Promising Electrode Material for Biobattery POWER: Oil Palm Front (OPF) Activated Carbon

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**Abstract**. This study aims to investigate the effect of NaOH immersion time and concentration on the activation of carbon from Oil Palm Frond (OPF), specifically focusing on the surface morphology and characteristics as the electrodes to biobattery application. The method employed involves carbonization and activation with NaOH at various concentrations: 0.5 M, 1 M, 1.5 M, 2 M, and 2.5 M, along with different immersion times of 12, 18, 24, 30, and 36 hours. Subsequently, the activated carbon is analyzed using a Scanning Electron Microscope (SEM) to observe its morphology, and the Brunauer Emmett Teller (BET) method is utilized to determine the carbon surface area. Furthermore, a voltage test uses a multimeter to assess the electric potential properties. Another outcome of this study is developing a prototype bio-battery POWER. Activated carbon from oil palm frond (OPF) testing resulted in 1 M NaOH, giving the highest surface area of 336.493 m2g-1, and immersion time at 30 hours gave the optimum result of 396,808 m2g-1. At the same time, the biobattery electrical test voltage of 0,653 V at a concentration of 1 M and 0,902 V at 30 hours of immersion.

**Keywords:** *Palm frond, Cathode, Anode, Carbon, Bio Battery.*

1. **Introduction**

Energy is important in a country when there is a significant societal need. All aspects of life, starting from household activities, transportation, agriculture, industry, and others, require energy, both in the form of primary energy (oil, gas, and coal)(Zou et al., 2016) and secondary energy (electricity, etc.)(Guney & Tepe, 2017). The use of energy can result in carbon emissions. The impact of carbon emissions on health and the environment is very difficult to avoid. Fuels containing hydrocarbons produce exhaust gases such as C, N, and other harmful gases (Kozina et al., 2020). Batteries can generate electrical energy through chemical reactions, which are then utilized in electronic devices. The energy produced by batteries is relatively clean and emits zero emissions, making batteries widely used in everyday life (Hoekstra, 2019). Batteries are a source of electrical energy that can be divided into two types: primary and secondary batteries. Secondary batteries are reusable batteries found in electronic devices, whereas primary batteries are disposable batteries, like those used in wall clocks. The components that comprise the battery, both primary and secondary, contain chemicals that can pollute the environment as they fall under Hazardous and Toxic Materials (Wang et al., 2014)

Various studies have been conducted to obtain environmentally friendly alternative batteries. One research method used to create batteries is the manufacturing of batteries from natural materials, commonly known as bio-batteries. A bio-battery is a device that functions as an electrical energy producer based on organic compounds. The currently developed bio-batteries have started to provide portable energy sources that meet the current market needs (Siddiqui, 2013). The bio-battery mechanism involves electron transport between two electrodes, separated by an electrolyte medium, to generate potential and electric current (Sudirjo et al., 2019). Bio-battery production using natural materials has been extensively explored, such as bio-batteries made from durian skin waste (Khairiah et al., 2018). Palm oil waste is one of the significant biomass potentials in East Kalimantan that can be utilized as a substitute for battery electrodes.

One part of the oil palm tree that is currently underutilized is the palm frond, which refers to the leaf stalks of the coconut plant. Palm fronds can be utilized as an ingredient for producing activated carbon, as they contain 35% carbon (Maulina & Anwari, 2018). Additionally, the carbon content of palm oil waste biomass is approximately 54% (Ameen et al., 2022). The cellulose content in palm fronds is about 50.78% (Azmi et al., 2018)(Hii et al., 2021). Indicating a high concentration of pure cellulose. This high cellulose content presents the potential for further processing of palm fronds (Szymanska-Chargot et al., 2017). One possible approach to maximize palm fronds’ benefits is converting them into activated carbon.

Activated carbon is a compound enhanced by carbon adsorption by carrying out the process of carbonation and activation. This process aims to eliminate hydrogen, water, and gasses on activated carbon surfaces so that the carbon pores are more open(Lubwama et al., 2022). The active groups are formed due to the interaction between free radical oxygen atoms and nitrogen on the surface of activated carbon.

Regarding using OPF as a primary material for electrode production, the common practice involves collecting and preparing palm frond waste. The fronds are then transformed into charcoal through the carbonization process. Subsequently, the regenerated carbon undergoes physical and chemical activation using NaOH. Finally, the activated carbon is assembled by the predetermined design.

In this study, the activated carbon derived from OPF was subjected to activation using various concentrations of NaOH and different immersion times. Furthermore, the activated carbon was examined and analyzed using Scanning Electron Microscope (SEM) and Brunauer Emmett Teller (BET) tests. Additionally, the electrical properties using a multimeter. Another outcome of this research is developing a prototype model for the POWER bio-battery.

**2. Experimental**

*2.1 Carbonization process*

Palm frond preparation is carried out by separating the frond peel, cutting, and drying. Pieces of OPF are carbonized in a muffle furnace at 500°C for 1 hour. After that, the carbon is cooled to room temperature, around 25-30°C.

*2.2 Carbon activation with NaOH concentration variation*

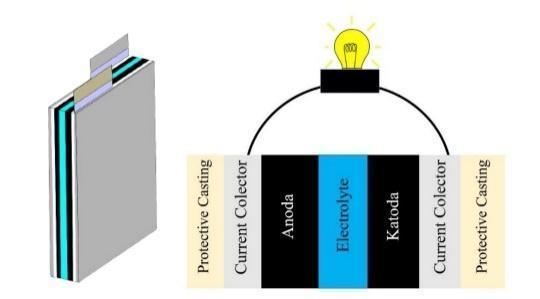
In the activation process, carbon was impregnated with NaOH activator, with variations of 0.5 M, 1 M, 1.5 M, 2 M, and 2.5 M, for 24 hours to determine the optimal concentration for the subsequent diffusion process into the interior of the carbon pores. The chemical activation solution was filtered, and the residue was dried at room temperature. Afterward, the chemically activated carbon was physically activated through pyrolysis by heating the carbon in a muffle furnace at 900℃ to enhance the pore surface of the activated carbon. Subsequently, the physically activated carbon was rinsed using HCl and then further rinsed with distilled water until the pH became neutral. The final step involved drying the obtained activated carbon in an oven at a temperature of 105℃ for 3 hours.

*2.3 Carbon activation with NaOH time immersion variation*

Impregnation was conducted using an optimum concentration of 1.5 M from the previous, with variations of immersion for 12, 18, 24, 30, and 36 hours to determine the optimal duration for the diffusion process into the interior of the carbon pores. Afterward, the chemically activated carbon was activated by heating it in a muffle furnace at 900℃ to expand the pore surface of the activated carbon. Furthermore, the physically activated carbon was rinsed using HCl and then further rinsed with distilled water to achieve a neutral pH. In the final step, the obtained activated carbon was dried in an oven at a temperature of 105℃ for 3 hours and subsequently stored in a crucible.

*2.4 Prototype design of bio-battery POWER.*

The biobattery prototype in this study consists of several components, including a protective casing, current collector, electrodes, and battery electrolyte. After the activation of the carbon, the electrode manufacturing process can be initiated. The initial step in making the electrode sheet is to create a slurry from activated carbon by adding distilled water as a solvent. Next, the Polymer Electrolyte is manufactured by mixing K2CO3 with PVA (PVA-K2CO3). This is achieved by dissolving 0.7 grams of PVA and 0.3 grams of K2CO3 in 20 mL of distilled water. The solution is stirred and heated until the temperature reaches 80℃. Once the polymer gel is prepared. Finally, all the ingredients are combined and stacked according to the scheme shown in Figure 1.

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**Figure 1 Design of the POWER Biobattery Prototype**

*2.5 Morphology and Composition Test*

The Scanning Electron Microscope (SEM) is a type of electron microscope that operates by scanning the surface using high-energy electrons in a raster pattern. SEM is used to analyze the carbon composition before and after activation and to observe the formation of pores on the carbon surface.

*2.6 Surface Area Analysis (SAA) Carbon*

SAA, also known as Brunauer Emmett Teller (BET) analysis, is a method used to determine the surface area of a solid. This test aims to calculate the surface area of each specimen based on the NaOH concentration as a variable. The surface area of the specimen can be obtained by extrapolating the curve and applying the BET equation.

1. **Result and Discussion**

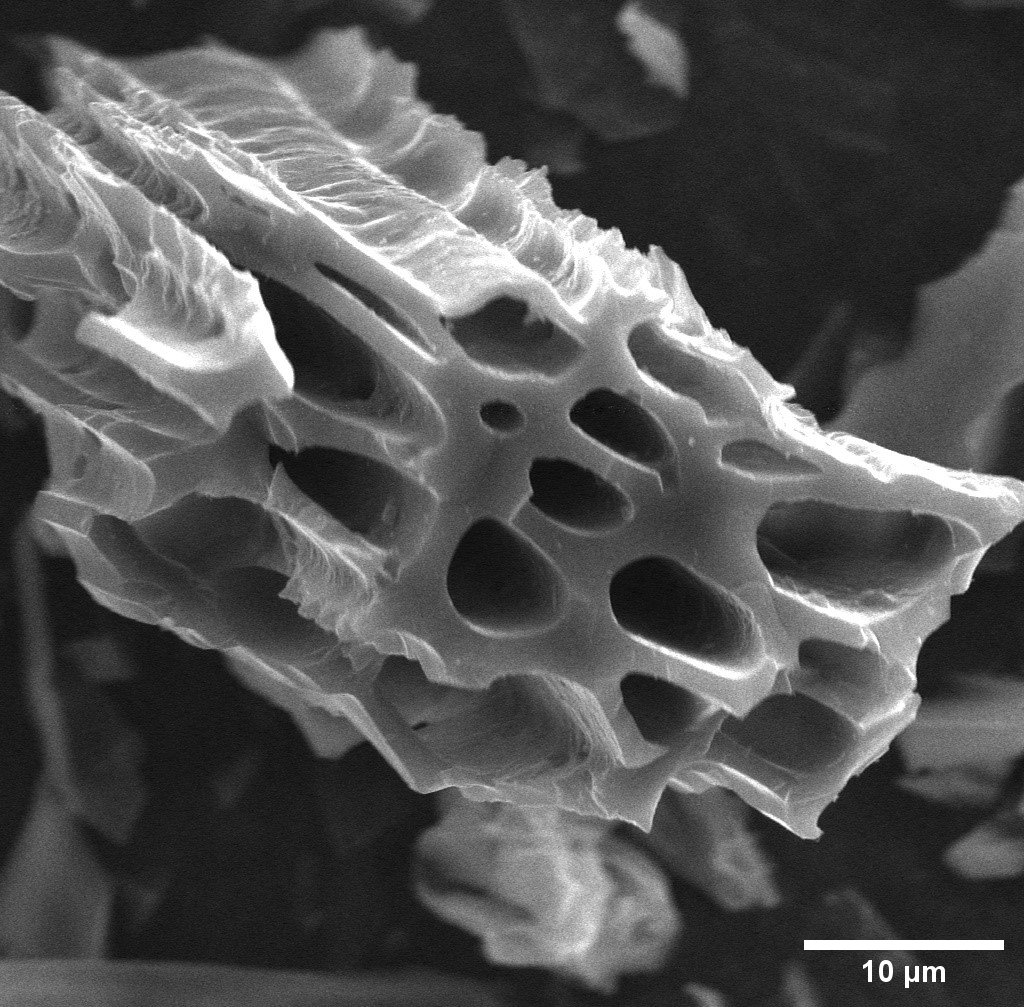
*3.1 Results of OPF carbonization*

The carbonized OPF appears black and has a brittle nature. This change is attributed to the release of volatile compound bonds from the carbon, resulting in a sample that primarily consists of carbon content. In general, the carbonization process involves the conversion of carbohydrate compounds found in OPF into carbon. The reactions that take place during the carbonization process are as follows:

|  |  |
| --- | --- |
|  | (1) |

At high temperatures, biomass OPF undergoes significant dehydration (Nizamuddin et al., 2017). In the carbonization reaction, the carbon (C), hydrogen (H), and oxygen (O) compounds present in the OPF come into contact with free oxygen from the air during the coagulation process. This reaction produces carbon compounds that are subsequently activated and utilized as materials for constructing biobattery electrodes. Throughout the carbonization process, a reaction decomposes the elements found in OPF and causes water evaporation. The elements to be elucidated include cellulose, hemicellulose, and lignin. (Fatih Demirbas et al., 2011)(Duku et al., 2011). OPF is utilized for carbon production due to its higher cellulose content compared to Empty Oil Palm Bunches and palm kernel shells (Shoaib & Al-Swaidan, 2015)(Okahisa et al., 2018). The presence of cellulose compounds in OPF results in a higher carbon weight in the final product (Haghighi Mood et al., 2013)

At a temperature of 200oC to 250oC hemicellulose decomposes. This process is marked by white smoke coming out of the chimney fireplace. Furthermore, at a temperature of 280 oC is the initial temperature of cellulose decomposition. This decomposition is terminated when the temperature is between 300oC up to 350oC. The cellulose decomposition stage is characterized by the presence of more smoke thick and dark. At a temperature of 300oC to 350oC also occurs the initial reaction of decomposing lignin where this process is characterized by the color of the smoke back thin and white which will eventually disappear. The decomposition process of this lignin compound ends at a temperature of 400oC to 500oC (Paananen & Pakkanen, 2020; Riyadi et al., 2021; Zhou et al., 2018).



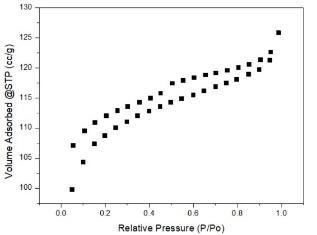
**Figure 2** Carbonization result of OPF

At a magnification of 5000x, it is observed in Figure 2 that the carbonized carbon exhibits pores. The carbon pores appear to have a large diameter and are sparsely distributed on the carbon surface. Moreover, the total area covered by carbon particles is relatively small. The spacing between the pores appears to be large and not closely packed. Therefore, additional treatment, such as carbon activation, is required to widen the pores and increase their quantity, thereby optimizing the adsorbability of the carbon.

*3.2 Results of OPF Activated Carbon with Activation Concentration and Immersion Time*

Carbon activation is a process carried out to enhance affects the absorption power of carbon, which previously had low absorption capabilities. This change occurs through both physical and chemical processes during carbon activation. The carbon activation process aims to produce carbon with a larger and wider carbon surface area or pore surface area compared to unactivated carbon (Cazetta et al., 2011)(Martins et al., 2015). During the activation of OPF carbon, several processes take place. Two important parts in this process significantly affect the increase in the surface area of OPF carbon: chemical activation and physical activation. This study used NaOH as a chemical activation agent, focusing on variations in concentration and immersion time for 24 hours. For physical activation, a furnace with a temperature of 900°C was utilized for 60 minutes (Martín-González et al., 2014).

*3.2.1 Surface Area comparison analysis of OPF Activated Carbon with Activation Concentration*



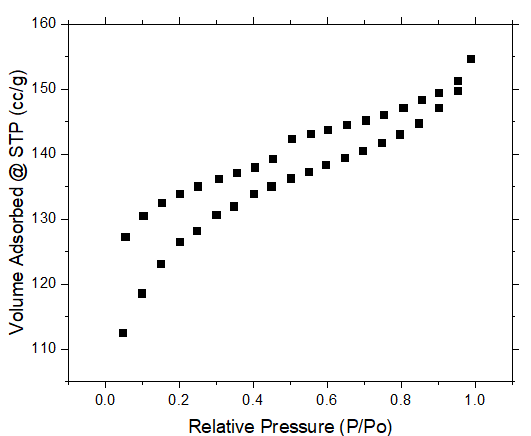
**Figure 3** Isotherm graph of concentration variation 1 M.

In the above isotherm variations, it can be concluded that the highest adsorption value of nitrogen gas on the surface of activated carbon was obtained by varying the concentration to 1 M. Thus, when using a concentration of 1 M with NaOH as the activator, the activated carbon formed had a maximal pore surface area and a high absorption capacity. According to IUPAC, the isothermal curve type of the five materials is a combination of types I and IV. This indicates that these materials possess both a microporous and mesoporous structure simultaneously.

**Table 1** Carbon surface area variation concentration

|  |  |
| --- | --- |
| **Sample** | **Surface area (m2.g-1)** |
| 0.5 M | 263.879 |
| 1 M | 336.493 |
| 1.5 M | 111.556 |
| 2 M | 89.779 |
| 2.5 M | 75.036 |

In Table 1, it can be observed that the lowest surface area value of 75.0357 is obtained from a concentration of 2.5 M. This is followed by concentrations of 2 M, 1.5 M, and 0.5 M. In contrast, the activated carbon with the highest surface area value of 336.49 m2g-1 is obtained from a concentration of 1 M. The carbon surface area values shown exhibit significant differences. There is an increase in value from a concentration of 0.5 M to 1 M, followed by a gradual decrease in value from a concentration of 1 M to 2.5 M. The decrease in surface area is attributed to the increasing concentration of NaOH. This observation is supported by research that states that an increase in the activating agent concentration enhances the surface area value of the precursor carbon, but excessive concentrations of the activator will reduce the surface area of the activated carbon (Borghei et al., 2021).



**Figure 4** Isotherm graph of immersion time 30 hours

Among the five types of variations, it can be concluded that the highest adsorption value of nitrogen gas on the surface of activated carbon was obtained after 30 hours of immersion Figure 4, with a value ranging from 150 to 160 cc/g. This means that when carbon is immersed in a NaOH activator for 30 hours, the maximum surface area of the formed pores and the absorption capacity of the resulting activated carbon is significantly high. The adsorb isotherms are classified into six types, and type IV isotherms represent the adsorption of water molecules on carbon. Generally, the isotherm graphs for all five variations exhibit a type IV isotherm. This type of isotherm occurs when both micropores and mesopores are in the carbon structure (Muttakin et al., 2018)

**Table 2** Carbon surface area variation of immersion time.

|  |  |
| --- | --- |
| **Sample** | **Surface area (m2.g-1)** |
| 12 Hours | 60,0668 |
| 18 Hours | 250,525 |
| 24 Hours | 254,958 |
| 30 Hours | 396,808 |
| 36 Hours | 377,228 |

The highest value for carbon surface area was obtained after 30 hours of immersion time, while the lowest surface area was obtained after 12 hours of immersion time. The increase in carbon surface area is usually caused by the evaporation of compounds contained in the material. This evaporation leads to the formation of pores on the carbon surface (Jeong et al., 2016). The pore volume helps determine the amount of nitrogen gas absorbed on the surface of the activated carbon from OPF. Among the five samples, it can be concluded that the sample with a 30-hour immersion variation had the highest surface area, specifically 396,808 m2.g-1. Based on these data, it was concluded that soaking the carbon with the NaOH activator for 30 hours was the optimal activation time because a larger surface area of carbon pores results in stronger carbon absorption.

Activated carbon can have a surface area of 300 m²/g or higher. For example, a study reported the preparation of activated carbon from pea peels by chemical activation with zinc chloride, which had a surface area measured by the Brunauer-Emmett-Teller analyzer (BET) of not specified value but was confirmed to be a very good adsorbent for efficient removal of Cr (VI) (Sahlabji et al., 2022). Another study reported the synthesis of a carbon-based nanoscale material with a unique highly porous structure, which had a BET-estimated specific surface area of 3167 m²/g [(Shulga et al., 2021).](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8156701/" \t "_blank)

3.2.2 *Comparative analysis of OPF morphology Activation Concentration and Immersion Time*

|  |  |
| --- | --- |
| (a) | (b) |
| (c) | (d) |
| (e) | |

**Figure 5** Scanning Electron Microscopy Test Results of Concentration Variations (a) 0.5 M, (b) 1 M, (c) 1.5 M, (d) 2 M, (e) 2.5 M.

Based on Figure 5, the results of activated carbon morphology can be determined, and the formed pores on the surface area of activated carbon can be observed. The activation process with a concentration variation of 0.5 M NaOH. As can be seen, pores are formed, but the number of pores formed in the activated carbon is insignificant. In Figure (5 b), the morphology results of activated carbon with a concentration variation of 1 M, which is the optimal concentration resulting in the largest surface area, show an increase in the number and size of pores compared to the previous concentration in the activated carbon. This indicates that increasing the concentration in the chemical activation of carbon can increase the surface area and the number of pores. This is also supported (Han et al., 2020), who stated that increasing the activator concentration in the chemical activation of carbon can enhance the pores in activated carbon.

In Figures (5 c), (5 d), and (5 e), pores are also formed; however, as the concentration used as a carbon activator increases, the formed pores become more damaged and covered by surface deterioration. Therefore, it can be concluded that excessive use of the activator can lead to the degradation and destruction of the surface area and form pores. This aligns with the findings (Han et al., 2020), as they stated that increasing the concentration in the activation process can enhance the surface area and the number of pores in activated carbon. Excessive concentration can result in the deterioration of the activated carbon's pore surface.

The carbon content in each concentration variation can be observed for both chemical and physical activation processes. The difference in carbon content is due to the temperature in the physical activation process. The activation process in carbon can trigger the release of other elements from the structure. Among the five tested variations, the highest content obtained is carbon (C). According to (González-García, 2018), the more carbon content produced, the more pores formed, increasing the surface area. Based on the above analysis, it can be concluded that the activated carbon from OPF with NaOH concentrations above 0.5 M and below 1.5 M, specifically at 1 M concentration, will result in more evenly distributed pores in the activated carbon and a diverse range of pore sizes on the carbon surface. The morphology analysis indicates that the highest number of pores is achieved at a concentration of 1 M, supported by a surface area measurement of 336.49 .

|  |  |
| --- | --- |
| (a) | (b) |
| (c) | (d) |
| (e) | |

**Figure 6** SEM-EDX Testing Results of Immersion Time Variations (a) 12 hours, (b) 18 hours, (c) 24 hours, (d) 30 hours, (e) 36 hours.

The SEM results in Figures 6a, 6b, 6c show the formation of pores. However, the resulting pore is small when compared to the pore surface images of other variations. In addition, the pore surface is clogged with broken carbon particles and impurities. According to a study, this was caused by activator activity during the activation process, where the short soaking time resulted in activation only occurring on the carbon surface (Han et al., 2020) Other studies have shown that the surface of activated charcoal is still covered with non-carbon molecules that change its absorption. The ash produced when the carbon is physically activated is the origin of impurities between the carbon surfaces. Air is carbonized in the furnace, which ultimately leads to additional oxidation of minerals from the raw material, possibly contributing to the presence of ash. The ability of activated carbon to absorb will decrease due to high ash content (Ayoola et al., 2022; Li et al., 2016).

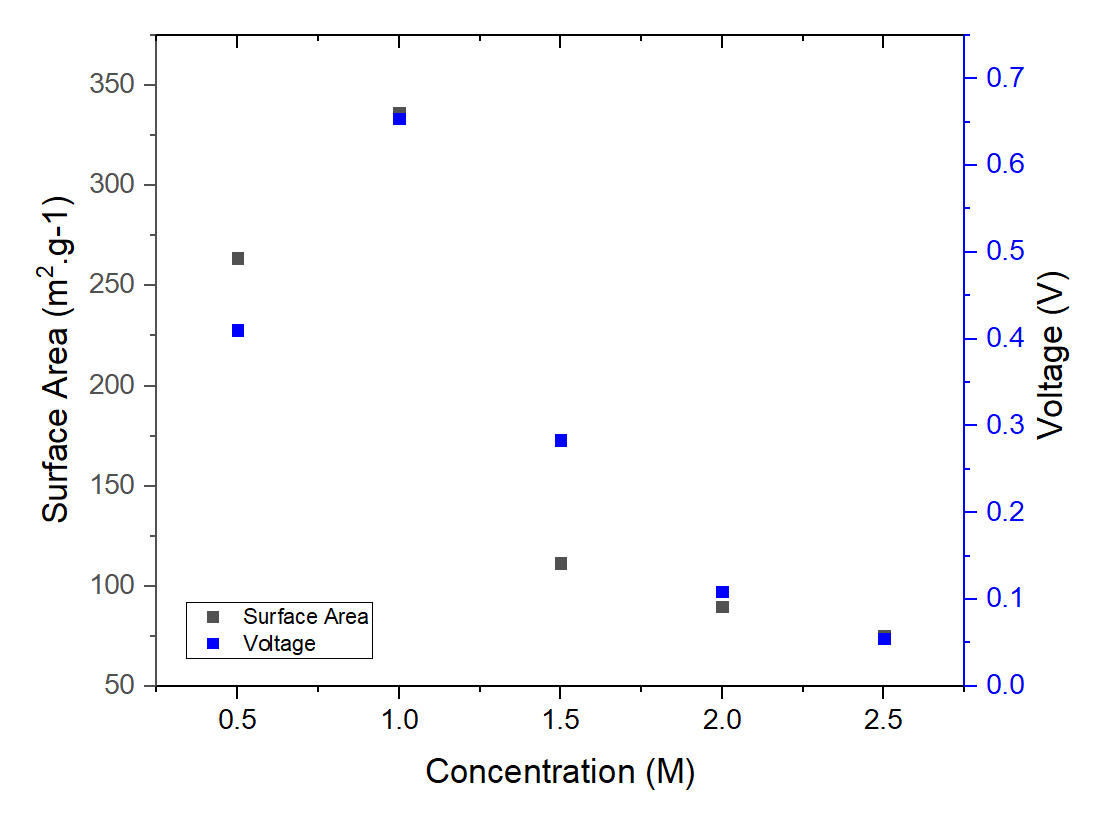
In Figure 6d with 30 hours of immersion time, it can be seen that the activation process with NaOH has an effect on the carbon of the palm fronds. In this figure it can be seen that 30 hours of immersion gives a small pore shape and a carbon form with a large surface area. From Figure 6e, with the carbon immersion time of 36 hours in NaOH solution, it can be observed that large and homogeneous pores are formed. The carbon surface image is almost similar to the carbon image at 30 h immersion. However, there is decay on the carbon edge due to too long soaking time. The other research confirmed that the activation time affects the absorption surface area of activated carbon. If the activation time is too long, it is likely that the carbon has reacted completely, conversely, if the activation time is too short, the carbon may not have reached its optimum condition (Ahmad et al., 2014).

From the five SEM test samples, it can be seen that the length of NaOH immersion with variations of 12, 18, 24, 30, and 36 hours affects the morphology of activated carbon OPF. The best morphology is found in activated carbon with 30 hours of NaOH immersion. Visible carbon surface that has many pores and a large carbon surface area. While the lowest morphology obtained on activated carbon samples is owned by samples with a 12-hour NaOH immersion where the pores formed are not perfect, and there is decay at the edges of the carbon. Pores formed are the same size and homogeneous. The edges of the carbon are also not damaged due to the 1 M NaOH activator, which makes the pores closed by impurities (Evelina et al., 2018).

The SEM-EDX test results of soaking time variations show that the amount of carbon content increases after activation. The highest carbon element was obtained in the 30-hour immersion variation with a carbon content of 97.60%. Activated carbon in OPF increases after activation because the activation process aims to increase the adsorption power of activated carbon by removing hydrogen, water, and gases on the active surface and resulting in physical changes (Y. Wang et al., 2021).

* 1. *Analysis Measurement Bio-battery POWER Voltage Activation Concentration and Immersion Time*

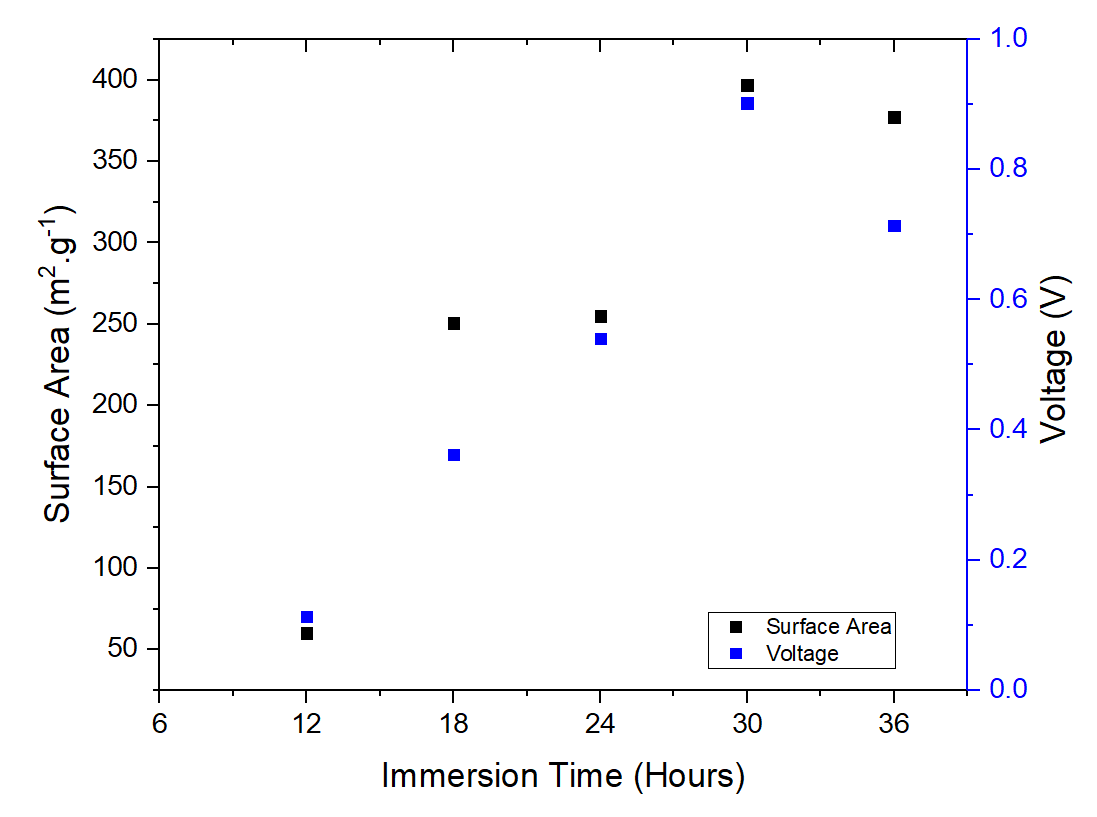
A concentration of 1 M, which is 0.653 V, followed by 0.5 M with a voltage of 0.410 V. As the concentration increases from 1.5 M to 2.5 M, the voltage gradually decreases, reaching its lowest value of 0.055 V at a concentration of 2.5 M. Therefore, it can be observed that the amount of stress produced is directly proportional to the surface area of the activated carbon used in manufacturing POWER biobattery electrodes. This is because the surface area of the activated carbon, which serves as the electrode’s base material, significantly increases the voltage output. The potential difference that occurs induces an attraction between opposite charges, causing ions in the electrolyte to diffuse through the separator and enter the pores of the oppositely charged electrode. As a result, the energy stored in the electrode is influenced by the specific surface area of the activated carbon (Saikia et al., 2020).



**Figure 7** Graph of the effect of variations in concentration on surface area and electrode voltage.

In Figure 7, it can be observed and known that increasing the concentration, which serves as a chemical activator, can affect the surface area and the resulting stress. It is evident that the surface area of activated carbon is directly proportional to the resulting voltage value. Therefore, a greater surface area of activated carbon leads to a higher voltage produced by the bio battery, whereas a lower surface area of activated carbon results in lower stress generated. Thus, it can be concluded that the high and low biobattery voltage is influenced by the surface area of activated carbon. This finding aligns with the research, which demonstrates that the energy generated by the electrodes is affected by the surface area of activated carbon (Bhattacharjya & Yu, 2014)

The results of the POWER bio-battery voltage test, which contains data on the voltage obtained from bio-batteries with electrodes made from activated carbon derived from palm oil fronds, with variations in NaOH soaking time. The highest voltage of 0.902 V was obtained by immersing NaOH for 30 hours, while the lowest voltage was produced by biobatteries with carbon soaked for 12 hours in the activator solution.

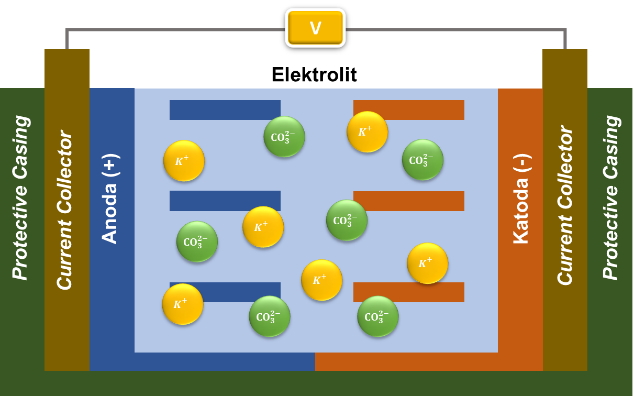


**Figure 8** Graph of the effect of immersion time on the surface area and electrode voltage.

The high and low voltage of the biobattery is influenced by the surface area of the carbon. This finding is consistent with research that demonstrates the impact of the surface area of activated carbon on the energy generated by the electrodes (Jin et al., 2014). In Figure 8, it is evident that the immersion time affects the surface area and the resulting stress. The surface area of activated carbon can be observed to be directly proportional to the generated voltage value. A higher carbon surface area leads to a higher voltage generated by the biobattery. Conversely, a lower surface area of activated carbon generates lower stress.

* 1. *Bio Battery POWER Mechanism*

The schematic of the Biobattery in Figure 9 illustrates the movement of electrons to generate electricity. The carbon electrodes in biobatteries do not produce electricity or react with other elements. However, the carbon electrodes are inert and serve as a means of storing battery power. Sodium chloride (NaCl) is added to the electrode used to create a potential difference, with the electrode acting as the cathode. This potential difference causes the movement of electrons from a high potential to a low potential. The following is the reaction that occurs in the POWER biobattery to produce an electric current.



**Figure 9** Bio Battery POWER Mechanism

|  |
| --- |
| Electrolyte: |
| Cathode: |
| Anode: |
| Reaction: 6 |

The carbon electrode that acts as an anode will degrade the cathode with the solid electrolyte PVA-K2CO3. The electrolysis reaction that occurs in the battery is the breakdown of the K2CO3 electrolyte to produce and . Ions. The reaction that occurs at the cathode is seen from the + ions in the electrolyte, namely cations. However, ions cannot react; therefore, what reacts at the cathode is water. While the reaction that occurs at the anode is seen from the electrode used. The electrode used in this reaction is carbon. The carbon that acts as an electrode is inert, so it does not react. Therefore, the compounds that react at the cathode are water molecules (). If this reaction continues, the anode will completely degrade in the electrolyte, and the battery will run out of power.

1. **Conclusion**

Based on the Scanning Electron Microscope (SEM) test, the manufacture of activated carbon made from OPF with a concentration of 1 M and a soaking time of 30 hours produces a carbon appearance that has many pores and contains carbon elements as much as 99.05% and 97.60%. Based on the Brunauer Emmett Teller (BET) test, the variation of 1M concentration and 30 hours of immersion resulted in a carbon surface area of 336,493 and 396,808 . Based on the pore volume and adsorption power, OPF activated carbon is included in the micropore and mesopore groups. Based on the electrical voltage test of the POWER biobattery with electrodes made from OPF carbon, it is known that the highest voltage produced is 0.653 V with a variation of 1 M and 0.902 V with a variation of 30 hours NaOH immersion.

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The authors declare no conflict of interest.

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