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Research Article

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Effects of pv cell modification to its performance in generating current and voltage with KI/KI_3 electrolytes system

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ABSTRACT

A research of the effects of pv cell modification to its performance in generating current and voltage with KI/KI_3 electrolytes system has been performed. This research intended on studying the effect of ceramic membranes modified with titania (TiO_2) on the performance of pv cells to generate current and voltage in generating currents and voltages. The pv cells that were assembled in this study have a thickness of 9.5 mm. Each cells were given a number code (ie: cell 0, cell 1, cell 2, cell 3, cell 4 and cell 5), according to the amount of titania coating on the used membranes. To study the performance of pv cells in generating current and voltage, the continuous flow of electrons system was used at the time of measurement. SEM and EDX analysis proved that the dip-coating process with titania on the cell 5's ceramic membrane successfully modified surface and the pore size of the ceramic membrane. The values of the performance characterization parameters of the cell 5 are as follows: voltage current short circuit (I_{sc}) 0,085 mA, open circuit voltage (V_{oc}) 80,9 mV, maximum current (I_{max}) 0,025 mA, maximum (V_{max}) 41,8 mV, maximum power (P_{max}) 1,045 x 10^{-6} Watt, Fill Factor (FF) 0,152 and energy coversion efficiency (η) 0,553 %.

Keywords: pv cell, KI/KI_3 electrolytes, ceramic membrane, UV-Vis spectrophotometer, SEM-EDX

INTRODUCTION

World energy demand continues to increase along with the progress of human civilization. Utilization of conventional energy sources such as coal, fuel oil, natural gas and others, on the one hand has low operational costs, but on the other hand faces greater obstacles. Hence, the development of renewable and pollution-free alternative energy sources is an urgent need for mankind [1].

Solar energy is the energy source that will never run out availability (solar energy that reaches the earth's atmosphere is about 1018 kWh / year). One of many tools for converting solar energy directly into electricity called photovoltaic (pv) cell. In 1970, when the world was faced with an energy crisis, researches on high efficiency photovoltaic cells were conducted intensively and expected to become an alternative energy to replace fossil fuels [2]. Pv cell has changed people's perspective about energy and provided a new way to obtain electrical energy without the need to burn fossil fuels. Photovoltaic cells attracted attention because of its low cost and the flexibility in generating energy [3]. Photovoltaics also offer the highest probability in providing meaningful and sustainable change in the business community to generate energy [4]. Photovoltaic cells can operate properly in almost all regionon the earth without causing pollution that can damage the environment making it more environmentally friendly [5].

Indonesia is located along the equator, so the sources of renewable energy is very abundant. Indonesia received solar radiation throughout the year with the annual daylight time is longer than sub-tropic countries. However, the energy utilization is not optimal either in the field of research and the application[6]. Therefore, this research aims to find and design a photovoltaic cell which has a slim size. As well, to study the effects of titania modification on ceramic membrane to the performance of the photovoltaic cells. Although the current photovoltaic cells have been widely available commercially, market expansion is still limited because of the use of liquid electrolytes, where stability is very low due to the reduction of solvent and electrode erosion. Replacement of liquid electrodes with solid medium is one good solution. However, compared to the liquid electrolytes, solid electrolyte pv cells have lower energy conversion efficiency [7].

EXPERIMENTAL SECTION

Materials

Circular rubber (diameter of 25 mm, thickness of 4 mm), transparent plastic sheet, ceramic membrane (diameter of 50 mm, thickness of 1 mm), carbon rod (diameter of 1 mm), and pipe glue, were used to assemble the pv cell.

Chemicals

Titanium isopropoxide ($C_{12}H_{28}O_4Ti$), diethanolamine/DEA ($C_4H_{11}NO_2$), potassium iodide (KI) and iodine (I_2) were obtained from Merck, Germany. Isopropanol (C_3H_7OH) was obtained from Fisons, UK. These chemicals were analytical grade. And Aqua DM (H_2O) was obtained from Brata Co Chemika PT, Indonesia.

Instruments

UV-Vis Spectrophotometer (SPECTROstar Nano-BMG Labtech) was used to analyze iodine absorbance. SEM (Hitachi S-3400N) was used for membrane surface morphology characterization.

Procedures

1.Preparation of Ceramic Membranes

Ceramic membranes with a thickness of 1 mm were prepared from ceramic floor. We created six membranes for this study.

2.Preparation of Sol Titania (TiO_2)

Titania sol preparation process was performed by mixing 30 mL of isopropanol with 4 mL of DEA in a beaker and stirred, then followed by the addition of 6 mL of TIP. Stirring was performed for about 4 hours to obtain titania sol.

3.Preparation of Ceramic Membrane Coating Variations with Titania

Ceramic membrane coating process was carried out by immersing five ceramic membranes into the titania sol for approximately 20 seconds. The process was followed by drying the solvent in the oven for approximately 15 minutes at 100^oC. Furthermore, the ceramic membranes were calcined in the furnace at a temperature of 400^oC for about 1 hour.

Coating process was repeated to obtain a ceramic membrane with subsequent coating variations. This process was carried out to obtain a ceramic membrane with five times the variation of the coating.

4.Preparation of Photovoltaic Cells

Each ceramic membranes were assembled into photovoltaic cells. Assembling process was started by attaching a plastic sheet on the rubber by using glue pipe. After drying, two of these rubber parts were attached to the ceramic membrane, the ceramic membrane was positioned in the middle of the two rubber. At the top of both rubbers, given a hole as an entry for the carbon electrodes.

5.Preparation of KI and KI_3 Electrolytes

A total of 20.75 g of KI was weighted and dissolved with aqua DM in 1000 mL volumetric flask to obtain KI solution with a concentration of 0.125 N. A total of 0.25 g of I_2 was dissolved in a solution of KI in 250 mL volumetric flask to obtain I_2 with a concentration of 1000 mg/L.

6.Measurement of Current and Voltage

One part of the cell was filled with 1.5 mL KI and other part with KI_3 with equal volume. The part containing KI was facing the light source. Current and voltage generated during the process of photovoltaic were measured using a multimeter that has been linked to the two electrodes of photovoltaic cell.

7.Measurement of Stability Photovoltaic Cells

Stability test was perfomed by measuring the current and voltage produced by the photovoltaic cells every day from 10.00 AM to 14.00 PM with a 30 minutes interval of measurement time.

8.Analysis of Iodine in Photovoltaic Cells with UV-Vis Spectrophotometer Method
Determination of iodine compound (I_2) in the photovoltaic cell after the current and voltage measurements was carried out by taking 1 mL solution of the two sides of the cell, respectively. Two drops of 1% starch solution were added into the solution. Then, absorbance measurements were performed using UV-Vis spectrophotometer at a wavelength of 240-750 nm.

9.Performance Characterization of Photovoltaic Cell
Characterization of the current and voltage generated by photovoltaic cells was carried out using the I-V device. Parameters measured were: short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum current (I_{max}), maximum voltage (V_{max}) and fill factor (FF).

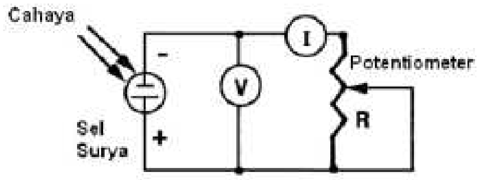

Figure 1. Electrical circuit schematic for the characterization of pv cell [8]

10.Characterization of Membrane Ceramics with SEM-EDX Method
Scanning Electron Microscopy (SEM) - Electron Dispersion X-ray spectroscopy (EDX) analysis was performed tolearn and confirm ceramic membranes modified with titania.

RESULTS AND DISCUSSION

1.The design of Photovoltaic Cells

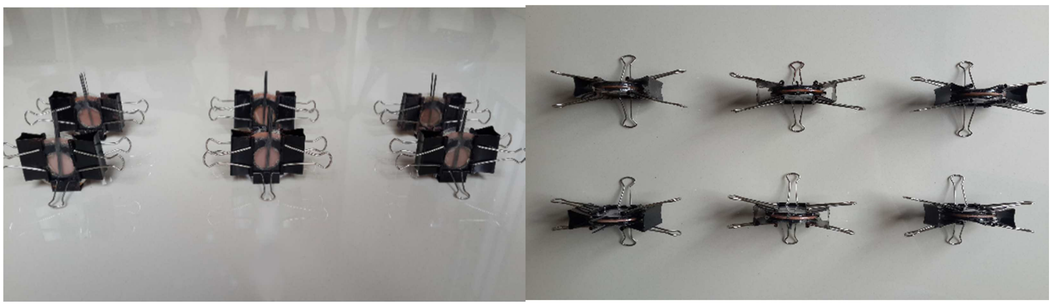

Figure 2. The design of photovoltaic cells

The design of photovoltaic cells used in this study was shown in Figure 2. The designed pv cells had a total thickness of 9.5 mm with 1 mm thick membrane. While the carbon electrodes had a length of 25 mm and a width of 2.7 mm with a surface area of 67.5 mm^2. Ceramic membrane that has been modified with titania has functions as a filter and a barrier between ½ anode and ½ cathode cell. Anode part of the cell contained a solution of KI was the part that is facing the direction of the sun while the cathode as a container of KI_3 was opposite side. The placement of both electrolytes was based on the following reaction.

Anode : $KI \rightarrow K^+ + I^-$
$I- + ђυ \rightarrow I^\bullet + e^-$
$I^\bullet + I^\bullet \rightarrow I_2$
Cathode : $I_2 + e^- \rightarrow 2I^-$

Reaction above occured continuously when the two electrodes were connected to each other using copper wire. In this study, the reaction was expected to take place in the cycle where the produced I^- ion at the cathode can be transfered to the anode to replace the I^- ion which has been turned into the I• radical due to contact with sunlight in generating electrons. Electrons will flow from the anode to the cathode through the copper wire when two electrodes were connected. The generated current and voltage can be measured using a multimeter. I^- ion transfer from the cathode to the anode occured with diffusion through the ceramic membrane which divided the two parts of the cell.

The number of cells used in this study was six cells. The difference between each cell was the ceramic membrane. Ceramic membranes were modified by using titania (TiO_2) in order to minimize the ceramic pore size. The smaller pore ceramic was able to withstand I_2 diffusion from the cathode to the anode.

The number of cells used in this study was six cells. The difference between each cell was the ceramic membrane. Ceramic membranes were modified by using titania in order to minimize the ceramic pore size. The smaller pore ceramic was able to withstand I_2 diffusion from the cathode to the anode. Each cell which has been used in this study was given a code number (ie: cell 0, cell 1, cell 2, cell 3, cell 4 and cell 5), according to the amount of titania coating on the membrane used by each cell. Cell 0 served as the control cell, where the membranes used in cell 0 was not modified with titania. To study the performance of photovoltaic cells that have been designed in generating current and voltage, was used the continuous flow of electrons.

Span of time used to test the performance of photovoltaic cells in generatinh current and voltage were from 10:00 am to 13:30 pm with a 30 minutes interval measurement time. This time span was used due to the sun produced light with the highest intensity at that time. With the best light conditions, the cell was also assumed able to produce a good performance in generating current and voltage.

2.Effect of Membrane Modification with Titania to Performance of Photovoltaic Cells

Effect of measurement time and modification of titania membranes with the performance of photovoltaic cells to generate current and voltage were tested by using a continuous flow of electrons for two days. This continuous flow is a state in which the electrons flow continuously from the anode to the cathode during the measurement time, from at 10:00 am to 13:30 pm. The Effect of measurement time and membrane modification on the performance of the six photovoltaic cells in generating on the first day can be observed in Figure 3. it can be seen that there was a decrease substantially in the second measurement time (10:30 am) for all cells. This was caused by the use of a continuous electron flow where in this flow condition, the electrons flowed continuously from the anode to the cathode from the initial measurement (10:00 am) until the second measurement time (10:30 pm).

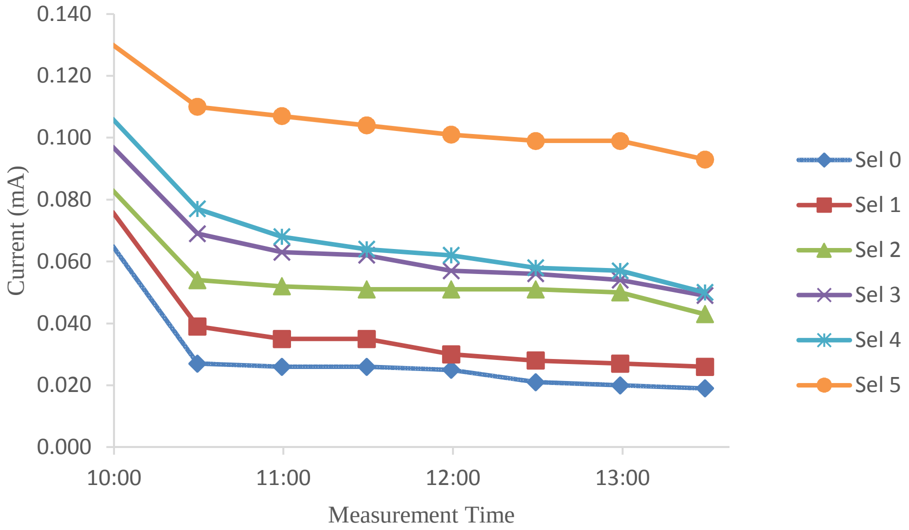

Figure 3. Effect of membrane modification on the performance of the photovoltaic cells to generate current on the first day

From Figure 3, it can also be concluded that cell 5 were the cells that has the best performance in generating current on the first day of measurement. This proves that the modification of the cell membrane by using titania greatly affected the performance of the cell to generate current. Current measurement data from all six photovoltaic cells on the first day was not shown in this paper. The maximum current generated for cell 0 to cell 5 on the first day were: 0.065; 0,076; 0.083; 0.097; 0.106 and 0.130 mA, respectively.

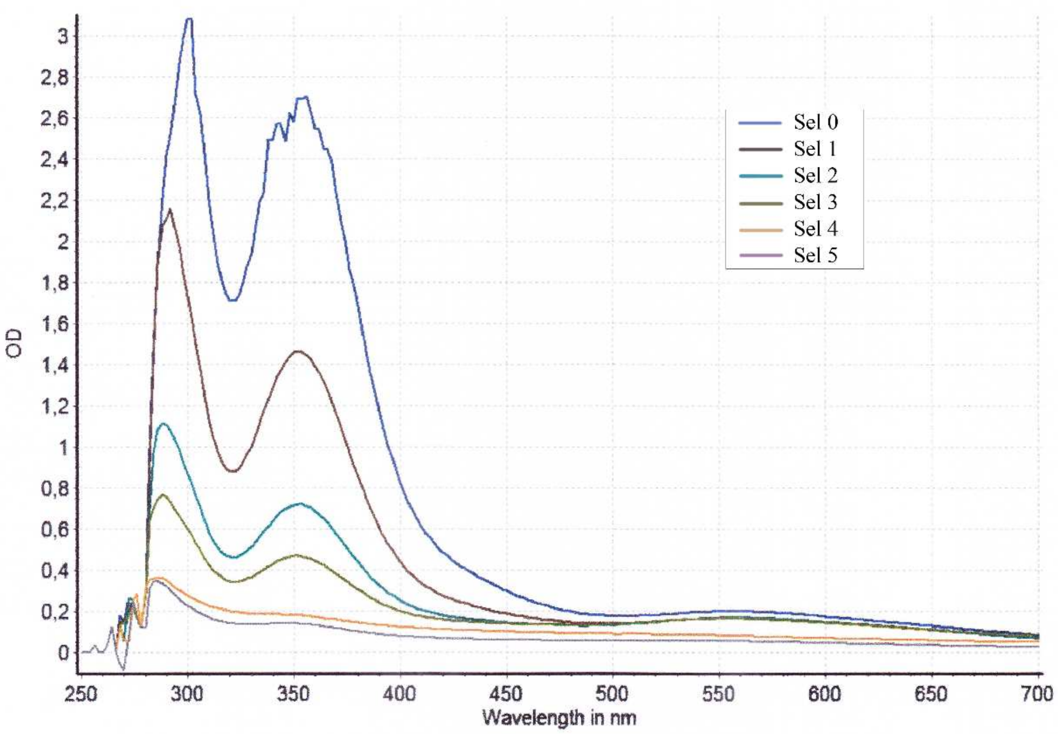

Figure 4. UV-Vis absorption Spectrum of I_2 in the anode after measurement on the first day

Effect of membrane modification with titania to withstand I_2 diffusion from the cathode to the anode was confirmed by using UV-Vis spectrophotometry analysis, as shown in Figure 4. Of the six spectral absorption peak of I_2 in the anode, at λ 350 nm, it can be said that cell 0 has the highest maximum absorption peak followed by cell 1, cell 2, cell 3, cell 4 and cell 5, respectively. Cell 5 is the cell that has the lowest maximum absorption peak. This proves that the cell 5's membrane was able to withstand I_2 diffusion longer than the others due to the cell 5's membrane had smaller pore size than the other five cell membranes.

Effect of time measurement on the performance of photovoltaic cells to generate voltage on the first day was shown in Figure 5. It can be said the voltage increased in respect with in respect with increasing measurement time. A a significant reduction occurred at the second measurement time, at 10:30 AM. This was the result of the continuous electron flow in all cells.

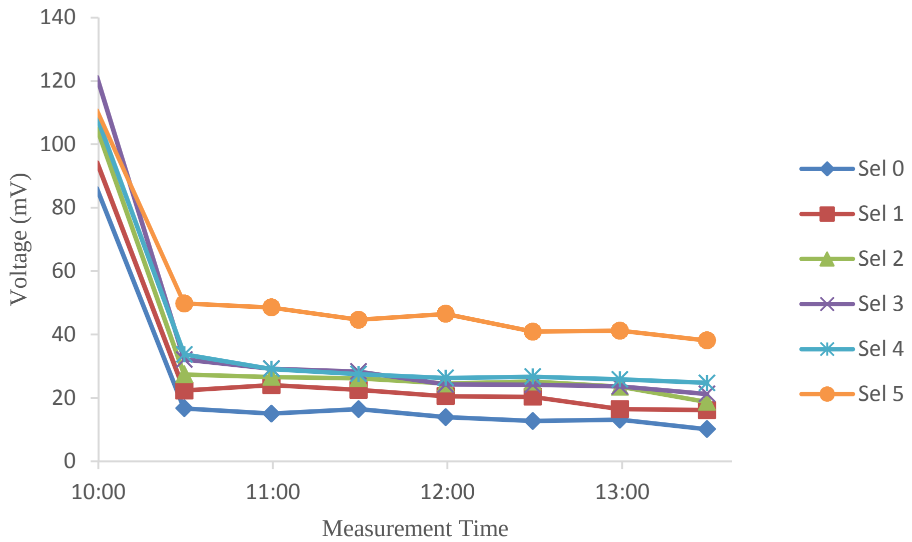

Figure5. Effect of membrane modification on the performance of the photovoltaic cells to generate voltage on the first day

The continuous flow of electrons caused the formation of I_2 in the anode proceeded rapidly, resulting the electrodes was also experiencing rapid saturation due covered by I_2. This caused the performance of the cell to generate voltage drop drastically during the second measurement (10:30 am). Based on Figure 5, cell 5 were the cell that had the best performance in generating voltage on the first day.

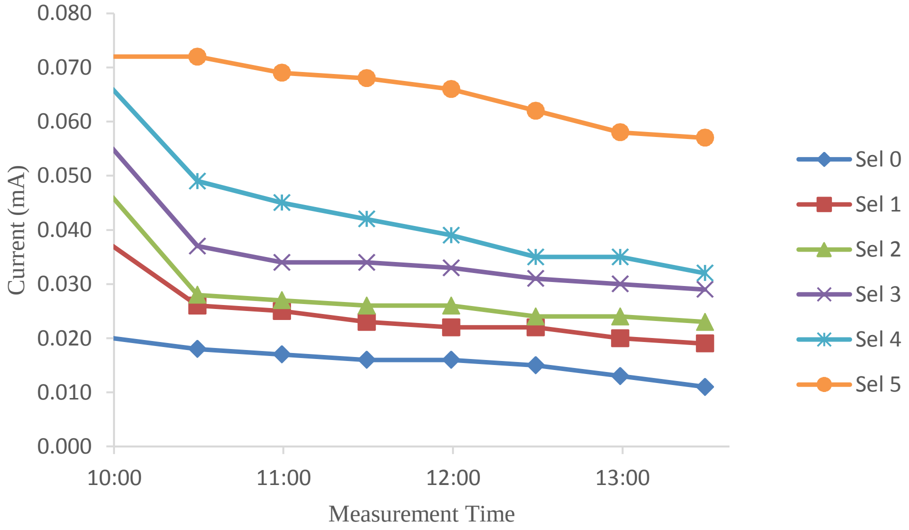

Figure 6. Effect of membrane modification on the performance of the photovoltaic cells to generate current on the second day

Effect of measurement time on the performance of six photovoltaic cells on the second can be seen in Figure 6. It appeared that the cell performance in generating current decreased alongside time measurement. The decrease in performance was caused by the increasingly saturated electrodes in the anode due covered by I_2. The more saturated electrodes caused the flow of electrons from the anode to the cathode restrained so that the resulting current would be smaller. Compared to the current measurement on the first day, currents obtained by the whole cells on the second day had decreased.

Effect of membrane modification by using titania on the cell performance in generating current on the second day can also be observed in Figure 6. From the graph of the six cells, it can be observed that cell 5 had the best performance compared to the other cells. The maximum current generated by the cell 0 to 5 on the second day were: 0,020 ; 0,037; 0,046; 0.055; 0.066 and 0.072 mA, respectively.

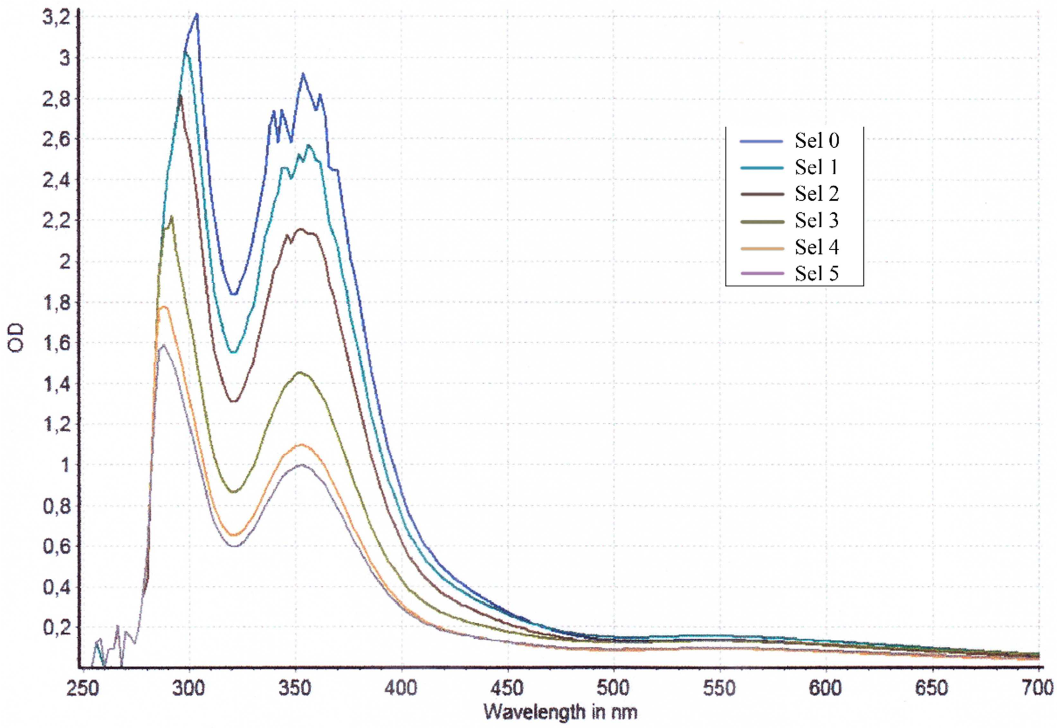

Figure 7.UV-Vis absorption Spectrum of I_2 in the anode after measurement on the second day

To confirm the formation of I_2 in the anode during the measurement time, UV-Vis spectrophotometer analysis was performed as can be seen in Figure 7. It was seen that absorption peak of I_2 (in the anode) at λ 350 nm for the cells 5 had the lowest absorbance compared to absorption peak of I_2 of the other cells. This proves that the cell 5's membrane could withstand I_2 diffusion from the cathode to the anode better than the other cell's membranes.

Effect of measurement time to the performance of photovoltaic cells in generating voltage on the second day was shown in Figure 8. It was seen that cell 5 was the cell with the best performance in generating voltage just like the first day, followed by cell 4, cell 3, cell 2, cell 1 and cell 0, respectively.

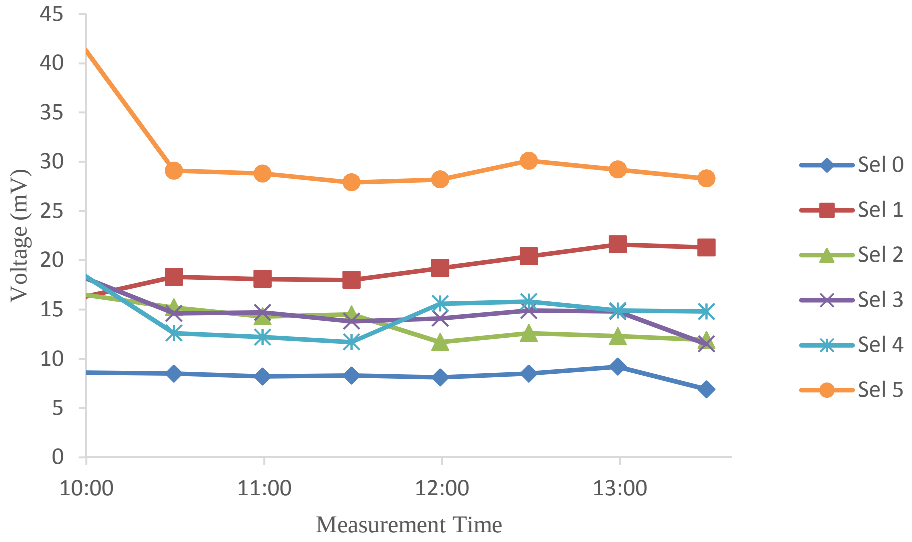

Figure 8. Effect of membrane modification on the performance of the photovoltaic cells to generate voltage on the second day

The performance of the entire cell in generating voltage decreased on the second day compared to the first day. It could also be caused by electrolytes reduction in both the anode and the cathode. The reduction of electrolytes volume resulted the performance of the entire cells in generating voltage on the second day reduced, as the number of electrons was much less that colud be generated on the second day. Voltage measurement data from all six photovoltaic cells on the second day was not shown in this paper.

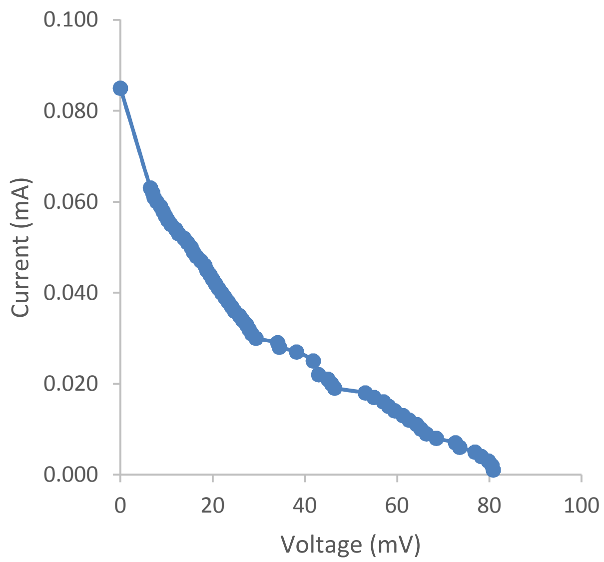

Figure 9. I-V Characteristics Curve of Cell 5

3.Current – Voltage Characteristics of Cell 5

Cell 5 has been proven as the cell with the best performance in generating both current and voltage during two days of measurement. Characterization of current – voltage (I-V curve) was carried out on cell 5 to study and analyze the performance of the cell, as can be observed in Figure 9. It was seen that the I-V curve was linear. The relationship between current and voltage was inversely. This relationship was obtained by setting resistance during measurement time. The greater the resistance, the current would be lower. Based on the I-V curve, the parameters of cell 5 could be determined. They were: short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum current (I_{max}), maximum voltage (V_{max}), maximum power (P_{max}), fill factor (FF) and energy conversion efficiency (η). The values of these parameters were as follows: I_{sc} (0.085 mA), V_{oc} (80.9 mV), I_{max} (0.025 mA), V_{max} (41.8 mV), P_{max} (1.045 x 10-6 Watts), FF (0.152) and η (0.553%).

The values of the energy conversion efficiency (η) and fill factor (FF) obtained from cell 5 by using the IV curve were 0.553% and 0.152, respectively. The values were small for a photovoltaic cell when used as a reference to characterize the performance of a cell. This was caused by the usage of single cell. To obtain more precise measurements of both current and voltage, some units of cell 5 arranged in series or parallel circuit were required.

4.Characterization of Membrane Surface Morphology

The morphology of the surface of the ceramic membrane used in the cell 0 and cell 5 were analyzed by using Scanning Electron Microscopy (SEM), as shown in Figure 10. As previously described, cell 0 is the cell that uses a membrane that was not modified with titania, while cell 5 is the cell with a membrane that had been coated five times with titania.

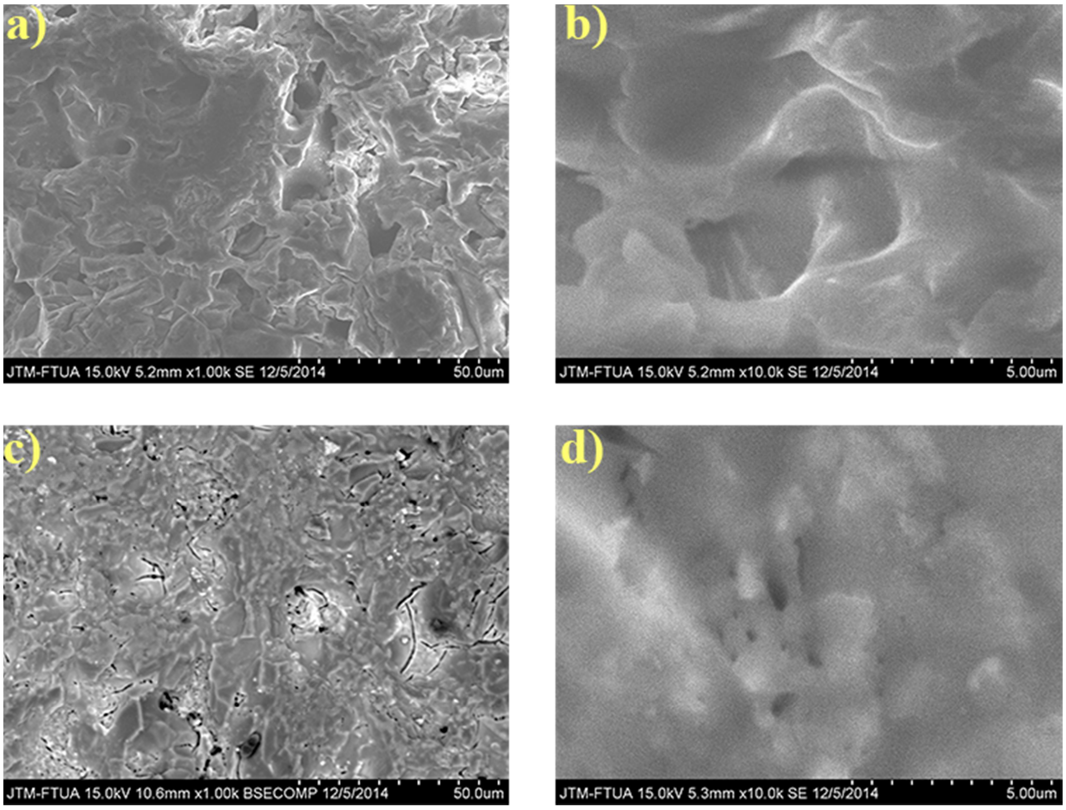

Figure 10. Results of SEM surface morphology of the ceramic membranes: a) Cell 0 (1.000x mag), b) Cell 0 (10.000x mag), c) Cell 5 (1.000x mag), d) Cell 5 (10.000x mag)

From the SEM images in Figure 10, it can be observed the difference between the surface morphology of ceramic membranes that has not been modified using titania (Figure 10. a and b) with a ceramic membrane that has been modified using titania (Figure 10. c and d). Membrane which has been modified with titania has smaller pore size (5-10 µm). While unmodified membrane has a surface pore size of 20-40 µm. This proved that the modification of titania on ceramic membranes used in pv cells, can reduce the pore size of the membrane.

The composition of elements contained in the ceramic membrane of cell 0 (without modification) and cell 5 (with modification), were analyzed by using Electron Dispersion X-ray spectroscopy (EDX), as can be observed in Figure 11. It can be seen that the main elements contained in the ceramic membrane used in the cell 0 is: O (53.92%), Si (24.76%), Al (8.33%) and C (5.05%). Meanwhile, the main elements contained in the ceramic membrane used in the cell 5 is: O (51.11%), Si (20.68%), Ti (14.22%), Al (4.95%) and C (3.30%). Compared to the both composition of the membranes above (cell 0 and cell 5), it is known that there are additional element of Ti (titanium) in the cell membrane that has been modified five times with titania (cell 5). This proves that the process of dip-coating on the ceramic membranes to modify the surface and simultaneously modify the pore size with titania, has been performed successfully in this study.

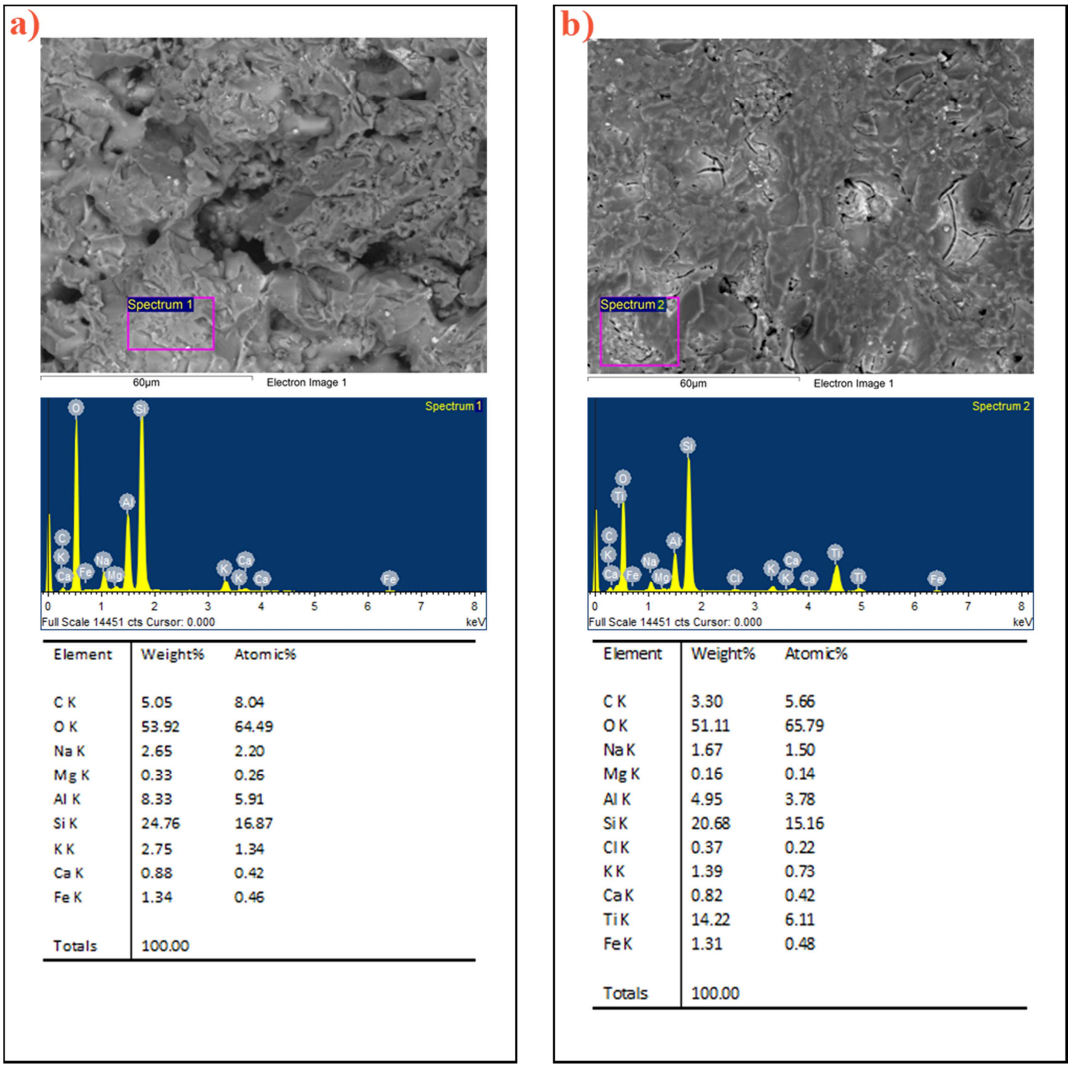

Figure 11. Results of EDX analysis on the surface of the ceramic membrane: a) Cell 0 b) Cell 5

CONCLUSION

Based on research that has been done, it can be concluded that cell 5 generated most current and voltage. It proved that the modification of the cell membrane with titania had effect on the performance of cell in generating current and voltage. SEM and EDX analysis proved that dip-coating process with titania on the cell 5's ceramic membranes successfully modified the surface and simultaneously modified the pore size of the ceramic membrane. To obtain larger, more stable current and voltage, it is advisable to set up several units of this pv cell in series or parallel circuit. Cells that have been designed can be assembled in large quantities because of its small size. Thus, it has potential as an alternative energy to replace fossil fuels.

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