Supercapacitor Cell Electrodes Derived from *Nipah Fruticans* Fruit Coir Biomass for Energy Storage Applications using Acidic and Basic Electrolytes

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Abstract. The performance of the supercapacitor is influenced by the pore distribution on the electrode surface and the conductivity, mobility, ion size properties of the electrolyte to achieve a high specific capacitance value. Carbon electrodes are synthesized from Nipah fruit coir (NFC) biomass through a pre-carbonization process, chemical activation by varying the molarity of KOH of 0.2 M, 0.3 M, and 0.4 M, and the pyrolysis process. The electrochemical properties of supercapacitor cells are analyzed using the cyclic voltammetry method with an electrolyte solution of sulfuric acid and potassium hydroxide which is testing through an asymmetrical two-electrode system. The results showed that the increase in the performance of supercapacitor cells occurred in the electrolyte in an acidic environment with the highest specific capacitance value of 214.31 F/g compared to the electrolyte in an basic environment with the highest specific capacitance value of 164.54 F/g. The results of the analysis of electrochemical properties indicate that carbon electrodes made from Nipah fruit coir biomass can be a suitable material for energy storage applications.

1. Introduction
Renewable energy storage devices are needed to meet the demand for high energy consumption along with rapid population growth every year and the negative impact of fossil fuels on the environment [1]. Energy storage developed from natural materials can produce a high electrochemical performance at an affordable price. Natural materials for making carbon materials such as activated carbon, metal-organic framework, and natural organic polymers have been widely used for energy storage such as supercapacitors as electrodes because they have good properties, namely high conductivity, electrochemical stability, lightweight, adjustable porosity, large surface area, economical, and environmentally friendly. Supercapacitors have superior performance compared to other devices such as high power density and energy density, fast charge-discharge rate, long cycle life (105 cycles) [2].

Materials derived from biomass materials are used to produce porous activated carbon which is applied in energy storage devices through chemical activation by activating agents such as KOH and ZnCl₂ and the carbonization process followed by physical activation with oxidizing gases such as air, steam, nitrogen, carbon dioxide [3-4]. To prepare materials with a larger surface area, high porosity, and porous structure that can be desorption-adsorption without chemical reactions through methods using chemical activation from organic materials that have a high carbon content [5-6], agricultural wastes [7], and animal waste [8] as carbon sources for supercapacitor applications.
The performance of supercapacitors is influenced by the components that make up electrochemical cells such as electrodes, electrolytes, separators, and current collectors. Electrolyte solution is a substance that dissolves or decomposes into ions that can conduct electric current well. Electrolyte solutions such as sulfuric acid, potassium hydroxide, and zinc chloride have different conductivity, mobility, and size of ions. Higher specific capacitance was obtained by using H$_2$SO$_4$ electrolyte because the smaller size of H$^+$ ions can easily be hydrated, intercalated, and accumulated into the pores of activated carbon compares to other electrolyte solutions [9].

Previous research by [1] demonstrated the manufacture of carbon electrodes made from Wisteria Sinensis seed biomass by varying the electrolyte solution, namely sulfuric acid and potassium ferricyanide, obtaining specific capacitance values of 110 F/g and 88 F/g, respectively. Researchers [10] also made carbon electrodes made from banana leaf biomass by varying the electrolyte, namely sulfuric acid and potassium hydroxide, obtaining specific capacitance values of 245 F/g and 189 F/g, respectively. Researchers [11] also made carbon electrodes made from bamboo biomass by varying the electrolyte, namely potassium iodide and sulfuric acid, obtaining specific capacitance values of 159F F/g and 200F/g, respectively. In this research, the manufacture of carbon electrodes made from Nipah fruit coir by varying the electrolyte solution of sulfuric acid and potassium hydroxide.

Nipah or *Nypa Fruticans* is one of the palm plants that grows in tidal areas and is spread almost evenly throughout Indonesia. Nipah fruit is a seasonal forest product with abundant fruit every season. Usually, people use the leaves of the Nipah fruit to make roofs and wickerwork, the sticks from the leaves are processed into brooms, and even Nipah nirah can be tapped like sugar palm. Nipah has a fruit that is flat and reddish-brown in color, where in the Nipah fruit there is a fruit skin consisting of coirs such as coir in the skin of a coconut, but the coir in the skin of the Nipah fruit are smoother. Nipah fruit coir can be a waste that can pollute the environment if left alone. Nipah fruit coir has the potential to be used as activated carbon for supercapacitor cell applications because it contains active chemical compounds of carbon, cellulose, and hemicellulose, and lignin of 58.19%, 62.35%, and 19.98% [12].

### 2. Synthesis and Characterization of Carbon Electrodes

Nipah fruit biomass which has browed is collected from the riverbank of Bengkalis, Riau, Indonesia. Nipah fruit is separated from the seeds and flattened to produce Nipah fruit coir. The Nipah fruit coir were dried in the sun for 3-4 days to a constant mass followed by a pre-carbonization processed at 200°C for 1 hour. The next process is chemical activation using KOH by varying the molarity of 0.2 M, 0.3 M, 0.4 M followed by the carbonization process at 800°C for 1h under an N$_2$ atmosphere with a heating rate 3℃ min$^{-1}$ followed and physical activation at 900°C for 2.5h under an CO$_2$ atmosphere with a heating rate 10℃ min$^{-1}$ in a horizontal tubular furnace. After the furnace is cooled to the room temperature, the sample is removed and washed with aquadest to remove residue on the carbon electrode to a neutral pH and the sample is dried in an oven at 110°C.

The physical properties of carbon electrodes consist of density measurement and X-ray diffraction characterization using the XRD Shimadzu 700 instrument with a scattering angle of 2θ using a Cu k-α light source and a wavelength of 1.5418. The electrochemical performance of the activated carbon of Nipah fruit coir was evaluated using a cyclic voltammetry system with two symmetrical electrodes. The supercapacitor cell consists of electrodes, electrolyte, separator, and current collector. The NFC carbon electrode is shaped like a circle with a diameter of 7 mm and a thickness of 3 mm which is immersed in an acidic (sulfuric acid) and basic(potassium hydroxide) electrolyte solution for 48 hours which is separated by a chicken egg membrane and the double layer charge will be stored in Stainless Steel. Cyclic Voltammetry was carried out using the Physics CV UR Rad-Far 5841 tool measured from a potential 0 to 1000 mV with a scanning rate of 1 mV/s, 2 mV/s, and 5 mV/s as shown in Figure 1.
3. Results and Discussions
Physical properties of carbon electrodes from Nipah fruit coir biomass were analyzed using density measurement and X-ray diffraction characterization. The density measurement aims to determine the density shrinkage before and after the pyrolysis process. The density value before pyrolysis is 1.235 gr.cm\(^{-3}\) and the density value after pyrolysis is 0.786 gr.cm\(^{-3}\) as shown in Figure 2a. Density shrinkage occurs because the pyrolysis process consists of an integrated carbonization-physics activation stage. The carbonization stage causes the volatile compound content at the carbon electrode to evaporate and the physical activation stage produces new pores and increases the surface area [13-14].

The resulting X-ray diffraction pattern is semi-crystalline consisting of two peaks at an angle of 2\(\theta\) about 24° and 44° indicating the direction of the (002) and (100) hkl planes, respectively as shown in Figure 2b. [15]. Based on data from the National Bureau of Standards (NBS) at 2\(\theta\) angles around 24°, 26°, 44° and 59° there are sharp peaks indicating the presence of silica compounds (SiO\(_2\)), the silica peaks are materials other than carbon and are crystalline. Based on ICDD (The International Center for Diffraction Data) data, there are a sharp peaks at 2\(\theta\) angles around 38° and 39° indicating the presence of MgO\(_2\) compounds and at 2\(\theta\) angles around 33° and 48° indicating the presence of potassium hydroxide compounds.
The electrochemical properties of supercapacitor cells were analyzed using cyclic voltammetry method with sulfuric acid and potassium hydroxide electrolyte solutions tested through a symmetrical two-electrode system. The electrochemical properties of supercapacitor cells are the specific capacitance value which is the ability of the supercapacitor cell to store charge to the mass ratio of the carbon electrode [16]. Specific capacitance is very influential on the performance of the supercapacitor. This analysis produces a voltammogram curve of voltage (V) against current density (A/cm²).

![Cyclic Voltammetry curve for activated carbon electrode Nipah fruit coir on electrolyte](image)

**Figure 3.** Cyclic Voltammetry curve for activated carbon electrode Nipah fruit coir on electrolyte (a)1M H₂SO₄ (b)1M KOH at a scan rate 1 mV/s

Figure 3 shows a Cyclic Voltammetric curve at a scanning rate of 1 mV/s for NFC carbon electrodes at different KOH molarities by varying the electrolyte solution. Based on Figure 2, it shows that the NFC-03 sample has a curve shape with a wider area than NFC-02 and NFC-04, so that NFC-03 has a higher performance capability and specific capacitance value. According to [17] the larger the area of the curve formed with the same scanning rate, the higher the specific capacitance value.

**Table 1.** Specific capacitance, energy density, and power density of supercapacitor cell electrodes from Nipah fruit coir biomass based on cyclic voltammetry method

| Code Sample | Molarity KOH (M) | Specific capacitance F/g | Energy density Wh/kg | Power density W/kg |
|-------------|-----------------|--------------------------|----------------------|-------------------|
|             | KOH H₂SO₄       | H₂SO₄ KOH                | H₂SO₄ KOH            | H₂SO₄ KOH         |
| NFC-02      | 0.2             | 186.95 125.22            | 25.96 17.39          | 93.54 62.66       |
| NFC-03      | 0.3             | 214.31 173.43            | 29.76 24.08          | 107.24 86.77      |
| NFC-04      | 0.4             | 163.57 92.67             | 22.71 12.87          | 81.80 46.37       |

Table 1 shows that the addition of the molarity of KOH from 0.2 M to 0.3 M can increase the specific capacitance in the electrolyte in an acidic environment and basic environment. On chemical activation occurs impregnation of KOH and carbon resulting elements of potassium, hydrogen and potassium carbonate [18]. Increasing the molarity of KOH causes the reaction to take place faster. The impregnation at 0.3 M molarity occurs rapidly causing elements other than carbon to evaporate and leave large numbers of pores on the surface of the carbon electrode. Evaporation of potassium carbonate will cause the formation of micropores and evaporation of potassium and hydrogen formation to form mesopores [19]. The addition of molarity higher than 0.3 M causes a decrease in the specific capacitance, this occurs because the impregnation reaction rate of KOH and carbon is very fast in an irregular manner and there is evaporation of potassium, hydrogen and potassium carbonate occurs simultaneously, leaving large pores or macropores in small quantities and can damage the physical structure of the carbon electrode [20]. The NFC-02 sample shows a lower specific capacitance than the NFC-03 sample because the concentration of KOH used is lower so that the
Impregnation reaction rate of KOH and carbon occurs slowly, which causes the potassium carbonate to evaporate to form microporous sized pore and potassium and hydrogen evaporate to form mesoporous size pore in small quantities [21]. Carbon electrodes having a large number of pores with micro-meso size can improve the performance of the supercapacitor because it can store electrolyte ions with a large capacity, meanwhile, carbon electrodes having a small number of pores with micro-meso size can reduce the performance of the supercapacitor because it store electrolyte ions with a small capacity [18]. Macropores cannot store electrolyte ion charges but serves as channel media to facilitate access to electrolyte solutions [10].

Sulfuric acid electrolyte has higher electrochemical performance than potassium hydroxide electrolyte. The sulfuric acid electrolyte has smaller H+ ions size and easily hydrated, intercalated, and accumulated into the pores of activated carbon compared to potassium hydroxide electrolyte solutions [1]. Sulfuric acid has the highest ionic conductivity which is 353.1 cm2/Ω mol compared to that of potassium hydroxide which is 73.5 cm2/Ω mol, while the size of the H+ ion is 2.8 Å smaller than K+ 3.31 Å, thus sulfuric acid is an electrolyte solution that has the highest mobility and conductivity with the size of the ion smaller one [11][18].

Based on the specific capacitance value data, we can obtain the energy density and power density values using the standard equation [22]. Table 1 shows that the value of energy density and power density at the electrodes of supercapacitor cells is directly proportional to the specific capacitance value. The electrochemical performance of a high supercapacitor cell will result a high energy density and power density, while a low electrochemical performance of a supercapacitor cell will result a low energy density and power density.

![Figure 4](image-url)

**Figure 4.** Curve of the relationship of current density to voltage for each scan rate of Nipah fruit coir sample a) NFC-02 Sample, b) NFC-03 Sample, and c) NFC-04 Sample under acidic environment.
Figure 4 shows the relationship between current and voltage density for samples of NFC-02, NFC-03, and NFC-04 with scan rates of 1 mV/s, 2 mV/s, 5 mV/s. When the scan rate value is large, the specific capacitance is small, it can be seen that the capacitance value decreases exponentially as the scan rate increases. A low scan rate causes the ions to have a long time to diffuse into the pores of the carbon electrode, meanwhile, if the scan rate is high, the ions only reach the surface of the carbon electrode [23]. Figure 5 shows the Specific capacitance value to scan rate on each samples in the electrolyte in an acidic environment.

![Image](image_url)

**Figure 5.** Specific capacitance value to scan rate on each samples in the electrolyte in an acidic environment.

4. Conclusion

Synthesis of low-cost activated carbon from Nipah fruit coir biomass through chemical activation method. The activated carbon material produced has a large number of meso pores and micro pores from impregnation of KOH and carbon in chemical activation process. The manufacture of supercapacitor cells in this study used an acid (sulfuric acid) and basic (potassium hydroxide) electrolyte solution. An increase in electrochemical performance occurred in an acidic environment electrolyte with the highest specific capacitance value of 214.31 F/g compared to in an basic environment electrolyte with the highest specific capacitance value of 164.54 F/g. The results of the analysis of electrochemical properties indicate that carbon electrodes made from Nipah fruit coir biomass can be a suitable material for energy storage applications.

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