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The Effect of Cell Surface Area on the Effectivity and Reusability of Bixin Sensitized Solar Cells

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Abstract

Dye-Sensitized Solar Cells or DSSC is the latest solar cell type generation that uses natural dyes as sensitizers. Bixin extracted from the seeds of kesumba (*Bixa orellana* L) is one of the natural dyes that can be used as a sensitizer. This study aims to determine the effect of the active surface area of solar cells on the effectivity and reusability of bixin-sensitized solar cells based on their open-circuit voltage (Voc), short-circuit current (Isc), and maximum energy conversion efficiency. This study will provide an overview of the best surface area to produce DSSC with the highest maximum energy conversion efficiency and the lifetime of bixin sensitized solar cells. The measurement results showed that the resulting Voc for each variation of the surface area of 1, 2, and 3 cm^2 was 344; 719; 1002 mV under the intensity of 100 mW cm^{-2}, while the Isc produced under the same intensity was 0.223; 0.471; 0.680 mA. We calculated that the maximum power generated by each surface area was 0,077; 0,338; 0,681 W. This means that the larger the active surface area of the solar cell, the greater the voltage and current generated. In this work, the highest efficiency was produced by solar cells with a surface area of 2 cm^2, with 0.085%. The solar cells fabricated in this study can be reused for five days under continuous irradiation.

Keywords: bixin, DSSC, surface area, reusability

1. Introduction

Solar energy is one of the sources of energy that is not limited. Therefore, scientists have used it to overcome the energy crisis in recent decades. One way to do this is to convert solar energy into electrical energy using solar cell electronic devices. Dye-sensitized solar cells (DSSC) are the third generation of solar cells that have been developed to overcome the shortage of silicon-based solar cells (first generation). Five main components make up DSSC: conductive glass (usually using indium tin oxide/ITO or fluorine tin oxide/FTO substrates), semiconductors (titanium dioxide/ TiO_2, zinc oxide/ZnO, and tin dioxide/SnO_2), sensitizers, electrolytes, and counter electrode [1].

A sensitizer is a molecule that can absorb sunlight in the range of ultraviolet to visible light, depending on the molecule's energy gap. One of the natural molecules used as photosensitizers is bixin due to its conjugated double bonds [2]. Bixin is one of the carotenoid derivatives of the xanthophyll class, an oxidized carotene derivative [3]. This compound gives a yellow-orange color to plants and is hydrophobic because it has a polyene chain [4]. Bixin has a carboxylic group that makes it easy to bond to the semiconductor surface [1]. In addition, bixin also has a high molar absorptivity. In dichloromethane, it shows an absorption coefficient of 282.6 $M^{-1}cm^{-1}$ at a wavelength of 467 nm, while in chloroform is 323.0 $M^{-1}cm^{-1}$ at a wavelength of 470 nm [5].

Research related to bixin as a sensitizer in DSSC proved that bixin showed better performance than norbixin [6,7]. Furthermore, incorporating bixin into the interlayer space of kaolinite can increase the stability of bixin. The stability of kaolinite-bixin organoclay increased up to 15% compared to pure bixin [8]. Another study has reported that when used as a sensitizer, the Zn-bixin complex can be stable up to 700 W m^{-2} irradiation [7]. However, most of the previous studies observed the performance of DSSC based on the maximum energy conversion efficiency parameter. Not many studies have been found that follow the parameters of the surface area of the active side of solar cells on their performance.

The active surface area of solar cells can be interpreted as the size of the place where the electrodes are deposited, both anode and cathode of the DSSC. It is known that the surface area can affect the amount of current and voltage generated by a DSSC. Research using musk rind extract as a

sensitizer in DSSC with variations in the surface area of the semiconductor showed that the voltage and current generated from DSSC with an active surface area (1.5x1.5) cm^2 is greater than that of (1x1) cm^2 [9]. Another study using ZnO-nanorod sensitized solar cells with an active surface area of 1.0, 0.25, and 0.1 cm^2 concluded that the decrease in active surface area increases the performance of the DSSC but does not significantly affect the efficiency value. The study shows that the different sensitizers used have different effects on the relationship between surface area and DSSC performance [10].

Besides the active surface area, the reusability of a solar cell is also important to know as a parameter in measuring DSSC performance. Cell reusability relates to how long the cell can last after repeated use. Measurement of DSSC reusability can be done by irradiating solar cells for several days until the cells are completely dead or unable to produce current. Rahmalia et al. [8] reported that TiO_2/treated metakaolinite-based DSSC could survive for up to 3 days with a rest period of 17 hours after being exposed to light continuously for 7 hours under an intensity of 200 Wm^{-2}.

In this study, the active surface area of bixin sensitized solar cells will be varied to see the effect of the active surface area of the cell on the current, voltage, and efficiency generated by the DSSC system. The solar cells with the highest efficiency are then reused to measure cell reusability to determine how long the bixin-sensitized solar cells can last after being irradiated regularly. In addition, this study also used the bixin extraction method, which is more straightforward than previous studies. The bixin produced was also characterized and compared to its purity and effect on DSSC cells with the bixin extracted using the previous method.

2. Experimental

2.1 Materials

The materials used in this study were: annatto seeds, ethyl acetate (MERCK), potassium iodide (MERCK), iodine (MERCK), TiO_2 (Sigma-Aldrich), FTO glass (SOLEMS), filter paper, *1-methyl-3-propylymidozalium iodide* (MPII) (Sigma-Aldrich), acetone (MERCK), ethanol (MERCK), methanol (MERCK), acetonitrile (MERCK), n-hexane (MERCK), triton-x (MERCK), and platinum paste (Sigma-Aldrich).

2.2 Extraction of Bixin from Annato Seeds

The annatto seeds were separated from the flowers and dried in an oven at 50°C for 7 hours. After that, the annatto seeds (100 g) were mixed with ethyl acetate solvent and then stirred. This extraction process was repeated until all the pigments were extracted. The mixture was filtered, while the filtrate was partitioned using n-hexane, methanol, and ethyl acetate. The ethyl acetate fraction was taken and evaporated at 40°C. The extract resulted from the process was then characterized using UV-Vis spectrophotometer with ethyl acetate as a solvent at a wavelength of 350-500 nm; FTIR in the wavenumber range of 4000–400 cm^{-1}; and ^{1}H-NMR with Deuterium Chloroform ($CDCl_3$) as a solvent.

2.3 Redox Electrolyte Preparation

The I-/I3- redox solution was prepared by dissolving 1.66 g of KI into 20 ml of acetonitrile and stirring until homogeneous. Then 0.127 g of I_2 was added to the solution and stirred again until homogeneous. Next, 5 ml of the solution was taken, and 0.504 g of MPII was added and then stirred again until homogenous.

2.4 DSSC Fabrication and Work Analysis

2.4.1 Titanium Oxide (TiO_2) Anode Preparation

30 ml of ethanol was added to 3.15 g of anatase TiO_2 powder, added 16 drops of triton-x, and 12 drops of acetonitrile, then stirred using a magnetic stirrer for 24 hours at room temperature to form a paste.

2.4.2 DSSC Assembly

The TCO glass was cleaned with ethanol and then dried for a few minutes. TiO_2 was deposited using the doctor-blade method with variations in the active surface area 1, 2, and 3 cm^2. The coating was dried for about 15 minutes and heated at a temperature of 450°C for 30 minutes. After that, the layer was soaked in a bixin solution for 24 hours, then dried with tissue paper. Next, the redox electrolyte is placed on the surface of TiO_2 and covered with a counter electrode to form a sandwich structure.

2.4.3 DSSC Performance Analysis

DSSC work analysis was carried out using an Agilent 34401A 6.5 digits multimeter by varying the intensity of the light given to the DSSC device. The

intensity variations were 0, 5, 6, 7,8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mW cm^{-2}. The solar cells with the highest efficiency were chosen to irradiate periodically for several days until the solar cells died to measure reusability. The light source used is a 500 W halogen lamp equipped with a dimmer to adjust the intensity. The parameters measured in this process are the voltage (Voc), and current (Isc) recorded on the multimeter.

3. Result and Discussion

3.1 Bixin Extraction and Characterization

Extraction in the context of analytical chemistry (analytical scale extraction) is the transfer of the target analyte from one phase to a different stage where further processing and analysis occur. The target analyte was isolated from the original sample and transferred to the extract [11]. Bixin extraction in this study was initiated by separating the seeds from the fruit skin. The seeds were dried in the oven at 50°C for 7 hours to minimize their water content. This number is used based on the best temperature and time from previous studies to prevent the damage of bixin pigment in annatto seeds. Amounts of 100 g of dried annatto seeds were mixed into ethyl acetate solvent and stirred. The reason for using ethyl acetate as a solvent is because the extract from annatto seeds is entirely soluble in ethyl acetate compared to other solvents.

The partition process begins by dissolving the extract into n-hexane. The aim is to dissolve compounds other than bixin, non-polar from the extract. The result is that the extract does not completely dissolve in the n-hexane solvent. This indicates that target compounds in the extract of annatto seeds are not soluble in non-polar solvents but dissolve in a polar and semipolar solvent. After that, the solution was filtered to separate the n-hexane extract and the EA fraction. The fraction contained in filter paper was then taken and redissolved in methanol solvent. The aim is to dissolve the polar compounds other than bixin which are still present in the extract. Then, the solution was filtered again with filter paper to separate the EA fraction and the methanol fraction. Finally, the results of the previous filter were taken back and dissolved into ethyl acetate. The reason for using ethyl acetate solvent in the last process is to obtain an extract containing only bixin compounds. The three fractions were then dried to remove their respective solvents. The extract was then Figure 1 shows the TLC results of the methanol (meta), n-hexane (hexa), and ethyl acetate (EA) fractions. These results indicate that each fraction contains different amounts of compounds. In the ethyl acetate fraction, the results of the elution look tailed. This can be caused there is still solvent eluted along with the compound. One spot that appears is suspected to be a bixin compound because, in the annatto extract, the compound completely soluble in ethyl acetate is the bixin compound [12]. There is only one spot in the methanol fraction, which indicates that there is only one compound in the methanol fraction. This compound is thought to be norbixin, a polar compound that is completely soluble in methanol in annatto seeds [13]. Meanwhile, in the n-hexane fraction, several spots indicated the presence of several non-polar compounds in the annatto seeds that were not soluble in methanol and ethyl acetate for further analysis.

The extract obtained was analyzed using Thin Layer Chromatography (TLC) and 2 Dimensional Thin Layer Chromatography (2D TLC) to test the purity of bixin. The principle of TLC is the distribution of compounds between a solid phase (thin layer) which is applied to a glass or plastic plate, and a liquid mobile phase (elution solvent) which moves over the stationary phase [13]. TLC aims to identify the compounds contained in each fraction and determine the purity of the resulting extract. The TLC procedure begins with cutting the TLC plate with a size of 3 cm x 7 cm, of which 7 cm is for the elution distance with a lower limit and an upper limit of 0.5 cm at each end. Meanwhile, 3 cm is the highlighting area divided into three for three fractions so that each fraction has a highlighting area with a width of 1 cm. The three fractions (methanol, n-hexane, and ethyl acetate) were taken slightly and dissolved in their respective solvents. After that, each fraction was spotted on the plate according to its separate area using a capillary tube, then dried to remove solvent so as not to interfere with the elution process. The eluent was made using a mixture of n-hexane: EA in a ratio of 7:3. The comparison was based on the best eluent for TLC extract bixin [14]. After the eluent is transferred into the chamber, the plate is inserted into the chamber and eluted to the mark. The results of this TLC are shown in Figure 1.

Figure 1 shows the TLC results of the

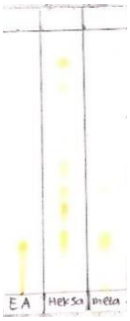

Figure 1. TLC Result.

methanol (meta), n-hexane (Hexa), and ethyl acetate (EA) fractions. These results indicate that each fraction contains different amounts of compounds. In the ethyl acetate fraction the results of the elution look tailed. This can be caused there is still solvent eluted along with the compound. One spot that appears is suspected to be a bixin compound because, in the annatto extract, the compound completely soluble in ethyl acetate is the bixin compound [5]. There is only one spot in the methanol fraction, which indicates that there is only one compound in the methanol fraction. This compound is thought to be norbixin, a polar compound that is completely soluble in methanol in annatto seeds [2]. Meanwhile, in the n-hexane fraction, several spots indicated the presence of several non-polar compounds in the annatto seeds that were not soluble in methanol and ethyl acetate.

After TLC was carried out for identification, 2D TLC was carried out to test the purity of the compounds obtained. Two-dimensional thin-layer chromatography (2D TLC) was performed by spotting a sample at one corner of a rectangular thin-layer plate and eluting it as usual with the first eluent. The chromatographic plate is then removed from the chamber, and the solvent is allowed to evaporate from the plate. Then the plate is placed on the second eluent so that elution can occur in a second direction that is perpendicular to the first elution direction [12]. This purity test was only used on the ethyl acetate fraction to determine how pure the bixin was obtained. The first step in this 2D TLC is to cut a plate with (7 x 7) cm, which is then marked with a boundary of 0.5 cm from each side. After that, the diluted ethyl acetate fraction was spotted at one corner of the spotting boundary, then eluted with n-hexane: ethyl acetate (7:3) eluent. After the first elution was completed, the plate was dried and then prepared for the second elution. Before carrying out the second elution, the eluent was replaced with a new one and still used a mixture of n-hexane: ethyl acetate (7:3). The second elution was carried out by rotating the plate in the direction of 90° from the first elution. The results of this 2D TLC are shown in Figure 2.

Figure 2. (2D TLC) Result.

Figure 2 shows the results of 2-dimensional TLC of the ethyl acetate fraction, which only produced one spot even though it was eluted in 2 directions and using different eluents. Based on this result, the ethyl acetate fraction contains only bixin, which is further confirmed by characterizing bixin using the FTIR instrument, ^{1}H NMR, and UV-Vis Spectrophotometer.

Characterization with FTIR was carried out to determine the functional groups in the analysis sample and ensure compounds formed are Bixin pigments based on spectra. The working principle of FTIR is a sample passed by infrared light, which causes vibration of the sample's function at a specific frequency according to the type of functional groups.

Several certain functional groups are characteristic of bixin compounds based on the vibration produced in their respective wavenumbers: at 3435 cm^{-1}, which indicates the existence of O-H stretching vibration; 1610 cm^{-1} for O-H bending vibrations; 1715 cm^{-1} for particular vibrations of ester group compounds; 2924 cm^{-1} for stretching vibration H-C-H; 1425 cm^{-1} for stretching vibration of alkene C=C; 1375 cm^{-1} for vibration bending methyl C-H; 1203 cm^{-1} for stretching vibration C=O; 1156 cm^{-1} for symmetrical vibrations and asymmetric groups of esther C-O-C; 965 cm^{-1} for methylene rocking vibration *trans*-cerotenoid compounds [7]. This result follows previous research and is not much different from pure bixin vibration data [16], as shown in Table 1.

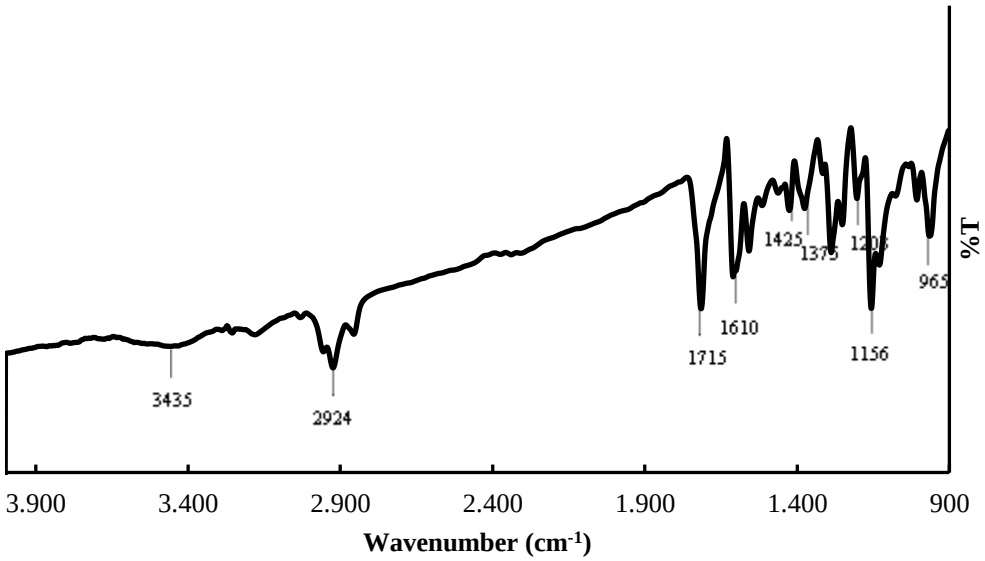

Figure 3. FTIR Spectra of Annatto Extract.

Table 1. Comparison of Bixin Vibration Standards and Bixin Extraction Results.

Bixin Standard vibration (cm^{-1})	Bixin Extraction Results Vibration (cm^{-1})	Fungsional Group
1717	1715	special vibration of esther group compounds
2922	2924	stretching C-H
1611	1610	bending O-H
1437	1425	stretching C=C
1273	1203	stretching C=O
1379	1375	bending methyl C-H
1165	1156	simetric and asymmetric esther group C-O-C
972	965	methylene rocking vibration trans carotenoid

The analysis using ^{1}H-NMR spectroscopy aims to determine the type of atom, number, and the hydrogen atomic environment in the sample. The principle of ^{1}H-NMR spectroscopy is the absorption of radio waves by the atomic nucleus in the sample in a strong magnetic field environment. It makes electrons that surround the core change direction, in the order or opposite direction with the magnetic field [17]. Each core has an identical resonance frequency, so it can be identified by looking at the chemical shift displayed from the results of characterization with ^{1}H-NMR.

Figure 4 shows spectra of bixin from ^{1}H-NMR measurement. The peaks that appeared in chemical shifts δ 8.08; 7.57; 6.51; 5.75; 3.77; and 1.96 show that the sample is a bixin compound. In addition,

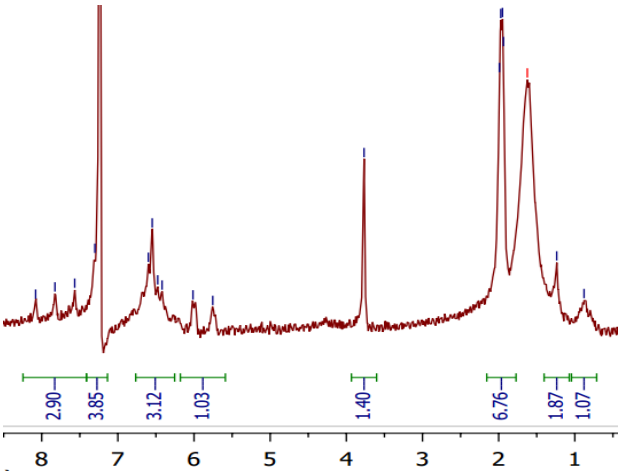

Figure 3. ^{1}H NMR Spectra of Annatto Extract.

specifically, the peak in a chemical shift of 3.77 ppm indicates the existence of a methoxy group. While the peak that appears on the change in 1.99; 1.97; 1.95; and 1.94 shows the presence of methyl groups in bixin compounds. Finally, a doublet-shaped peak is connected in a chemical shift of 7.83 and 7.50 ppm, a response of protons on the alkene, which forms conjugation bonds in the bixin structure [6]. These results are also not much different from the bixin standard, as shown in Table 2.

Table2. Chemical Shifts of Bixin [18] and Bixin Extraction Results.

Atom C	^{1}H NMR (δ, ppm)	
	Bixin	Bixin Extraction Results
CH_3	1.8-2.0 m	1.94-1.99 m
CH	6.30-7.00 m	6.42-6.60 m
OCH_3	3.66 s	3.77 s

The UV-Visible spectrophotometer was also used to find out the area of sample absorption, which is predicted to be a bixin compound. Figure 5 shows annatto extract in this study has a spectrum with three peaks at a wavelength above 400 nm, which is 488, 458, and 434 nm (bottom graph). This result is also not much different from the three peaks that appear in the measurement of the standard bixin absorbance (top graph), and it was at a wavelength of 489, 461, and 425 nm [19]. The absorbance that occurred in the wavelength area above 400 nm indicates a conjugated double bond on bixin compounds [7]. The peak that appears at a wavelength of 488 nm and 459 nm shows the existence of electron transitions from π to π* resulting from conjugated bonds C=C. While the peak at a wavelength of 434 nm appears because of the electron transition from n to π * produced by carbonyl group C=O [7, 14, 20].

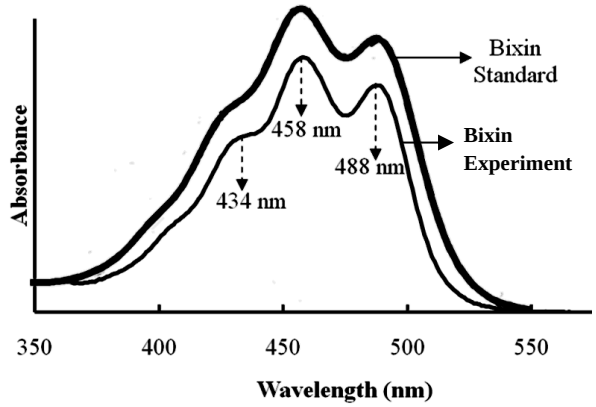

Figure 4. UV-Vis Spectra of Bixin in Acetone.

3. 2 Effect of surface area on the Effectivity of DSSC

Solar cells were assembled with three variations of active surface area, which were 1, 2, and 3 cm^2. These active surface areas were made by depositing TiO_2 on TCO glass as anode and platinum on other TCO glass as a cathode. Each glass that has been deposited with TiO_2 was then soaked in 5 g l^{-1} bixin solution and left for 24 hours. The aim is that the sensitizer will have a strong bond with TiO_2. The bonds between bixin compounds and TiO_2 anodes occur in carboxylic groups and esters from bixin and form a monodentate ester bond through C = O [7].

After that, all anodes bonded with bixin added a few drops of the electrolytes, then covered with a cathode like a sandwich structure. The three cells that have become further illuminated with halogen lights and measured the Voc value, a large voltage produced when the current is equal to 0. Also measured the Isc cell, which is a large current generated when the voltage is worth 0 on the variation of light intensity (5, 6, 7, 8, 9, 10, 20, 30, 50, 60, 70, 80, 90, and 100 mW cm^{-2}). From the results of the measurements, the graphics are made as in Figure 6.

Based on Figure 6, it can be seen that the Isc and Voc produced by the three cells are directly proportional to the intensity given. The resulting Voc and Isc increase is also directly proportional to the active surface area. Under the intensity of 100 mW cm^{-2}, cells with an active surface area of 1 cm^2 produce a voltage of 344 mV. In contrast, cells with an active surface area of 2 and 3 cm^2 at the same intensity result in a row voltage amounting to 719 mV and 1000 mV, which is almost two times and three times than that of the cell with the active surface area of 1 cm^2. This is because the more significant the surface area of a solar cell, the more bixin electrons can be excited in the DSSC system, causing an increase in maximum voltage [21]. The active surface area variation of these cells also affects the Isc generated by DSSC cells.

The current graph against intensity shows that the current of the three cells is also directly proportional to the intensity given to solar cells. The significant difference of the active surface area of the cell also has a considerable effect on the current

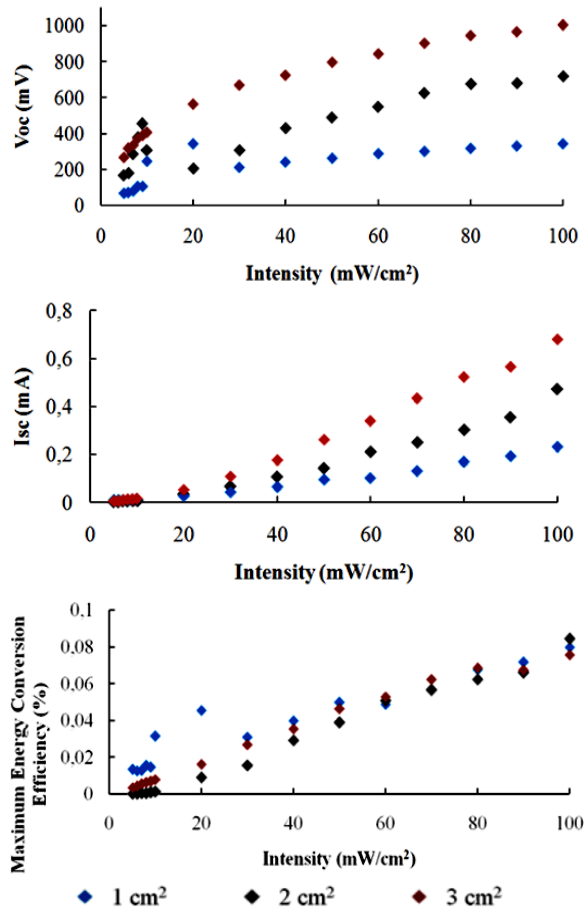

Figure 5. The results of Voc, Isc, and maximum energy conversion efficiency of DSSC with active surface area variations.

generated, where when viewed on the graph, the highest current is also generated by solar cells with the active surface area of 3 cm^2 at the intensity of 100 mW cm^{-2}, which is equal to 0.680 mA. While the highest current produced by cells with the active surface area of 1 and 2 cm^2 at the same intensity in a row of 0.232 mA and 0.472 mA. That shows that the greater the active surface area of a cell, the greater the Isc is generated. It is related to the increasing number of electrolytes that can occupy anodes to increase the number of electrons produced from each cell. The more electrons can improve, the intensity of electron transfers between the bixin and the electrolyte increases, causing the cell's maximum current [21].

The Isc and Voc in this study are similar to the results of Isc and Voc measurements that use the bixin purified results with the gravitational chromatography column (KKG), especially in cells with the same surface area of 1 cm^2 [22]. This shows even though it uses a more uncomplicated extraction and partition method, the performance of the bixin produced as a DSSC sensitizer is almost as good.

The maximum energy conversion efficiency of DSSC illustrates the amount of solar energy that can be converted into electrical energy. These values were obtained by comparing the power generated by the DSSC (Isc x Voc) with the power of the light source used. Based on the graph of maximum energy conversion efficiency to the intensity, the efficiency of the three cells is also directly proportional to the intensity given. The efficiency of the three cells is relatively the same and not too significantly different, so the surface area does not affect overall. But to produce greater electrical power, it is recommended to use solar cells that have the highest efficiency. The highest efficiency of the three cells is generated by solar cells with an active side area of 2 cm^2 which is 0.085% at the intensity of 100 mW cm^{-2}. In comparison, the intensity produced by solar cells with an active surface area of 1 and 3 cm^2 at the intensity of 100 mW cm^{-2} in a row is 0.080% and 0.076%. Decreasing cell efficiency on the surface area of 3 cm^2 is thought to be caused by fabrication that uses the doctor blading method, which can cause differences in the thickness of the anode and cathode during the deposition process. The thickness of this anode also affects the current and the voltage produced, where the thinner anodes, the smaller the current, and the voltage produced, resulting in a smaller efficiency.

3.3 Reusability of DSSC

Reusability of cells is the ability of a solar cell to recover from being reused. This reusability measurement is carried out by illuminating solar cells with variations in the intensity of 5-100 mW cm^{-2} for several days until the cell is dead or does not produce current when it is illuminated. The selected cells for reusability measurements are solar cells with a surface area of 2 cm^2 because based on the results of the previous measurement of solar cells with an active side area of 2 cm^2 has the highest current and voltage compared to solar cells with a surface area of 1 cm^2 and 3 cm^2. The results obtained from the measurement of cell reusability are shown in Figure 7.

The first graph shows the changes in the current generated solar cells for five days of irradiation. This irradiation is carried out per day,

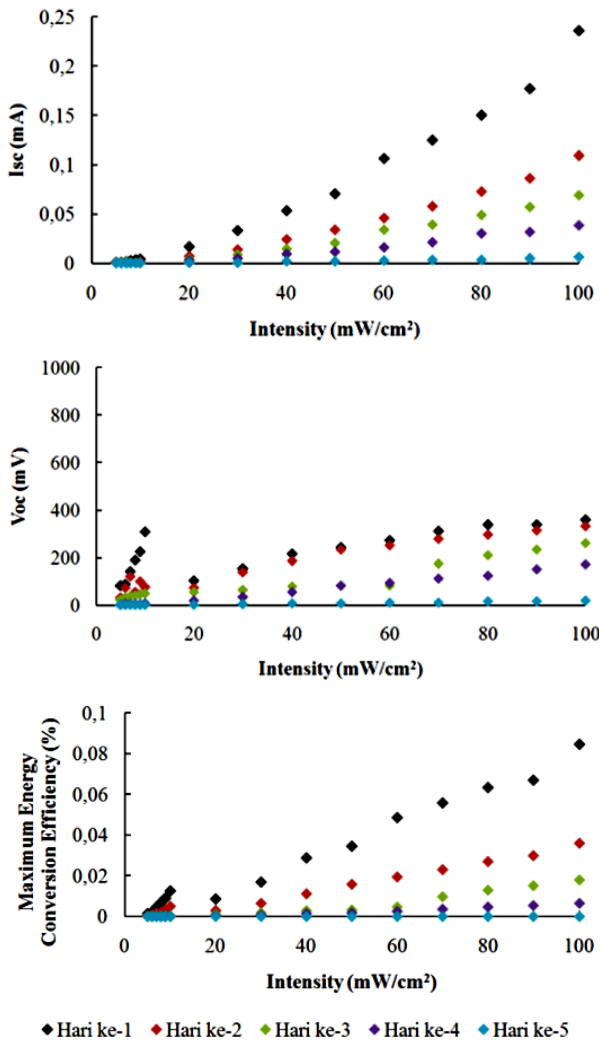

Figure 6. The results of Isc, Voc, and efficiency of DSSC on intensity variations (5-100 mW cm^{-2}) for 5 days.

where everyday measurements are carried out and cell voltage is carried out on the intensity variation of 5 to 100 mW cm^{-2}. The cell is rested and repeated on the following day until the fifth day. Based on the current graph of the intensity, it can be seen that the resulting current changes are not too significant at the intensity of 5 to 10 mW cm^{-2}. While at the intensity of 20 to 100 mW cm^{-2} there is a significant current change, especially from the first day to the second day. The most significant change occurs at the intensity of 100 mW cm^{-2}, where the current generated on the first day is equal to 0.236 mA down to more than 100% to 0.109 mA on the second day.

Furthermore, at the same intensity of the current measured on the third, fourth, and fifth, respectively 0.069; 0.038, and 0.006 mA. The current generated on DSSC is very dependent on the electrolytes used in the system. Liquid electrolytes are most often used in the DSSC system because they produce high conductivity. But one of its weaknesses is that liquid electrolyte quickly evaporates, which happens to DSSC cells after being used many times for five consecutive days. The presence of solvent evaporation on electrolytes causes electrolyte concentration in cells to increase. This causes ion mobility I^-/I_3^- and electrons to be lower. As a result, the regeneration of coloring molecules (dye) by iodine becomes hampered, which ultimately leads to disrupted electron excitation so that the current falls per day [23].

The second graph shows the voltage relationship produced by solar cells on the intensity variations used. Based on these graphics, on the first and second day, the voltage produced at the intensity of 5 to 10 mW cm^{-2} has a less stable pattern, whereas at the intensity of 10 mW cm^{-2} voltage on the first and second day is 307 and 275 mV. Then, at the intensity of 20 mW cm^{-2}, the voltage produced drops to 103 mV and 73 mV, and then gradually rises to make the highest voltage at the intensity of 100 mW cm^{-2}, consecutively by 359 mV and 332 mV. On the third day, the measured voltage decreased compared to the first and second days on all intensity variations. On the fourth day, there was also a decrease in voltage from the third day. Still, under the intensity of 50 and 60 mW cm^{-2}, the resulting voltage was measured higher than on the third day, which was 81 mV and 95 mV. The measured voltage mV is equal to 81 mV. On the fifth day, the voltage produced under the intensity of 5 to 10 mW cm^{-2} is not too different from the fourth day, but at the intensity of 20 to 100 mW cm^{-2} a significant decrease is down from 171 mV to 18.7 mV. This happens because of the degradation experienced by the sensitizer after being periodically illuminated for five days.

The sensitizer degradation was indicated by changes in the color of the cells. A more stable sensitizer will produce a more stable DSSC, meaning that cells can be used several times after collapsing with certain intensity or in particular irradiation. Bixin sensitizer is considered one of the most stable compounds than other pigments. This is because the bixin compound has many hydrogen bonds in the structure. The stability of a compound can be explained through the influence of hydrogen bonds that can occur in a compound [24]. Compounds that can experience hydrogen bonds have higher stability than compounds that cannot

form hydrogen bonds. The more hydrogen bonds are formed, the more stable the compound is. Bixin has one carboxylic group and one ester group at the end of the chain of its chemical structure. The hydrogen bond can be formed on carboxylic groups through H and carbonyl [25] atoms. This causes bixin pigments to be more stable and can last up to 5 days of usage periodically.

The third graph shows the maximum relationship of energy that can be converted solar cells for five days. Based on the graph, a very significant decline only occurred on the first day to the second day. At the intensity of 100 mW cm^{-2} the efficiency produced is 0.085% on the first day down to 0.036% on the second day. This is caused by cell currents that fall more than 100%, as previously discussed, to generate efficiency based on the calculation results also decreases more than 100%. However, the efficiency decline on the third day to the fifth occurred gradually up to 0,0001% at the intensity of 100 mW cm^{-2}. Then the cell died on the sixth day.

Based on the three graphs above, it can be concluded that this solar cell can be reused (reusable) for up to 5 days. This cell recovery can be associated with increased cell performance induced by light. It can occur by recovering and/or reorganizing some dangle or tense bonds between sensitizer and photoelectrode in coloring molecules [8].

The measurement of Voc, Isc, and efficiency shows that these solar cells' performance is quite similar to solar cells that were studied by Septiani in 2020 [22], even though the sensitizer bixin from this study was extracted by a simpler method. The reusability result shows that this cell has better resistance than TiO_2/treated metakaolinite, which only survived for three days.

4. Conclusion

The characteristics of bixin extraction results are shown from the KLT, KLT 2D, the UV-Vis spectrophotometer, FTIR spectra, and ^{1}H-NMR spectra. The result is based on TLC and TLC 2D compounds in the ethyl acetate fraction. Only one compound, as evidenced by only one spot on the KLT plate. Then this compound is ascertained as bixin through UV-Vis, FTIR, and ^{1}H-NMR spectra.

The effect of surface area on the effectivity of solar cells is shown through voltage, current and efficiency produced. The results of voltage measurements and currents indicate that the bigger the surface area, the greater the current and voltage generated. In contrast, the highest efficiency is produced by solar cells with an active side area of 2 cm^2. Solar cells with this highest efficiency are then taken to measure cell reusability for six days. The result shows the highest efficiency day produced is getting lower per day until the fifth day, the highest efficiency produced is only 0,0001%, then the cell dies on the sixth day.

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