Study and Fabrication of Super Low-Cost Solar Cell (SLC-SC) Based on Counter Electrode from Animal’s Bone

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Abstract. The synthesized carbon from bones of chicken, cow, and fish with the calcination temperature at 450 and 600°C have been successfully fabricated for counter electrode in the Super Low-Cost Solar Cell (SLC-LC) based on Dye-Sensitized Solar Cells (DSSC). The main proposed study was to fabricate SLC-SC and investigate the influence of the synthesized carbon from animal’s bone for counter electrode towards to photovoltaic performance of SLC-SC. X-Ray Diffraction and UV-Vis was used to characterize the phase and the optical properties of TiO₂ as photoanode in SLC-SC. Meanwhile, the morphology and particle size distribution of the synthesized carbon in counter electrodes were investigated by Scanning Electron Microscopy (SEM) and Particle Size Analyzer (PSA). The results showed that the TiO₂ has anatase phase with the absorption wavelength of 300 to 550 nm. The calcination temperature for synthesizing of carbon could affect morphology and particle size distribution. The increasing temperature gave the effect more dense in morphology and increased the particle size of carbon in the counter electrode. Changes in morphology and particle size of carbon give effect to the performance of the SLC-SC where the increased morphology’s compact and particle size make decreased in the performance of the SLC-SC.

1. Introduction

The oil and gas supplies in Indonesia will not be available all time. Solar Cell is one of the solutions to this problem because of its ability to convert sunlight into electric current. Along with the development of a solar cell, the most vigorous research conducted now is DSSC (Dye-Sensitized Solar Cell). DSSC is the 3rd generation in Solar Cell which has inexpensive fabrication compared to conventional solar cells (silicon-based) [1]. DSSC is composed of nanoporous TiO₂ photoanode and Pt or carbon counter electrode separated by iodide/triiodide electrolyte [2]. Based on statistical data in 2015 from Indonesia’s farm and animal’s health department, meat production levels increased compared to 2014, so it makes new problem due to increased waste animal’s bone [3]. In 2012 [4], there was research about comparative analysis and characterization of animal’s bone as an adsorbent substance, and it can be used to synthesize carbon. In 2017 [2], carbon could be applied to be a counter electrode which had electronics conductivity, corrosion resistant to tri-iodide, high reactivity for reducing tri-iodide, and low cost. From these statements, it can be said that animal’s bone can replace Pt as the counter electrode. From this issue, the utilization of animal’s bone to synthesis carbon as a counter electrode in the component of DSSC as Super Low-Cost Solar Cell (SLC-SC) will be
investigated. The morphology and the particle size distribution of the synthesized carbon from animal's bone will be observed and characterized too.

2. Research Method

2.1. Preparation of TiO₂ paste

TiO₂ powders were synthesized by previous research method [2,5]. The mixture of 20 mL of Titanium (III) chloride (TiCl₃) and 100 mL of distilled water was stirred for an hour. NH₄OH solution was dropped slowly to the mixed solution until the rate of the acidity reached to 9 and then the result of the solution was stirred until a white precipitate appeared. The precipitate was filtered and washed several times with distilled water; this process would be stopped at the rate of the acidity equal to 7. Removal process of residual organics and the stabilization of the materials were carried out by calcination for 3 hours at 450 °C. The TiO₂ pastes were prepared by the mixture of distilled water, ethylcellulose, terpineol, and ethanol was then added and kept stirring for 10 min. The mixed oxide pastes were obtained from 0.7 mL of acetic acid, 0.3 g of PEG, and 0.7 mL of Triton X-100.

2.2. Preparation of Carbon

Bones dried at 170 °C for 4 h. After dried, the bones were calcination at 450 and 600 °C for 1 h. The solids carbon that obtains from calcination then crushed in a mortar to make carbon powder. The same way prepares the bones of chicken, fish, and cow.

2.3. Preparation of Photoanode

TiO₂ paste was deposited by screen printing method with a dimension of 1 × 1 cm² onto ITO glass with size 2.5 × 2.5 cm². The deposited TiO₂ paste onto the ITO glass was then heated for 5 min at 100 °C. The photoanode was immersed overnight in the dye that extracted from grape skin at room temperature

2.4. Preparation of Counter Electrode

Carbon paste was prepared by mixing carbon powder with ethanol and was then stirred for 1 h. The carbon pastes were deposited onto a conductive glass substrates-ITO glass using doctor blade method with the thickness around ~10 μm. The electrode was heated for 30 min at 250 °C to remove the residual organic and stabilize the material.

2.5. SLC-SC fabrication

SLC-SC was fabricated using previous research [2] with the dye-sensitized TiO₂ photoanode, mostly as an electrolyte, and the synthesized carbon as the counter electrode.

3. Result and Discussion

3.1. TiO₂ phase analysis

The match!software was used for qualitative analysis of all data from X-Ray Diffraction (XRD). Figure 1 shows the TiO₂ anatase has been successfully formed. The crystal plane 101 situated at 20 around 25.3° is the crystal plane with the highest intensity in the TiO₂ powder [5]. Another crystal field also identified namely (004), (200), (105), (211), (204), (116), (220) and (215) that are located at 20 for 38.3 °, 48°, 54°, 55°, 62°, 69°, 71° and 75°, respectively. The results are consistent with those obtained by S. Mahshid et al.[6].

3.2. Optical characteristics of Dye and Photoanode

UV-Vis performed the optical properties of dye and photoanode. Figure 2 shows the absorbance graph of TiO₂ thin film, a dye that extracted from the grape skin, and TiO₂ that immersed in the dye for 24 hours. It can be analyzed from Figure 3 that the TiO₂ thin film can absorb 300 – 550 nm wavelength with maximum wavelength range at 300 – 380 nm whereas the dye has two peaks wavelength range that can be absorbed in the range of 200 – 300 nm and 550 – 800 nm. After immersed the TiO₂ thin
film in the dye, it was found that the wavelength that can be absorbed by the thin film layer is in the range of 200 – 800 nm with maximum absorbable wavelength at 300 – 800 nm.

![XRD of TiO₂ powder](image1.png)

**Figure 1.** Graphic XRD of TiO₂ powder shows anatase phase

![UV-Vis absorbance graphs](image2.png)

**Figure 2.** UV-Vis shows the absorbance graphs of (a) TiO₂ thin film, (b) dye that extracted from the grape skin, (c) TiO₂ thin film that immersed in dye for 24 hours

3.3. Study of Morphological and Particle Size Analyzer in Counter Electrode
The morphology of each type of counter electrode shows the same form of flakey or in pieces and there are pores of different particle sizes as shown in Figure 3. Measurement of the particle size of carbon from SEM micrograph was performed using the ImageMif software. Figure 4 shows the particle size of the synthesized carbon powder with calcination temperature at 450 °C from a fish, chicken, and cow bones. It can be analyzed that the synthesized carbon powder from fish bone has the biggest size compared to the others with dominant particle size found at 1, 0.8 and 0.4 μm, respectively. Meanwhile, the synthesized carbon with calcination temperature at 600 °C showed that each carbon powder is denser, and increased their particle size.

To obtain the result more accurate, we used Particle Size Analyzer device so that the measurement results are in the form of particle distribution and overall condition of the sample. Figure 4 shows the particle size distribution of the synthesized carbon with calcination temperature at 450 and 600 °C,
respectively. The results revealed that the calcination temperature could be increasing the particle size. This fact also had been reported by [7].

![Figure 3](image1.png)

**Figure 3.** The SEM micrograph shows the surface morphology of animal’s bone with calcination temperatures: a) 450 °C (fish (a), chicken (b), and cow (c)), and b) 600 °C (fish (a), chicken (b), and cow (c))

The Polydispersity Index (PdI) and average particle size of the synthesized carbon from each calcination temperatures are summarized in Table 1. It can be concluded from Table 1 that the addition of temperature during the manufacturing process could enhance in particle size whereas the average Polydispersity Index (PdI) in each sample also varies. PdI shows the uniformity of size, the smaller the PdI value indicates an increasingly uniform size. The synthesized carbon can achieve the lowest and highest average PdI value from the bones of cow and chicken with calcination temperature at 600 °C, respectively.

![Figure 4](image2.png)

**Figure 4.** Particle size distribution of the synthesized carbon using imageMif with calcination temperatures: (A) 450 °C (fish (a), chicken (b), and cow (c)), and (B) 600 °C (fish (a), chicken (b), and cow (c))
Table 1. Particle size from Particle Size Analyser measurement

| Sample    | Average Particle Size | Average PdI |
|-----------|------------------------|--------------|
| Fish 450°C | 1455.00                | 0.712        |
| Fish 600°C | 4702.67                | 0.832        |
| Chicken 450°C | 705.90              | 0.562        |
| Chicken 600°C | 2781.33              | 0.911        |
| Cow 450°C  | 1528.00                | 0.750        |
| Cow 600°C  | 5902.00                | 0.374        |

3.4. I-V characterization

Characterization of current, voltage and efficiency of Super Low-Cost Solar Cell was measured with the solar simulator under illumination at 100 mW/cm² were summarized in Table 2. Table 2 shows the highest efficiency (0.063%) can be achieved by the synthesized carbon from the fishbone with calcination temperature of 450 °C. Decreased efficiency can be seen for all sample due to increasing calcination temperature from 450 to 600 °C except for the chicken bone. The fact due to increased in particle size. The particle size affects the contact area of the electrode counter, the wider the contact of the electrode the more electrons can be passed on the electrode counter in the electron transport process from the outer circuit of the DSSC to electrolyte [5]. Meanwhile, the photovoltaic performance of SLC-LC with the synthesized carbon from animal’s bone as a counter electrode has the better performance compared to the SLC-SC with commercial black carbon as the counter electrode. The results show that the synthesized carbon from animal’s bone has a potential application in dye-sensitized solar cells (DSSC) and also can be one of the solutions for animal’s bone waste problems. Based on the results from [8], the counter electrode based on composite carbon black and Pt, it had given the efficiency value of 0.43%. This fact shows that the synthesized carbon from animal's bone has a potential to be applied to the counter electrode for DSSC with very low cost in the future.

Table 2. Performance characteristics of the SLC-SC

|          | $J_{SC}$ (mAcm⁻²) | $V_{oc}$(V) | FF     | $\eta$(%) |
|----------|-------------------|-------------|--------|-----------|
| Fish 450° | 0.05739           | 1.58475     | 0.69186| 0.06292   |
| Fish 600° | 0.05718           | 1.56553     | 0.41677| 0.03730   |
| Chicken 450° | 0.08092       | 1.55064     | 0.34468| 0.04325   |
| Chicken 600° | 0.06587       | 1.61891     | 0.475714| 0.05072  |
| Cow 450°   | 0.06768           | 1.63598     | 0.512190| 0.05671   |
| Cow 600°   | 0.06656           | 1.67014     | 0.461573| 0.05131   |
| Commercial black carbon | 0.01029 | 0.42144 | 0.424568 | 0.00184 |

4. Conclusion

The calcination temperature on synthesized carbon from animal’s bone gave effect to morphology and particle size distribution. The increased temperature gave the effect more dense in morphology and increased the particle size of carbon. Changes in the morphology and particle size of carbon give effect to the performance of the SLC-SC where the increased morphology’s dense and particle size make decreased in the performance of the SLC-SC. The synthesized carbon from animal’s bone has a potential application in dye-sensitized solar cells (DSSC) and also can be one of the solutions to animal’s bone waste problems.
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