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Making supercapacitor carbon electrodes from lemongrass leaf biomass with variations in physical activation temperature

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ABSTRACT

Supercapacitor is energy storage device consisting of current collector, electrodes, separator, and electrolyte. Material selection and fabrication of the electrodes play an important role in improving the performance of the supercapacitor. In this research, carbon electrodes of supercapacitors were made from citronella leaves using variations in physical activation temperature. The preparation of carbon electrodes were starts from the pre-carbonization at temperature of 200℃ for 2 hours, chemical activation using 0.3 M KOH as activating agent, carbonization process using N_2 gas at temperature of 600℃ and physical activation using CO_2 gas with temperature variations of 750℃, 800℃, and 850℃. The highest of percentage density reduction at temperature 800℃ is 51.42%. Analysis using X-ray diffraction showed that the sample has a semicrystalline structure with the highest of ratio L_c/L_a and average number of microcrystalline layer (N_p) at temperature of 800℃, are 0.27 and 1.67 respectively. The highest of specific capacitance value is 122 F/g at temperature 800℃. The result show that the optimum physical activation temperature for carbon electrodes based on citronella leaves is 800℃.

Keywords: Carbon electrode; citronella leaves; physical activation; temperature; supercapacitor

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INTRODUCTION

Technological developments have progressed over time, especially in energy storage systems. Current energy consumption still relies on natural gas, coal, and fossil fuels, which are non-renewable energy sources. Renewable energy such as water, wind, and solar have many shortcomings, including intermittent costs, regional nature, and inability to be widely applied [1]. Therefore, it is necessary to develop technology in the conversion and storage of alternative energy at this time [2].

The current energy storage device that is getting the attention of all countries, including Indonesia, is the li-ion battery. However, li-ion batteries have several disadvantages, including low power density, slow energy transfer processes, and long charging times [3]. Much research has been done to find alternative energy storage devices that can be used for a long time, are cost-effective, and easy to obtain, one of which is a supercapacitor. Supercapacitors have one of the main components, namely electrodes. The optimal capacitance value of a supercapacitor is influenced by the electrodes. The electrodes are in the form of activated carbon which can be produced from biomass that have gone through chemical and physical activation processes. Biomass usually comes from organic materials such as plants, animals, and industrial waste.

Biomass that has the potential to be used as a carbon electrode in supercapacitors is lemongrass waste. Lemongrass (*Cymbopogon nardus L.*) is a grass plant that has a leaf structure like thatch [4]. Lemongrass is widely found in Asia, especially Indonesia. Lemongrass waste that has passed the harvest period is usually used as animal feed and organic fertilizer [5].

Lemongrass leaves contain quite high lignocellulose, consisting of around 28.15% cellulose, 32.22% hemicellulose and 18.78% lignin [6]. This content makes lemongrass leaves have the potential to be used as carbon electrodes in supercapacitor cells. This study focuses on the role of the influence of physical activation temperature on the density reduction and specific capacitance of the resulting supercapacitor cells.

RESEARCH METHODS

This research method explains the procedure for making carbon electrodes for supercapacitor cells made from citronella leaves. Citronella leaves are separated from the bones, then cut into 5 cm lengths and dried in the sun until constant mass. The pre-carbonization process uses an oven with a temperature of 200℃ for 2 hours and the sample is ground using ball milling for 24 hours with a rest period of 4 hours. The sample is sieved using a 53 µm sieve to standardize the particle size of the carbon powder. The chemical activation process uses 0.3 M KOH as an activating agent. The manufacture of pellets from carbon powder uses a hydraulic press with a pressure of 7.5 tons and is held for 2 minutes. The carbonization process is carried out by heating the pellets in a furnace at a temperature of 600℃ which is flowed with nitrogen gas (N_2). The physical activation process uses Carbon dioxide gas (CO_2) with temperature variations of 750℃, 800℃, and 850℃. The carbon electrode is soaked using distilled water until the pH is neutral. The manufacture of supercapacitor cells was carried out using several materials, namely carbon electrodes, current collectors, Teflon, separators (2nd layer of Softies surgical masks), and electrolytes (H_2SO_4) as much as 1 M. Each sample was subjected to density calculations and X-ray diffraction analysis, as well as electrochemical properties testing using the cyclic voltammetry method.

RESULTS AND DISCUSSION

Density Analysis

Figure 1 is a graph of the density reduction of carbon electrodes before and after the pyrolysis process. Density is related to the pores and surface area of the carbon electrode. Density reduction is caused by the evaporation of non-carbon compounds at the carbonization stage, the formation of new pores and opening old pores at the physical activation stage [2]. The density of each sample of SW-750, SW-800, and SW-850 after the carbonization-physical activation process is 0.702, 0.625, and 0.662 gr/cm^3 with a percentage of density reduction of 35.09%, 51.42%, and 42.29%, respectively. SW-800 has the lowest density compared to SW-750 and SW-850. A temperature of 800℃ is the optimum temperature for the formation of carbon pores in citronella leaf biomass. Density shrinkage is related to the porosity properties of the carbon electrode, because the lower the density, the carbon electrode will have high porosity. High porosity indicates that the carbon electrode has many pores and is able to improve the performance of the carbon electrode [7].

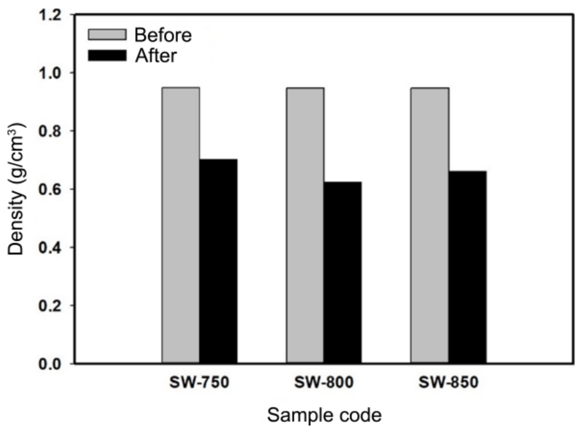

Figure 1. Graph of carbon electrode density shrinkage.

X-ray Diffraction Data Analysis

The resulting X-ray diffraction pattern is a typical activated carbon diffraction pattern, namely there are 2 gentle peaks in the diffraction angle range 2θ angle 24º – 25º with a reflection plane of 002 and an angle of 44º – 45º reflection plane 100. The two gentle peaks mark the scattering angles that correspond to the semicrystalline structure of carbon materials made from biomass [8].

The surface area of the carbon electrode is influenced by the values of L_a and L_c, the higher the L_c, the greater the surface area, because L_c is directly proportional and L_a is inversely proportional to the surface area [9]. In Table 1, the SW-800 sample has a higher Lc value of 6.10 nm and a lower La value of 22.46 nm compared to the SW-750 sample, therefore SW-800 has the highest L_c/L_a ratio and average layer (N_p) of 0.27 and 1.67.

Table 1. Interplane distance and microcrystalline dimensions of carbon electrode.

Sample code	2θ		Interplane distance		Microcrystalline dimensions		L_c/L_a	N_p
	002	100	d_{002} (°)	d_{100} (°)	L_c (nm)	L_a (nm)		
SW-750	23.26	44.98	3.82	2.01	5.16	30.37	0.17	1.35
SW-800	24.34	45.16	3.65	2.00	6.10	22.46	0.27	1.67

Cyclic Voltammetry Analysis

The cyclic voltammetry test curves of the SW-750, SW-800, and SW-850 samples with a scan rate of 1 mV/s are shown in Figure 2. The resulting CV curves have a curve and approach a rectangular shape, where this form is the ideal property of electrochemical double layer supercapacitors (EDLC) [10]. The CV curve on SW-750 has the smallest area and the CV curve on SW-800 has the largest area, this can affect the magnitude of the specific capacitance value in the supercapacitor cell. The wider the CV curve, the greater the charge-discharge current value, so the specific capacitance is high.

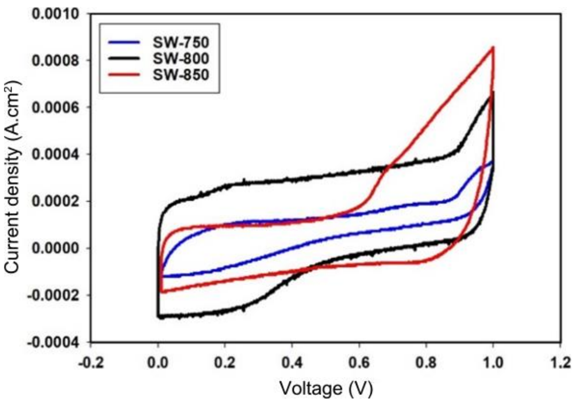

Figure 2. Cyclic voltammetry curve.

The specific capacitance values for each sample of SW-750, SW-800, and SW-850 are 29, 122, and 70 F/g. In the curve of each sample, there is a significant increase in current density. This increase in current density is due to the heteroatom content in the sample [11]. The high specific capacitance value in SW-800 is due to having the lowest density value after the pyrolysis process of the other samples. The low density value of the carbon electrode can increase porosity which indicates that there are many pores in the carbon electrode. Low physical activation temperature causes little formation of pores in the carbon electrode. While too high a physical activation temperature damages the pore structure of the carbon electrode [8, 12].

CONCLUSION

The results and discussion show that 800°C is the optimum physical activation temperature for lemongrass leaf samples. A temperature of 800°C can produce carbon electrodes with the highest density shrinkage percentage of 51.42%. The physical activation temperature of 800°C has high L_c, L_c/L_a, and N_p values so that it can increase the surface area of the carbon electrode. Analysis using cyclic voltammetry shows that a temperature of 800°C can produce a C_{sp} of 122 F/g.

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