
The Impact of Using Bamboo Activated Carbon as Counter Electrode and Dye from Suji Leaf toward the Efficiency of Dye Sensitized Solar Cells

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Abstract: Dye-sensitized solar cells (DSSCs) have attracted great interest due to their ability to convert solar energy into electricity cost-effectively and efficiently. This study aims to create Dye-Sensitized Solar Cells (DSSCs) by utilizing bamboo activated carbon as the counter electrode and natural dyes derived from suji leaves as photosensitizers. Bamboo activated carbon was chosen because of its sustainable nature, large surface area, and excellent conductivity. Likewise, suji leaf dye was chosen because of its capacity to absorb various wavelengths of light. These materials were analyzed using UV-Vis spectroscopy, XRD, and SEM to determine their structure and characteristics. The results of the DSSC efficiency showed that using bamboo activated carbon as the counter electrode produced the highest energy conversion efficiency of 0.0000896%, surpassing the achievement of carbon black electrodes, which only reached 0.0000505%.

Keywords: counter electrode, activated carbon bamboo, suji leaf, dye-sensitized solar cells

1. Introduction

Indonesia, due to its tropical environment and proximity to the equator, possesses considerable capacity for harnessing solar energy all year round. Indonesia has an average solar energy potential of around 4.8 kWh/m²/day, which makes it a feasible choice for renewable energy initiatives.[1] Dye-Sensitized Solar Cells (DSSCs) have gained prominence as a viable substitute for conventional silicon-based solar cells, owing to their reduced manufacturing expenses and simplified production methods.[2]

Developed in 1991 by O'Regan and Gratzel, third-generation solar cell technology represents a substantial advancement in photovoltaic technology. These cells have attracted considerable attention because of their capacity to provide cost-efficient and eco-friendly alternatives to conventional silicon-based solar cells. [3], [4]

The primary constituents of DSSC consist of transparent conductive oxide (TCO) glass, dye sensitizers, semiconductors, electrolytes, and counter electrodes. Transparent Conductive Oxide (TCO) glass, commonly composed of materials like fluorine-doped tin oxide (FTO) or indium tin oxide (ITO), acts as a base for the semiconductor and dye, enabling the movement of electrons. [5], [6]

The counter electrode (CE) in Dye-Sensitized Solar Cells (DSSC) is essential since it serves three primary purposes:

- Collecting electrons
- Catalyzing the reduction of the electrolyte
- Aiding in the transportation of holes

Initially, the counter electrode gathers electrons from the external circuit and conveys them to the electrolyte, which is crucial for sustaining the current flow within the cell [7]

The electron collection is essential for optimizing the efficiency of DSSC since it guarantees the efficient use of the electrons produced at the photoanode. Furthermore, the counter electrode acts as a catalyst for the reduction of the redox electrolyte, commonly the iodide/triiodide pair (I⁻/I₃⁻), which is a crucial process in the restoration of the dye and the ongoing photovoltaic cycle. [8], [9]

An optimal counter electrode should possess elevated levels of catalytic activity, conductivity, and reflectivity [10] It should be cost-effective, have a large surface area, and be porous. [11]. It should maintain optimal thickness, be chemically, mechanically, and electrochemically stable, corrosion-resistant, have energy levels compatible with the redox pair potential difference, and exhibit good adhesion properties to the TCO [12]

Platinum is the prevailing choice of material for the counter electrode. Nevertheless, the excessive expense and limited availability of Pt have prompted investigations into other materials for counter electrodes. An additional option that may be utilized is activated carbon. Activated carbon (AC) is a cost-effective material with a large surface area and outstanding electrochemical characteristics. It is an attractive choice for counter electrodes in dye-sensitized solar cells (DSSC) and other energy storage devices. For instance, activated carbon generated from hemp (HAC) has a well-organized porous arrangement with many active sites, which enhances its electrocatalytic activity and makes it suitable for use in DSSC [13] Similar to this, activated carbon made from burned coconut shells has demonstrated enhanced performance metrics in perovskite solar cells, including V_{OC} 0.7 V and a fill factor (FF) of 0.371. This makes it a competitive substitute for pricey silver or gold counter electrodes. This is especially true when combined with paraffin oil[14]

Counter electrode materials play a vital role in improving the efficiency and sustainability of DSSCs by directly influencing the electron transfer mechanism and the regeneration of the redox pair inside the cell. Therefore, continuous improvements in CE materials are essential. [15]

The objective of the current investigation is to determine that the carbon material utilized is generated from bamboo charcoal. The rationale for choosing activated carbon derived from bamboo charcoal lies in its abundant supply and ready accessibility in Indonesia. One additional benefit of using activated carbon obtained from bamboo is its relatively cheaper cost in comparison to platinum. Additionally, it possesses a large specific surface area and exhibits outstanding electrochemical performance, making it well-suited for utilization as a counter electrode in DSSC. [16]

2. Material and Method

2.1. Material

The materials utilized in this research comprise bamboo charcoal, 3 M hydrochloric acid (HCl), distilled water, Whatman filter paper, 97% ethanol solution, PEG-400, PVA, acetonitrile, potassium iodide (KI), iodine (I₂), fluorine-doped tin oxide (FTO) coated glass, suji leaf extract, and aluminum foil. The equipment utilized comprises a UV-Vis spectrophotometer, X-ray diffraction (XRD) instrument, scanning electron microscope (SEM), hotplate, solar power meter, and several other conventional laboratory equipment.

2.2. Activation of Bamboo Activated Carbon

The initial step in producing activated carbon begins with placing pieces of bamboo-derived charcoal into a ball mill to grind the charcoal into a fine powder. The powdered charcoal is then sieved using a sieving shaker to obtain a consistent particle size of 200 mesh. Next, 100 grams of the sieved charcoal is weighed in preparation for activation. The subsequent step involves the chemical activation of the charcoal powder using HCl. Add 500 ml of 3 M HCl to the 100 grams of charcoal powder and allow the mixture to stand for 24 hours to ensure thorough activation.

After soaking, filter the mixture using Whatman filter paper to separate the activated carbon from the acid solution. Wash the filtered residue with distilled water (aquadest) until the wash water reaches a neutral pH (pH 7). Finally, dry the washed activated carbon in an oven at 110°C for 3 hours.

2.3. Preparation of ITO Glass

The ITO glass (2.5 x 2.5 cm) is inserted in a beaker containing 70% alcohol. Afterward, the glass is subjected to a 30-minute ultrasonic cleaning process to eliminate contamination. Once the cleaning process is complete, the glass is then dried. Subsequently, the electrical resistance of the dehydrated glass is quantified using a multimeter[17]

2.4. Preparation of TiO₂ Paste

A solution is created by mixing 0.5 grams of polyvinyl alcohol (PVA) with 4.5 milliliters of distilled water. The solution is vigorously stirred using a magnetic stirrer at a temperature of 80°C for approximately 30 minutes until it attains a more compact texture and complete uniformity. The resultant solution is then combined with 0.5 grams of TiO₂ powder, using a ratio of 2 spatula scoops of TiO₂ along with 15 drops or 0.75 mL of the PVA solution, resulting in the creation of the TiO₂ paste[18]

2.5. Preparation of TiO₂ Paste on FTO Glass



Figure 1. synthesis proses of Activated carbon from bamboo

In order to deposit TiO₂ onto the surface of the conductive glass, which has already been assessed for its resistance, a specific region of 0.5 cm x 0.5 cm is restricted on the FTO glass using tape. Next, the surface is covered with a layer of TiO₂ paste using the Doctor-Blade process. Subsequently, the glass that has been coated is subjected to a temperature of 450°C on a hot plate for 10 minutes[19]

2.6. Preparation and Extraction of Suji Leave

The materials are desiccated using solar radiation. Afterward, the suji leaves are pulverized into a fine powder using a blender. After the suji leaves have been finely ground, 100 grams of the powdered suji leaves are measured. The subsequent step involves maceration. During this procedure, the suji leaves are inserted into a maceration container, and ethanol is introduced in a 1:6 proportion of substance to the dissolving agent. The suji leaves are immersed in ethanol and allowed to rest for 24 hours at ambient temperature. Following the process of maceration, the solution is subjected to filtration using filter paper in order to separate the resulting filtrate from the residue. Subsequently, the solution that has been filtered is carefully put into a light-restricted container, which is sealed with a lid and covered with aluminum foil.

2.7. Preparation of Counter Electrode in

The counter electrode in a DSSC is composed of conductive glass that is covered with black carbon and activated carbon. Carbon catalyzes to expedite reactions in DSSC. The catalyst is formed by dissolving 3.5 grams of black carbon in 15 cc of ethanol. The components are agitated using a magnetic stirrer at a temperature of 80°C for 1 hour, resulting in the formation of a colloidal carbon paste. The objective of utilizing a magnetic stirrer at a temperature of 80°C is to achieve a uniform mixture of the solution and diminish the concentration of ethanol within the solution. Subsequently, the artificially produced colloidal carbon paste is applied onto the FTO substrate using the doctor blade technique. Next, the counter electrode layer is subjected to heating on a hotplate at a temperature of 200°C for 30 minutes. The objective of this technique is to promote crystal growth, enhance grain uniformity, and reinforce the adhesive forces between the layers and the substrate.

2.8. Preparation of Electrolyte Solution

A solution is created by mixing 1 mL of distilled water with 0.83 grams of potassium iodide. Then, either 9 mL of acetonitrile or 10 mL of PEG 400 solution is added. Subsequently, a quantity of 0.127 grams of iodine (I₂) is added to the solution and stirred vigorously using a magnetic stirrer. The solution is contained within a jar that is not transparent and has been tightly sealed

2.9. DSSC Assembly

The FTO glass, which has been coated with a layer of TiO₂ paste, is submerged in a solution of suji leaf dye for one day. To prevent any contamination from external substances, the glass is

then wrapped with aluminum foil. Subsequently, the FTO glass, which has been coated with bamboo-activated carbon/counter electrode, is positioned on the working electrode in a sandwich configuration. The glass is then secured at both ends using clippers. Next, the electrolyte solution is inserted between the layers.



Figure 10. DSSC Assembly

3. Result and Discussion

3.1. UV-Vis dan FTIR suji leave

UV-Visible (UV-Vis) spectrophotometry and Fourier Transform Infrared (FTIR) spectroscopy were employed to extract and analyze chlorophyll from suji leaves. This analysis yielded important information on the effectiveness and durability of chlorophyll as a dye. The absorption wavelengths and band gap energy of chlorophyll isolated from suji leaves were determined using UV-Vis

spectrophotometry. The Agilent 8453 UV-Vis spectrophotometer was employed for UV-Vis spectrophotometry analysis, whereas the Shimadzu equipment was used for FTIR analysis.

capable of absorbing red light as well. This property contributes to enhancing the efficiency of absorbing a wider range of solar spectrum. The extremely low absorbance at a wavelength of 555.0 nm suggests that the suji leaf dye has a



Figure 2. extraction of dye suji leaf

Figure 3 illustrates the ultraviolet-visible (UV-Vis) findings

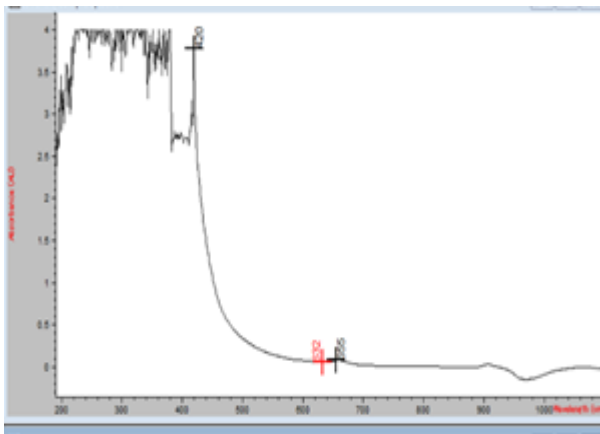


Figure 3. UV-Vis of dye suji leaf

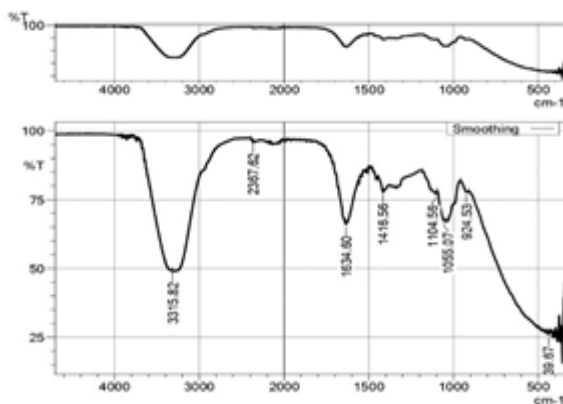


Figure 4. FTIR of dye suji leaf

of suji leaves. The graph exhibits two absorption peaks at certain wavelengths. The graph shows that the suji leaf dye exhibits significant absorption at wavelengths of 382.0 nm and particularly at 435.0 nm, indicating its great ability to absorb ultraviolet (UV) and blue light. This is crucial for optimizing electron excitation. The dye's relatively high absorption at a wavelength of 668.0 nm suggests that it is

poor ability to absorb green light. This might provide a drawback as green light constitutes a substantial portion of the visible spectrum. Figure 4 illustrates The FTIR spectrum of suji leaf extract exhibits the following peaks, At a wavenumber of 3315.16 cm^{-1} , this peak is likely attributed to the absorption of hydroxyl (-OH) groups, which are typically present in compounds such as alcohols or phenols. This summit frequently emerges in the elevated area, signifying the existence of unbound hydroxyl groups. At a wavenumber of 1634.60 cm^{-1} , this peak is likely associated with the absorption of C=C double bonds, namely in alkenes or aromatic compounds. At a wavenumber of 1055.07 cm^{-1} , this peak is likely caused by the absorption of C-O or C-N bonds, depending on the particular molecule. It may suggest the existence of compounds such as ethers, esters, or amines. At a wavenumber of 924.53 cm^{-1} , this peak may correspond to distinct vibrational motions in organic molecules. The presence of peaks in this particular area is frequently linked to the existence of C-H bonds and the absorption of aromatic or aliphatic molecules.

3.2. Characteristics of activated carbon crystal

Crystal structure analysis is the process of determining and describing the precise organization of atoms or molecules inside a crystal lattice. The crystal structure of the Counter Electrode material was investigated in this work using X-ray diffraction. The X-ray diffraction test was conducted using a Rigaku Miniflex 600 XRD apparatus.

Based on the XRD test analysis results depicted in Figure 5, no further chemicals were detected in the sample. The

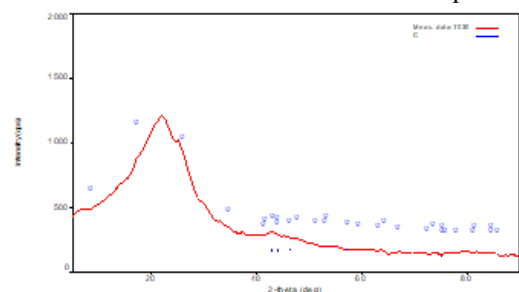


Figure 5. XRD pattern of activated carbon from bamboo

X-ray diffraction (XRD) analysis of the activated carbon revealed two prominent diffraction peaks at 2-theta angles of 25.16° and 42.74° . The peak value form closely resembles the studies undertaken by Sidim[20]

The initial peak corresponds to an interplanar spacing (d) of 3.53959 \AA , exhibiting a significant peak intensity of 1638.69 cps. The subsequent peak displays an interplanar spacing of 2.11568 \AA , accompanied by an intensity of 217.34 cps. The two peaks were identified as carbon phases (0,0,6) and carbon (1,0,1), suggesting the presence of a crystal structure that is significant for electrochemical applications.

3.2. Characteristics of FTIR carbon activel

The supplied FTIR data displays the infrared spectrum of activated carbon, indicating peaks that correspond to distinct wavenumbers associated with different chemical vibrations. Below is a breakdown of the traditional meaning associated with each peak:

The value 3217.64 cm^{-1} : Explanation: This peak is often linked to the elongation of O-H bonds in hydroxyl groups (OH), which suggests the existence of water or hydroxyl groups that have been absorbed into the surface of the activated carbon. The value 2347.78 cm^{-1} is given. Analysis: The observed peak may be indicative of the existence of $\text{C}\equiv\text{C}$ (alkyne) or $\text{C}\equiv\text{N}$ (nitrile) bonds, which implies the presence of certain carbon compounds that are produced during the activation process. The value is 2074.00

cm^{-1} . Explanation: Peaks observed in this specific area are frequently associated with carbonyl ($\text{C}=\text{O}$) or isocyanate ($-\text{N}=\text{C}=\text{O}$) functional groups. This implies potential alterations to the activated carbon surface or the presence of contaminants. The value is 1564.56 cm^{-1} . Explanation: This peak is commonly linked to the bending of N-H bonds or the stretching of $\text{C}=\text{C}$ bonds in aromatic rings, suggesting the existence of aromatic structures in the activated carbon. The value is 1384.39 cm^{-1} . Explanation: This peak is commonly associated with the bending of carbon-hydrogen (C-H) bonds in methyl ($-\text{CH}_3$) or methylene ($-\text{CH}_2-$) groups. These groups can be found in the structure of activated carbon or in compounds that have been adsorbed onto it. The value is 1078.52 cm^{-1} . Explanation: This particular peak often indicates the existence of C-O groups, which are commonly seen in alcohols, esters, or ethers. It suggests that there are oxygen-containing functional groups present on the surface of the activated carbon. The value is 388.87 cm^{-1} . Explanation: Peaks appearing at lower wavenumbers may suggest the presence of intricate bending vibrations or interactions involving larger functional groups, which are connected to the basic composition of activated carbon or impurities.

3.3. Characteristics SEM of activated carbon

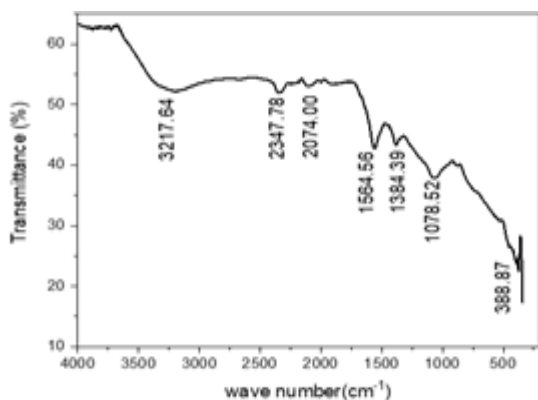


Figure 6. FTIR of activated carbon from bamboo

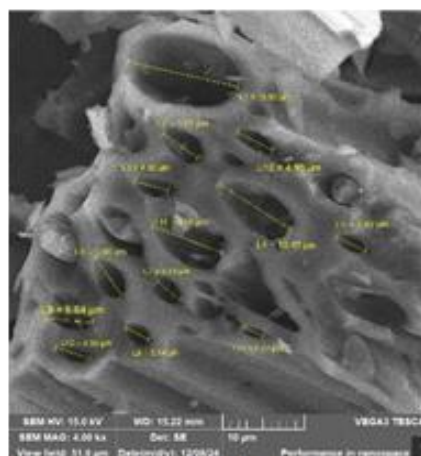
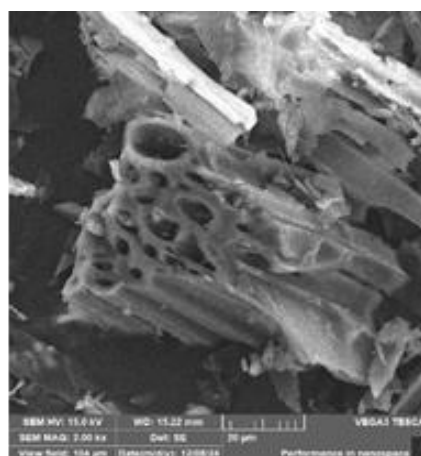


Figure 7. SEM images of activated carbon bamboo

Scanning Electron Microscopy (SEM) is a vital technique used to analyze activated carbon's surface morphology and structural features. These characteristics are critical in determining its suitability for use in dye-sensitized solar cell (DSSC). The scanning electron microscopy (SEM) examination of bamboo-activated carbon uncovers many surface characteristics that play a crucial role in determining its effectiveness in dye-sensitized solar cells (DSSCs). For example, scanning electron microscope (SEM) photographs of bamboo-activated carbon reveal a clean and orderly surface structure, which enhances the efficiency of electron transfer and the absorption of dyes in dye-sensitized solar cells (DSSCs[21] Figure 7 illustrates a fibrous structure that has linked pores. This structure is beneficial because it helps to maintain a large surface area and promotes effective electron transmission in DSSC.

3.4. Current and voltage characteristics of DSSC

The DSSC's current and voltage were measured throughout 14 days, between 11:30 AM and 1:00 PM, while exposed to sunshine. Two distinct counter electrodes, DSSC with activated carbon and DSSC with carbon black, were employed to examine the DSSC's current and voltage properties. This is illustrated in Table 1. And Figures 8 and 8 depict the voltage and current curves for the two different types of counter electrodes. These figures demonstrate a daily drop in both voltage and current. The instability of the counter electrode may be attributed to the carbon type

Table 1. Voltage and current measurement of DSSC

Day	Irradiance (W/m ²)	Karbon aktif		karbon black	
		Voc (mV)	Isc (μ A)	Voc (mV)	Isc (μ A)
1	935.4	325	02.5	315	01.5
2	850.3	318	02.2	294	01.3
3	930.1	315	02.2	302	01.5
4	784.3	305	02.0	289	01.0
5	890.2	321	02.4	308	01.5
6	525.6	275	01.7	278	00.7
7	780.5	280	01.9	280	01.0
8	1085.8	214	01.3	214	01.0
9	995.2	244	01.5	172	00.8
10	850.4	124	00.8	87	00.6
11	759.4	76	00.5	40	00.2
12	856.3	80	00.5	35	00.2
13	785.3	42	00.4	20	00.2
14	842.3	31	00.4	20	00.2

employed. The graphs indicate that activated carbon exhibits

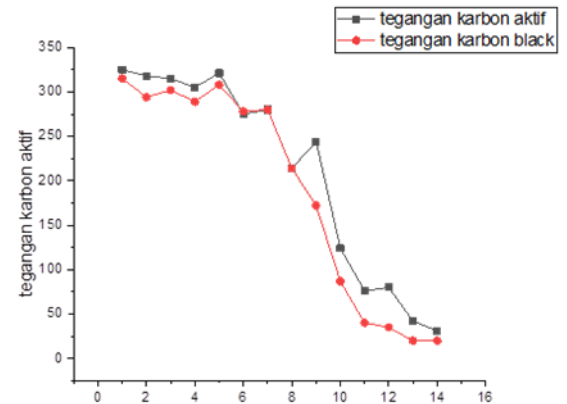


Figure 8. Voltage produce by DSSC

superior efficiency compared to carbon black.

4. Conclusion

In this study, DSSC has been successfully made using bamboo activated carbon electrodes and dyes from pandan leaves. The highest efficiency is produced in DSSC using a carbon counter electrode layer derived from bamboo activated carbon of 0.0000896%. When viewed from the existing graph, DSSC produces high voltage and current at the beginning of use, then decreases after one week of use. This may occur due to the incompatibility between the electrolyte solution and the chemical components of the DSSC. Further research is needed on the appropriate electrolyte for this bamboo activated carbon DSSC.

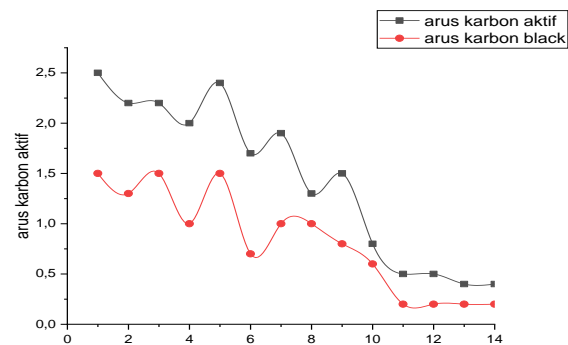


Figure 9. Current produce by DSSC

Table 2. Efficiency of DSSC

Nama sel	V max (mV)	I max (μ A)	Pmax (mW/cm ²)	Pin (mW/cm ²)	η (%)
Karbon aktif	325	02.5	0.8125	935.4	0.0000869
Karbon black	315	01.5	0.4725	935.4	0.0000505

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