 | 0.38 | 0.39  |
| 4  | 2   | 1   | 2   | 3   | 0.5 | 0.48| 0.47 | 0.48  |
| 5  | 2   | 2   | 3   | 1   | 0.51| 0.5 | 0.49 | 0.5   |
| 6  | 2   | 3   | 1   | 2   | 0.5 | 0.49| 0.49 | 0.49  |
| 7  | 3   | 1   | 3   | 2   | 0.41| 0.38| 0.36 | 0.38  |
| 8  | 3   | 2   | 1   | 3   | 0.43| 0.4 | 0.38 | 0.4   |
| 9  | 3   | 3   | 2   | 1   | 0.38| 0.37| 0.35 | 0.36  |
The following response table uses Minitab 18 base software Higher is Better.

| Factor | A     | B     | C     | D     |
|--------|-------|-------|-------|-------|
| 1      | 0.3933| 0.4133| 0.4200| 0.4133|
| 2      | 0.4900| 0.4363| 0.4167| 0.4267|
| 3      | 0.3800| 0.4133| 0.4233| 0.4233|
| Delta  | 0.1100| 0.0233| 0.0067| 0.0133|
| Rank   | 1     | 2     | 4     | 3     |

From the calculation of the following response table, it is found that the level of influencing factor is factor 2 level A (ratio of TiO2: ethyl cellulose, 5:1), factor 2 level B (buni extract ratio: ethanol, 5:1), level C factor 3 (Carbon amount 1.5 g), and factor D level 2 (amount of electrolyte solution 0.3 ml). The potential of solar cells as alternative energy is so promising, it cause the technology of solar cell is increasing extremely. In 1954, the first generation conventional solar cells were found using silicon. Then the second generation of thin film solar cells [14]. The first generation has the disadvantages of expensive, silicon fabrication process is very difficult and complex. Furthermore, in the second generation has weaknesses, the fabrication process produces waste that pollute the environment and lower efficiency than the first generation [15].

Along with the development of nanotechnology, the dominance gradually began to be replaced with the presence of solar cells of the latest generation of dye-sensitized solar cell (DSSC). DSSC is one of the potential candidates for next generation solar cells, this is because it does not require material with high purity so the cost of production process is relatively low. Unlike conventional solar cells where all the processes involve the silicon material itself. In DSSC light absorption and electrical charge separation occur in a separate process. The absorption of light is done by dye molecules and the charge separation by inorganic nanocrystal semiconductors having a wide band gap [16].

The chemical reactions that occur sequentially in the solar cell are as shown below [17].

\[
D + \text{Light} \rightarrow D^* \\
D^* + \text{TiO}2 \rightarrow e^- (\text{TiO}2) + D^* \\
D^* (\text{Oxidized}) + \frac{3}{2} I^- \rightarrow D + \frac{5}{2} I^3^- \\
\frac{1}{2} I_3^- + e^- (\text{Counter electrode}) \rightarrow \frac{3}{2} I^- 
\]

The voltage generated by dye sensitized solar cells is derived from the difference in conductivity energy levels of the semiconductor electrode (TiO2) and the electrochemical potential of the redox coupling pair (I- / I3-). While the resulting current is directly related to the number of photons involved in the conversion process and depends on the intensity of irradiation as well as the dye performance used [18].

In this study, solar cells were developed using a modified ethyl cellulose TiO2 electrode to form a composite. Meanwhile, to reduce the occurrence of electrolyte degradation, iodine (I2) solution as redox coupling is used. The polymer gel electrolyte also acts as a second electrode adhesive, ie a dyezensized TiO 2 / ethyl cellulose dye and an opposing electrode (cathode) in the form of a carbon plate [19]. Solar cells made in this study as shown in Figure 2.
Figure 2. Solar Cell from Buni Fruit

The advantages of this new type of dyestuff-based solar cell that is very cheap so it is very efficient to be produced and as an alternative energy source. Table 5 below shows the price of solar cell production per 5 x 5 cm.

Table 5. Cost of Solar Cell Production

| No | Material     | Quantity | Cost (Rp)   | Total Cost (Rp) |
|----|--------------|----------|-------------|-----------------|
| 1  | Glass preparations | 2 piece | 200/ piece  | 400             |
| 2  | NH4F         | 0.1 g    | 2000/g      | 200             |
| 3  | SnCl2        | 0.1 g    | 1000/g      | 100             |
| 4  | H2O          | 1 ml     | 1 ml        | 1               |
| 5  | Buni Fruit   | 5 g      | 5/g         | 25              |
| 6  | Ethanol      | 1 ml     | 30/ml       | 30              |
| 7  | TiO2         | 1 g      | 1500/g      | 1500            |
| 8  | Iodine       | 1 ml     | 35/ml       | 35              |
| 9  | Ethyl cellulose | 1 g    | 30/g        | 30              |
| 10 | Filter paper | 1 piece  | 50/piece    | 50              |
|    | Total        |          |             | 2.371           |

4. Conclusion
Dye sensitized solar cell from buni fruit (*Antidesma bunius L.*) has been successfully fabricated and tested by multimeter as a measure of solar cell voltage. Factor levels for this research are determined by Taguchi Method. The highest voltage average of dye sensitized solar cell is 0.5 volt with the levels of influencing factor are 5: 1 for ratio of TiO2: ethyl cellulose, 5: 1 for buni extract ratio: ethanol, 1,5 g for Carbon amount, and 0.3 ml for amount of electrolyte solution. The simple calculation of the price is Rp 2.371 per 5 x 5 cm a piece of dye sensitized solar cell.

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6. References

[1] Balai Informasi Teknologi. 2009. *Pangan dan Kesehatan*. Jakarta: Lembaga Ilmu Pengetahuan Indonesia.

[2] Balat, M., Balat, H. & Öz, C., 2008, *Proses Fotosintesis*.

[3] Chung, I, et al, 2012, *All-solid-state dye-sensitized solar cells with high efficiency*. Department of Chemistry, Northwestern University, Evanston, Illinois 60208, USA.

[4] Grätzel, Michael, 2003, *Review Dye-sensitized solar cells*, Journal of Photochemistry and Photobiology C: Photochemistry Reviews 4 (2003) 145–153, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland

[5] Hardeli, Suwardani, et al. 2013. *Dye Sensitized Solar Cell (DSSC) Berbasis Nanopori TiO2 Menggunakan Antosianin dari Berbagai Sumber Alami*. Padang: UNP.

[6] Hug, H., et al, 2014, *Biophotovoltaics: Natural pigments in dye-sensitized solar cells*, Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland.

[7] Irawan, T 2007, *Jenis-jenis Sel Surya*, Universitas Udayana, Bali

[8] Irmansyah. 2008. *Fabrikasi dan Karakterisasi Sel Surya Tersensitisasi Dye Berbasis Elektroda Komposit TiO2/SnO2 dan Elektrolit Polimer*. Bogor: IPB

[9] Jannah, M., Riskiyani, S & Rahman, A 2014, *Pemanfaatan Budidaya Tanaman Indonesia*, Universitas Hasanuddin, Makassar.

[10] Komarayati, S & Gusmailina 2010. *Prospek Buah Buni di Indonesia*, Pusat Penelitian dan Pengembangan Hasil Hutan, Bogor.

[11] Prastowo, B, 2007, *Pergerakan Matahari Beserta Jumlah Cahayanya*. 6(2):57-104

[12] Purwanti, Asef. 2012. *Studi Pembuatan Tio2 Nanotube Dengan Teknik Anodisasi Pada Plat Titanium Dan Aplikasinya Untuk Sel Surya Tersensitisasi Zat Warna (DSSC)*. Jakarta: Universitas Indonesia.

[13] Rusdiana, Dadi. 2014. *Pembuatan Sel Surya Berbahan Dasar Antosianin Sebagai Material Dye*. Bandung: Universitas Pendidikan Indonesia.

[14] Salakory N.M, 2012, *Peningkatan Kebutuhan Listrik di Indonesia*, Unstrat, Manado.

[15] Saxena, R.C., Adhikari, D.K. & Goyal, H.B., 2009, *Mekanisme Kerja Sel Surya*. 

[16] Septina, Wilman. 2007. *Pembuatan Prototipe Solar Cell Murah dengan Bahan Organik-Inorganic*. Bandung: Institut Teknologi Bandung.

[17] Siregar, R. 2006. *Kondisi Energi Secara Umum*, USU, Medan.

[18] Susanti, D., et al, 2013, *The Preparation of Dye Sensitized Solar Cell (DSSC) from TiO2 and Tamarillo Extract*, Materials and Metallurgical Eng. Dept., Institut Teknologi Sepuluh Nopem (ITS), Surabaya

[19] Wijayanti, M.S. 2016. *Uji Aktivitas Antioksidan Penetapan Kadar Fenolik Total Ekstrak Etanol Buah Buni (Antidesma bunius L.) dengan Metode 2,2-Diphenyl-1-picrylhydrazyl (DPPH) dan Metode Folin-Ciocalteu*. Yogyakarta: Universitas Sanata Dharma