DSSC with PEDOT-Carrageenan Electrolyte as Learning Media for Photovoltaic Concept Physics

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Abstract. This study aims to create a DSSC using PEDOT-Carrageenan-based electrolyte as a learning media for photovoltaic physics concepts. This research was experimental research conducted in the laboratory of subdepartment of physics education, Tadulako University. In this study, DSSC making process used a substrate made from TCO-FTO polymer. The TiO₂ photoelectrode layer was deposited using the doctor blade technique and Ruthenizer as a dye-sensitizer and the platinum layer was deposited on the counter electrode using the sputtering technique. Process parameters that affect the characteristics of solar cells were analyzed and measured using the I-V characteristic curve. The samples measured consisted of several types of PEDOT-Carrageenan electrolytes, including Kappa, Lambda and Iota. The results of voltage measurements of each sample of the DSSC prototype were obtained quite well at a voltage of 91.8 mV using PEDOT-Carrageenan Kappa 1:2 electrolyte and the short circuit current obtained reached 57.6 uA. The best solar cell prototype produces an efficiency of 0.0003333728 %. It indicates that DSSC can be made by PEDOT-Carrageenan electrolyte and can be used as a learning tool for photovoltaic physics concepts.

1. Introduction
The world's economic growth is proportional with the increasing demand of energy to meet the economic growth and human needs. However, the majority of the energy supply still depends on fossil fuels, such as coal, oil and gas. Since these resources are non-renewable natural resources, most nations have urged to use of renewable energy resources which are more environmentally friendly. In Indonesia for example, through the presidential decree of the Republic of Indonesia No. 5/2006 about the National Energy policy, the government encourages the use of renewable energy resources up to 5% of the total primary energy at the year 2025 [1]. Some renewable energy sources that frequently used as alternative energy sources to overcome the current energy crisis are solar, biomass, wind and hydropower energy resources.

The alternative energy resources are urgently required since the availability of fossil fuels as the main energy resource is running low. As a country that passed by the equator and has tropical climate, sun is one of the abundant and environmentally friendly alternative energy sources. Sunlight can be converted into electrical energy using solar cells by converting sunlight directly into electrical energy. Solar cells based on silicon technology, which is the result of the development of electronic
semiconductor technology, is the most frequently used today [2]. Despite its popularity, its drawback was associated with the high cost of producing silicon that makes its consumption cost more expensive than fossil energy sources. In addition, the use of hazardous chemicals in the fabrication process contributes to another disadvantage of silicon solar cells. Therefore, another alternative has been found, namely Dye Sensitized Solar Cells (DSSC) [3].

DSSC is a power plant capable of converting sunlight into electric current [4]. DSSC attracts a lot of attention from academia and industry because it offers renewable energy solutions with low pollution levels, environmental friendliness and low cost of electricity production. DSSC consists of a photoanode made of Transparent Conductive Oxide (TCO) glass with a substrate (ITO) coated with a semiconductor such as TiO2, ZnO, SnO2, Nb2O5 with various methods such as doctor blade, screen printing, electroposition, and spin coating [5].

Mostly the dyes used as sensitizers can be synthetic dyes or natural dyes. Due to the toxicological and ecological reasons, the use of natural dyes is preferable and suggested than the synthetic dyes. Moreover, natural dyes are relatively cheaper and are more environmentally friendly. However, these products have disadvantages, including the different and inconsistent quality and quantity of the raw materials since they are influenced by the condition of the nature. Substances such as chlorophyll, beta carotene, anthocyanins, tannins, curcumin in plants can be used as sensitizers [6]. In recent years, many studies have used plants as natural dyes. These natural dyes are extracted from trees, flowers, fruits, and vegetables as absorbent substances (DSSC) [7][8][9][10][11].

Numerous research related to DSSC have been conducted. Most of them focused on increasing the energy performance value that was produced by DSSC and the materials development that can reduce the production costs [12]. Some research investigated the use of natural dyes using anthocyanin extract content, the use of pencil-type carbon catalysts and combustion products, and the use of iodine types [12]. A study of Camacho [13] about the use of electrolyte polymers in the form of a mixture of Poly (3,4-ethylenedioxythiophene) PEDOT Carrageenan polymers for DSSC found that an efficiency value was 0.421%. The value obtained indicates that there is potential for the development of an electrolyte polymer based on a carrageenan PEDOT mixture which is referred to a PEDOT/Carr polyblend.

This study aims to make DSSC type solar cells using PEDOT Carrageenan electrolyte and uses it as learning media for photovoltaic physics concepts. A research topic regarding the use of PEDOT Carrageenan mixture is still rarely carried out, especially on its use as a substitute for iodine electrolyte in the DSSC layer. On that account, this research can give new information and reference regarding the use of a mixture of PEDOT Carrageenan as an electrolyte in DSSC. In this study, researchers tested DSSC based on TiO2 nanoparticles using a synthetic ruthenizer produced by Solaronix and modified the use of iodine electrolyte using a mixture of PEDOT Carrageenan. In addition, the product of this study was intended to be used as a learning media. DSSC learning media is an active element that can convert sunlight into electrical energy, which is made of a wedge of semiconductor material with a positive pole and a negative pole. A simple DSSC that can be easily implemented in classroom learning has rarely been conducted. In previous studies, most focused on developing teaching materials in the form of written learning resources such as practicum modules or worksheets. Since the application of media in learning can increase the efficiency and activeness of the learning process [14][15], the availability of final product can be used to convey information related to the photovoltaic concept.

2. Methods

This research was laboratory experimental research. This research was conducted at the subdepartment of Physics Education Laboratory of Faculty of Teacher Training and Education, Tadulako University in August 2020. The samples used in this study were PEDOT Carrageenan Kappa 1:2, PEDOT Carrageenan Iota 1:1, Iota 1:2, Iota 1:4, PEDOT Carrageenan Lambda 1:1 and Lambda 1:2.

At the beginning, a study was conducted on the Fabrication of Dye Sensitized Solar Cell (DSSC) sing Ruthenizer as a synthetic dye. It began with the study of the characteristics of the DSSC and was followed by the characteristic tests of the current and voltage in the circuit with an I-V meter. The data were collected using a digital multimeter connected in series to the DSSC circuit. The data were analysed to measure the DSSC efficiency value.
3. Results and Discussion

3.1. DSSC Solar Cell Characteristics
The DSSC prototype that has been made can be seen in Figure 1.

![Figure 1. Sample of a DSSC prototype with different electrolytes; (a) Sample DSSC with PEDOT-Carrageenan Kappa 1:2 electrolyte, (b) Sample DSSC with PEDOT-Carrageenan Iota 1:2, (c) Sample DSSC with PEDOT-Carrageenan Iota 1:2 electrolyte, (d) Sample DSSC with PEDOT-Carrageenan Lambda 1:4, (e) Sample DSSC with PEDOT-Carrageenan Lambda 1:1 electrolyte, and (f) Sample DSSC with PEDOT-Carrageenan Lambda 1:2 electrolyte.](image)

The DSSC prototype is assembled with a sandwich arrangement consisting of a working electrode (anode), electrolyte and counter electrode (cathode). The working electrode consists of TCO-FTO, TiO2 coating and dye. The counter electrode consists of a layer of Carbon (Platina) and TCO-FTO. The size of the working area on the TCO (working electrode) glass of each DSSC sample is different. For the DSSC sample with PEDOT-Carrageenan Kappa 1:2 electrolyte, it has an area of 2.2 cm x 2 cm. For DSSC samples with PEDOT-Carrageenan Iota 1:1 has an area of 2.4 cm x 2.1 cm, Iota 1:2 has an area of 2.3 cm x 2.1 cm, Iota 1:4 has an area of 2.2 cm x 2.2 cm. For the DSSC sample with PEDOT-Carrageenan Lambda 1:1 electrolyte which has an area of 2.5 cm x 2.8 cm, Lambda 1:2 has an area of 2.4 cm x 2.6 cm. Based on the six samples of the DSSC prototype built, each of them has a different size of TCO glass so that the size of the working area on the TCO glass is also different.

3.2. Current and Voltage Characteristics of Solar Cells with Circuit
To determine the performance of solar cells, measurements of current-voltage (I-V) characteristics were carried out in illuminated conditions by using a solar light source and by adjusting the resistance used. The circuit is shown in Figure 2.

![Figure 2. I-V DSSC Characteristic Test Circuit](image)

By varying the resistance value, the current and voltage values generated from the solar cell will be obtained. In this research, the solar cell system was produced from the dye electrons which were in excited state because they were visible to light, and was injected into the conduction band of the TiO2 semiconductor. The injection of dye electrons into the TiO2 conduction band was facilitated by the interaction or bonding of the dye with TiO2. If there is no interaction between the dyestuff and TiO2, it will be more difficult for electrons to be injected. Accordingly, there will be no electron flow that could produce a solar cell system. This process could show how the effect of the dye electrons on the efficiency of the solar cell made.
3.3. Current and Voltage Characteristics of DSSC with I-V meter

In the I-V DSSC measurement, the working electrode and the counter electrode were arranged like a sandwich. Between the two, an electrolyte was inserted in the space between the working electrode and the counter electrode. Data collection for each sample Kappa, Lambda and Iota were conducted differently, including the day and time. The sunlight intensity for the Kappa 1:2 sample was 921 W/m², the Lambda 1:1 was 746 W/m², the Lambda 1:2 was 734 W/m², the Iota 1:1 was 104.7 W/m², Iota 1:2 was 110.3 W/m² and Iota 1:4 was 114.5 W/m².

From the results of research conducted using PEDOT Carrageenan Kappa 1:2, Lambda 1:1, Lambda 1:2, Iota 1:1, Iota 1:2, and Iota 1:4, the use of PEDOT Carrageenan Kappa 1:2 electrolyte has better results and success rates in the manufacture of DSSC than electrolytes with other types of PEDOT Carrageenan. The data of current and voltage were presented in I-V curves to determine the performance of solar cells. The voltage in the open-voltage circuit in the DSSC sample with PEDOT Carrageenan Kappa 1:2 electrolyte reached 91.8 mV, the short-circuit current (Isc) obtained reached 57.6 μA, Vmax reached 34.5 mV and Imax reached 39.2 μA, so the efficiency value obtained was 0.000333728%. According to the data, the relationship between current and voltage produces an I-V characteristic curve, with some parameters, including the short-circuit current (Isc), the open-voltage circuit (Voc), the voltage with the maximum power value (Vmax), and current that gives the maximum power value (Imax). Although this result was still very low compared to previous studies [13] which produced a Voc value of 0.439 V on the use of a mixture of PEDOT Carrageenan as an electrolyte. The current value resulted in this study was also still in the micro-Ampere order. Overall, the performance of solar cells was not good enough, especially the value of the conversion efficiency which was still very small (below 1%) [13]. The very low efficiency value was due to the very small current and voltage values. The low efficiency values obtained were associated with a very rigid PEDOT configuration in the electrolyte system. Due to the rigidity of the PEDOT chain, electron transport was not as efficient as compared to liquid systems.

The DSSC sample was made using PEDOT-Carrageenan electrolyte as a light sensitive agent at the thickness of TiO₂ paste. The preparation process included the manufacture of TiO₂ paste, synthetic dye solution from Ruthenizer, and the counter electrode preparation of PEDOT Carrageenan as electrolyte. PEDOT Carrageenan in the form of powder was dissolved in distilled water at a temperature of 70°C. After each DSSC component was ready, the DSSC assembly was carried out. The first assembly process was depositing the TiO₂ paste onto the working electrode using the doctor blade technique. Next, the working electrode was soaked with dye for 1 hour. After that, the platinum was deposited onto the counter electrode through a heating technique in a furnace for 45 minutes at a temperature of 450°C. Both electrodes were clamped with paper clips. The last step was to drip PEDOT-Carrageenan Lambda, Kappa, Iota as electrolyte about 2 drops into the space between the two electrodes. The DSSC prototype was ready to be tested.

The PEDOT-Carrageenan electrolyte in DSSC functions as a reaction generator which replaces the function of the iodolyte electrolyte which is often used in DSSC consisting of pairs of iodine and triiodine as a redox in the solvent. The characteristics of the PEDOT-Carrageenan Electrolyte used in DSSC has the redox potential that is in accordance with the redox potential of the dye for maximum cell voltage and has high solubility of the solvent to support a high concentration of charge on the electrolyte. The solvent has a high diffusion coefficient for the efficient solution transportation. From the process of making DSSC, the reaction that occurred in the DSSC was the conversion of sunlight energy into electrical energy. Results indicate that the DSSC has succeeded in converting sunlight into electrical energy which was indicated by the value of current and voltage.

The developed DSSC can also be used as learning media. It can help teachers to visualize the abstract concepts to students, which will make the concepts more concrete and easier to comprehend. The components are affordable and the making steps are easy to follow thus it can be applied as hands-on activity in schools. The use of the DSSC can help students, who are not familiar with the field of material physics, to understand how to assemble a simple prototype and the processes that occur in the DSSC to produce an electric current. It can be integrated in physics concepts related to the photovoltaic concept, such as dynamic electric material. In addition, the use of DSSC as learning media can contribute to introducing and increasing students’ awareness regarding the renewable energy resources [5].
4. Conclusion
The PEDOT-Carrageenan that can be used as an electrolyte system in the manufacture of DSSC is PEDOT-carrageenan Kappa 1:2. The efficiency value obtained based on the measurement of the I-V characteristics was 0.000333728%. It shows that the success rate of making DSSC with PEDOT-carrageenan electrolyte was still very low. It was owing to the equipment, materials, and work procedures used that have not met the standards. As with the use of the coarse TiO₂ powder, the thickness of the TiO₂ paste layer on the working electrode and the platinum layer on the counter electrode were not uniform in each sample. Nevertheless, the developed DSSC solar cells can be used as learning media.

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