The use of a battery as a power supply for small electronic devices, such as camera, laptop, and handphone, with a wireless sensory network, is currently being developed. Besides, climate change keeps on worsening because of the use of fossil fuel emitting carbon and increase in global warming. However, due to climate change, many have sought alternatives to reduce carbon emissions. Therefore, the use of environmentally friendly material such as bamboo is essential. The generation of electrical energy in this study used bamboo-based activated carbon as an electrode, which was put between counter electrodes. The electrical energy was generated from a system consisting of a counter electrode – electrode – counter electrode. Three types of counter electrode tested were copper, aluminum, and aluminum foil. An electrolyte was injected between the electrode and counter electrode before being heated. The electrolyte tested was distilled water. The electrostatic force was generated by water electrolyte ions toward the poles of functional groups, the electrical charge of the pores, and electron mobility in the counter electrode; so, the release of electrons occurred. The result shows that the highest thermal sensitivity of the electrical voltage (dV/dT) was generated by aluminum 64.043 mV/°C, followed by aluminum foil 63.578 mV/°C and copper 6.136 mV/°C. This is because the electron mobility in aluminum was higher while the phosphorus content of the aluminum foil tends to attract electrons, inhibiting the release of electrons. The electrical voltage generated was effective when above the temperature of T=45 °C. This is because the hydrogen bond of the water molecule was weakened, causing the ions to become easily attracted to the activated carbon surface inducing more release of electrons

Keywords: bamboo activated carbon, counter electrode, water, thermal, functional group, voltage

UDC 677
DOI: 10.15587/1729-4061.2020.213099

DEVELOPMENT OF VOLTAGE GENERATION USING BAMBOO-BASED ACTIVATED CARBON WITH WATER ELECTROLYTE IN THREE TYPES OF ELECTRODES

Si Putu Gede Gunawan Tista
Doctoral Student in Mechanical Engineering*
E-mail: gunawantista@unud.ac.id
Eko Siswanto
Doctorate in Mechanical Engineering*
E-mail: eko_s112@ub.ac.id
Mega Nur Sasongko
Doctorate in Mechanical Engineering*
E-mail: megasasongko@ub.ac.id
I Nyoman Gede Wardana
Professor in Mechanical Engineering*
E-mail: wardana@ub.ac.id
*Department of Mechanical Engineering
Brawijaya University
Jl. Mayjend Haryono, 167, Malang, Indonesia, 65145

Received date 02.10.2020
Accepted date 16.11.2020
Published date 09.12.2020

1. Introduction

Activated carbon material, such as in batteries [1], is widely used to generate electricity. However, due to climate changes, many have sought alternatives to reduce carbon emissions [2, 3]. Carbon emissions are the result of the use of fossil fuel, which continues to diminish [4, 5] and increase global warming [6, 7]. Therefore, the use of environmentally friendly materials such as bamboo has become necessary.

The use of thermoelectric material to convert heat energy into electrical energy works well at a high temperature (>350 °C); while in a heat source with a low temperature (<130 °C), the conversion efficiency is low [8]. Besides, the fact that a battery is used as a power supply for small electronic devices (e. g., camera, laptop, and handphone) necessitates the power to be in milliwatt (mW) up to microwatt (μW) for a wireless sensor network [9, 10]. Therefore, materials with high thermal sensitivity and a high specific surface area (100–1,000 m^2/g) that are also environmentally friendly are very needed [11]. One of the materials matching such needs is bamboo-based activated carbon. Carbon pores are widely used for conversion of heat energy into electrical energy thanks to the good electrical conductivity, so it is suitable to be used as electrode material [12]. Carbon pores include carbon nanotubes, graphene, and activated carbon [13]. The process of making activated carbon that is by heat treatment is to remove the oxygen content from the functional groups so it can be more reactive [14]. An electrolyte is needed in the electron-releasing process; one of the types of electrolyte is water. Ions from the water electrolyte interact with functional groups, the pores of activated carbon and counter electrode. This agrees with the work [15].

Therefore, this research generates electricity using bamboo activated carbon nanoparticles with nano-pores as electrodes while copper, aluminum, and aluminum foil were used as counter electrodes. Water was used as the electrolyte for this system.

2. Literature review and problem statement

Several studies, which have converted heat energy into electrical energy use carbon nanopores, such as in the paper [16]. In the research, two electrodes of carbon nanopores are immersed in the electrolyte solution of sodium chloride and placed at different temperatures to convert the heat energy into electrical energy. Every sandwich consists of the copper film (counter electrode), porous polymer membrane separator, and nanoporous carbon disk (electrode). The result shows that with the temperature increase of around 35°C the output voltage is more than 100 mV. It appears that the voltage generated is still small so that it cannot significantly increase efficiency. The method used is by soaking two sandwiches with electrolytes, making it impractical. Moreover, the research conducted by [17] uses a Thermally Chargeable Supercapacitor (TCS) system to generate electrical energy from the uniform temperature field of a changing glow-level heat source. TCS consists of two identical electrodes immersed in the electrolyte solution of sodium acetate. The electrode is from nickel carbon nanotubes and nanoporous carbon coated with nickel. The counter electrode is pure nanoporous carbon. The generated output voltage is around 100–160 mV at the temperature of around ~50 °C. It appears that the voltage obtained is still small so that it has not significantly improved efficiency. The method used is by soaking TCS with electrolytes, so it is impractical because the temperature increase and the voltage increase take a long time.

Research conducted by [18], which converts heat energy into electrical energy uses a TCS system. In TCS, half supercapacitors (HSC) are placed at different temperatures and connected through a salt bridge. Every HSC consists of a nanoporous electrode coated with nickel and immersed in an electrolyte solution. The result shows that the specific energy per thermal cycle per each gram of electrode mass is ~1.8 mJ with a temperature difference of 50 °C. The specific energy obtained is still small, so that it does not significantly increase efficiency. HSC is immersed in an electrolyte solution, so it is impractical and takes a long time to increase the output voltage. Furthermore, research conducted by [19] utilizes electrokinetic effects from the electric-thermal nanogenerator to harvest thermal energy. In the nanogenerator, water flow is driven by evaporation in the porous medium with a small temperature gradient. The result shows that with a piece of porous carbon film and deionized water, a voltage of 0.89 V at the temperature difference of 4.2 °C is generated. It has a pseudo-Seebeck coefficient of 210 mV×K^{-1}. The large pseudo-Seebeck coefficient gives the nanogenerator sufficient power output to power electronic devices directly. It appears that the resulting stress is relatively high, but the method used by soaking the carbon is less practical, so it takes a long time to reach such a temperature and stress.

From the above elaboration, the method used is by immersing in electrolytes. However, there is no research fundamentally discussing the electron-releasing process on functional groups, pores, and the counter electrode. In the process of making activated carbon using heat treatment, the oxygen content is removed from the functional groups on the activated carbon surface so the more reactive carbon surface will emerge. As a result, the pores are electrically charged. Therefore, when being given water electrolyte, there will be an electrostatic force among functional groups, the pores on the activated carbon surface, counter electrode and the ions from the electrolyte. Water electrolyte at a high temperature, with the hydrogen bond of the water molecule being weakened, causes the ions to be more easily attracted to the activated carbon surface. Hence, it releases electrons easily. Meanwhile, at a low temperature, the hydrogen bond of the water molecule is still strong, so the ability to release electrons is little. Therefore, due to the uniqueness of the active carbon characteristics, it is hard to explain mechanically, and such uniqueness can only be explained molecularly. The focus of this research is to examine the effect of the use of water electrolyte toward the electrical voltage generated by giving thermal energy. A variation of counter electrodes was obtained from a model, including aluminum, aluminum foil and copper. The method used was by injecting electrolytes between the electrode and the counter electrode.

3. The aim and objectives of the study

This research aims to generate high power in a cheap, easy and environmentally friendly way.

The objectives of the study are formulated as follows to achieve the above aim:

– to create a voltage generation model that is composed of a counter electrode-electrode-counter electrode. The electrode material is bamboo activated carbon while the counter electrode is varied: aluminum, aluminum foil, and copper;

– to inject water electrolyte into the voltage generation model, namely between the electrode and the counter electrode so that there is an interaction between the electrolyte, activated carbon, and the counter electrode for electron release;

– to apply heat to the voltage generation model to accelerate electron release and increase electron mobility.

4. Materials and methods of research

4. 1. Making bamboo-based activated nanocarbon

Bamboo was used as the basic material of activated carbon. The process of making activated carbon was through physical treatment such as carbonization and activation [20]. The process of making bamboo-based activated nanocarbon material is shown in Fig. 1.

Fig. 1. Process of making bamboo-based activated carbon

The bamboo was cut into small pieces and dried in the sun for ten days. Then, the carbonization process was carried out by heating the sample in an electric furnace to a temperature of 700 °C for an hour; the result is charcoal. To become powdered charcoal, it was ground. It was further sifted with a 200 mesh to get a smaller powder size. A ball mill was then used to obtain the size on the nanoscale, which was processed for 1 million cycles. The activation process for pores formation includes the nanoscaled material being reheated to a temperature of 800 °C for an hour. Nitrogen gas (N_2) was streamed with a gas flow rate of 50 ml/minute, and the heating rate is 10 °C/minute.

4. 2. Characterization of activated carbon

The morphology of the bamboo-based activated carbon surface was obtained from a Scanning Electron Microscope (SEM) test using a machine called FEI INSPECT S50. The surface structure of the bamboo-based activated carbon was processed using Image J software. The elemental content of the bamboo-based activated carbon was obtained from the Energy Dispersive X-Ray Spectroscopy (EDX) test. The type of functional groups of the bamboo-based activated carbon bamboo was obtained through the Fourier Transform Infrared Spectroscopy (FTIR) test, using the FTIR testing machine named Shimadzu IR Prestige 21/FTIR 8400.

4. 3. Making electric energy generation model

Bamboo-based activated carbon used as electrodes has a size of 19–32 nm. According to the Brunauer-Emmet-Teller (BET) test, it also has a specific surface area of 172,493 m^2/g and an average pore diameter of 2.70782 nm. 0.052 g of bamboo-based activated carbon as an electrode was attached to the surface of aluminum, aluminum foil and copper counter electrodes. In this research, three models of electrical energy generation were tested. Those are 1 – aluminum-bamboo-based activated carbon-aluminum; 2 – aluminum foil-bamboo-based activated carbon-aluminum foil; 3 – copper-bamboo-based activated carbon-copper. The size of bamboo-based activated carbon attached to the surface of the counter electrode is 25×25 mm, while the effective size is 25×15 mm. The counter electrode has a size of 50×25×0.3 mm. Meanwhile, the electrolyte used is a distilled water solution. Electrolyte with a volume of 0.2 ml was injected into the model using a syringe.

4. 4. Experimental apparatus

The data collection process can be described based on the installation scheme from the experimental apparatus, as shown in Fig. 2.

Water electrolyte was flowed into the model using a syringe with a volume of 0.2 ml. Then, it was heated using an electric heater with an input power of 800 W, which was placed 1 cm below it. Meanwhile, the heating rate is 3.3 °C/s. The temperature of the heat source surface and the bottom surface of the models was measured using a type K thermocouple with a diameter of 0.3 mm. The thermocouple was connected to a data logger with an Advantec brand, product type of 127 USB-4718 and a sampling frequency of 1 kHz. The data were then stored in a computer and processed using the Excel software. A digital multimeter equipped with a data logger was used to measure the voltage. Multimeter with the product type of MS8250C has been calibrated using the transportable tool of calibrator 9,000 series. The difference in the voltage of one wire was connected to the electrode, and the other cable was to the counter electrode, then connected to the multimeter.

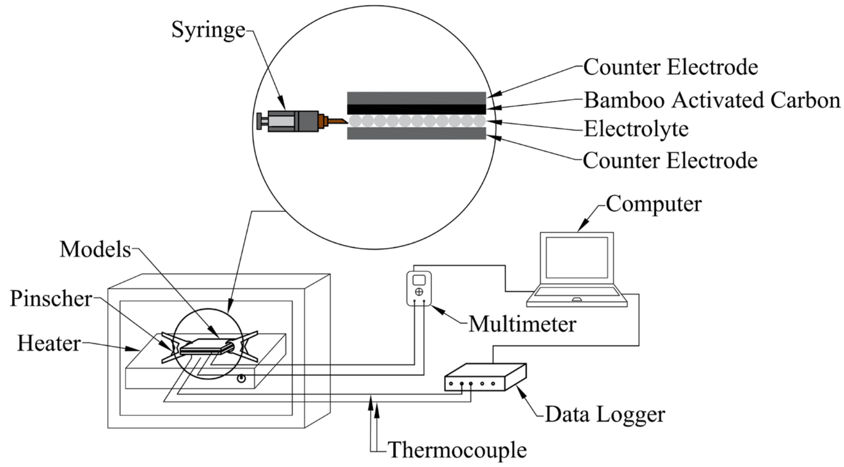


Fig. 2. Installation scheme of experimental apparatus

5. Results of voltage generation using bamboo-based activated carbon with water electrolyte in three types of electrode

5. 1. Results of SEM and EDX tests on bamboo-based activated carbon

Fig. 3 is the results of SEM and EDX tests on the bamboo-based activated carbon. At 200000x magnification, cracks appear on the surface called nano crack [21], as shown in Fig. 3, *a*. Processing using Image J software shows the surface structure of the bamboo-based activated carbon is in the form of mountains, as shown in Fig. 3, *b*. The process of releasing electrons occurs in the surface structure when it contacts with water.

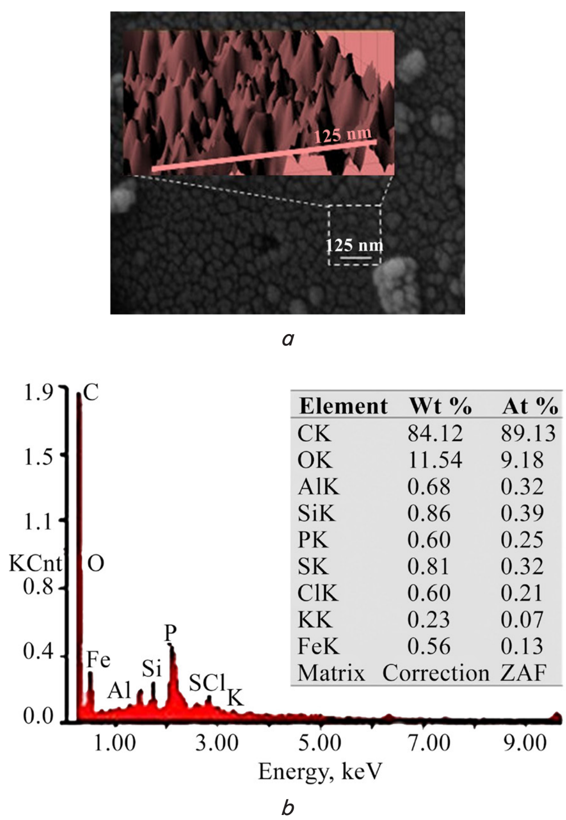


Fig. 3. Results of SEM and EDX tests on the bamboo-based activated carbon: *a* – surface morphology and 3D surface structure; *b* – elemental content of activated carbon

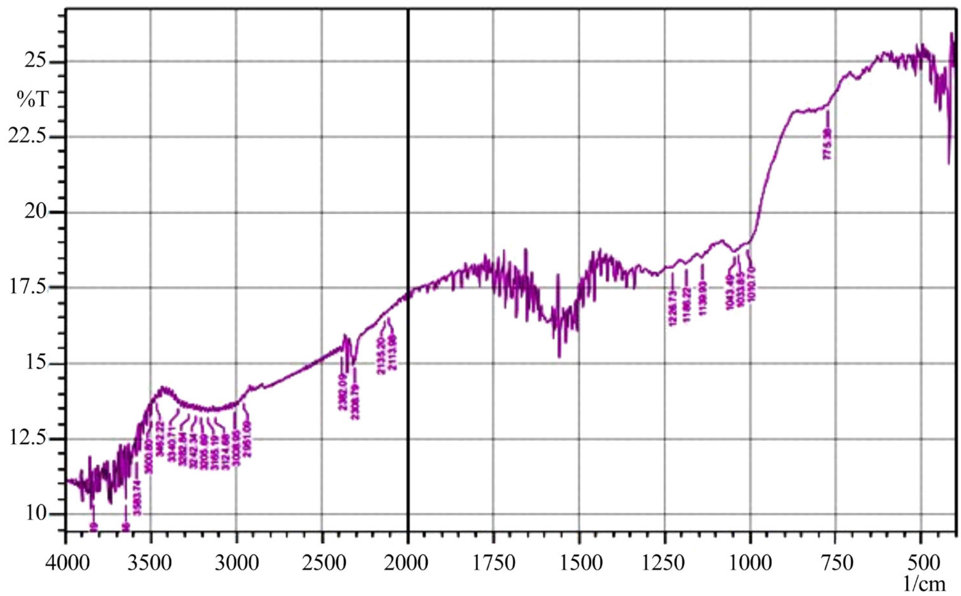
Based on the Energy Dispersive X-Ray Spectroscopy (EDX) test, it is found that the elemental content of the bamboo-based activated carbon is as shown in Fig. 3, *c*. The percentage content of the element carbon (C) is quite high, namely 84.12 %, the oxygen content (O) is 11.54 % and other elements are in a small percentage.

5. 2. Result of FTIR test of the bamboo-based activated carbon bamboo

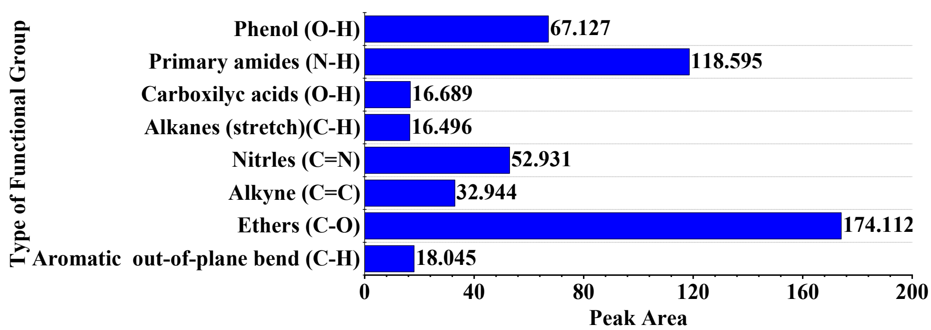
The type of functional groups of the bamboo-based activated carbon bamboo obtained from the FTIR testing machine is shown in Fig. 4, *a*. The type of functional group is estimated based on the wavenumber as shown in Fig. 4, *b*. Their molecular geometry and their position on the carbon surface are shown in Fig. 5, *a*, *b*, respectively.

In Fig. 4, *a*, each wave crest on specified transmittance represents a particular functional group. Crest at 775.38/cm represents the functional group of C-H aromatic out-of-plane bend. Then, crests from 1010.7 to 1226.73/cm belong to the functional group of C-O ethers. Crests at 2113.98 and 2135.2/cm belong to the functional group of C≡C alkyne. Crests at 2308.79 and 2382.09/cm belong to the functional group of C≡N nitriles. Then, crests at 2951.09 and 3008.95/cm belong to the functional group C-H alkanes (stretch). Crest at 3008.95 belongs to carboxylic acids. Crests from 3124.68 to 3466.22/cm belong to the functional group of N-H primary amides. Crests from 3500.8 to 3834.49/cm belong to the functional group of O-H phenol. In total, there are eight functional groups on the bamboo-based activated carbon, as shown in Fig. 5, *a*. The positions of the functional groups are scattered on the activated carbon surface, as shown in Fig. 5, *b*.

Meanwhile, the spread of the peak area of the functional groups is shown in Fig. 4, *b*, where the largest peak area is on the ether functional group. Hence, the most frequently emerged functional group is ethers. Therefore, the elaboration on the electron-releasing process is conceptually built based on the ether functional group in the discussion section.

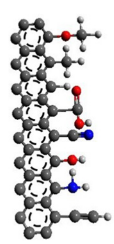


a

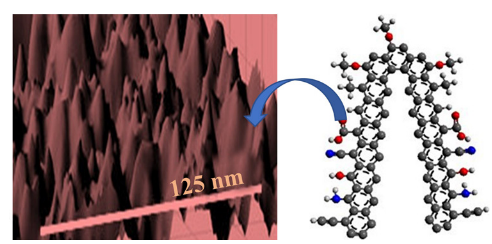


b

Fig. 4. Functional groups on the bamboo-based activated carbon surface: *a* – wave crests on specified transmittance from the FTIR test results; *b* – peak area of functional groups



a



b

Fig. 5. Functional groups on the bamboo-based activated carbon surface: *a* – type of functional groups; *b* – position of functional groups

5. 3. Results of voltage generation using bamboo-based activated carbon with injecting water electrolyte into the models and providing heat

In Fig. 6, the voltage difference of the aluminum, aluminum foil, and copper counter electrodes can be seen increasing as both the heating time and the temperature increase. At the initial stage until t=12 seconds, the voltage difference on the counter electrode of aluminum foil was a little higher than that of aluminum while on copper, it was much lower. But after that, the voltage of aluminum was higher. On the aluminum counter electrode, the voltage difference generated increased significantly for 8 seconds (i. e., from t=32 seconds to t=40 seconds). On copper, the voltage difference increase was slow for 40 seconds. While the rise in temperature occurred significantly for 40 seconds.

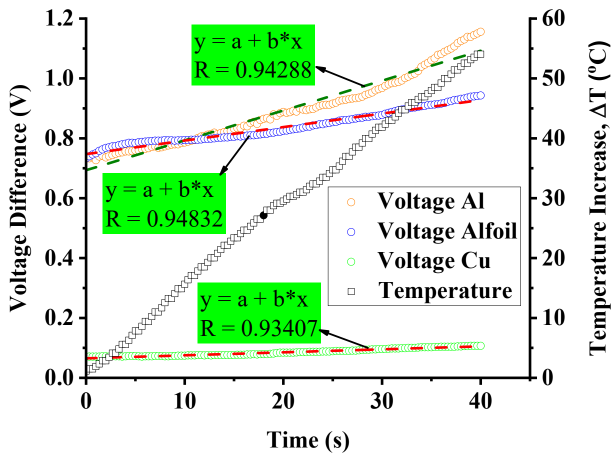


Fig. 6. Voltage difference and temperature increase at counter electrodes (i. e., aluminum, aluminum foil, and copper)

Afterwards, Fig. 7 shows that when the temperature increases (ΔT), the voltage difference generated by aluminum, aluminum foil and copper counter electrodes increases. ΔT is the temperature increase of the lower surface of the models from room temperature.

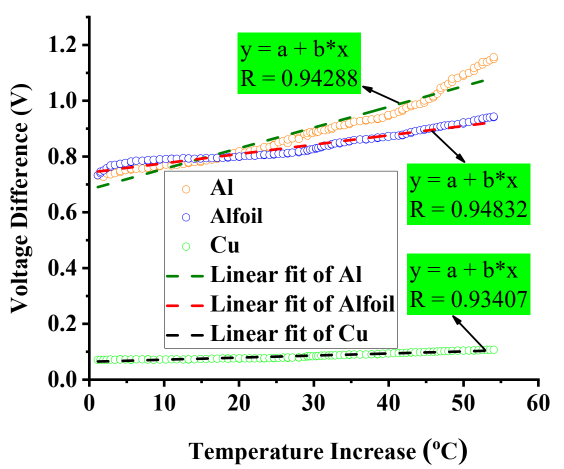


Fig. 7. Voltage difference vs temperature increase at counter electrodes (i.e., aluminum, aluminum foil, and copper)

When the water electrolyte was streamed into the models, the voltage difference generated on the aluminum and aluminum foil counter electrodes was around 0.7 volts. While on copper, it was 0.07 volts. When the model received heat with an increase in temperature up to ΔT=54 °C, the voltage difference generated increased up to 1.156 volts for the aluminum counter electrode, 0.943 volts for aluminum foil, and 0.107 volts for copper. On the aluminum counter electrode, the voltage difference generated tended to increase. Once it was above the temperature of ΔT=45 °C, it increased significantly because the hydrogen bonds of water molecules were weakened, so the ions were easily attracted to the activated carbon to release the electrons. On the aluminum foil counter electrode, the voltage difference generated tended to increase. However, it was still lower than on aluminum since the phosphorus content in aluminum foil tended to attract electrons. Hence, it inhibited the release of electrons. While on copper, the voltage difference generated tended to increase but was lower than on aluminum and aluminum foil since its ability to release electrons was low. The average amount of thermal sensitivity of the voltage (dV/dT) for the aluminum counter electrode is 64,043 mV/°C; 63,578 mV°C for aluminum foil; and 6,136 mV/°C for copper, shown in Fig. 8.

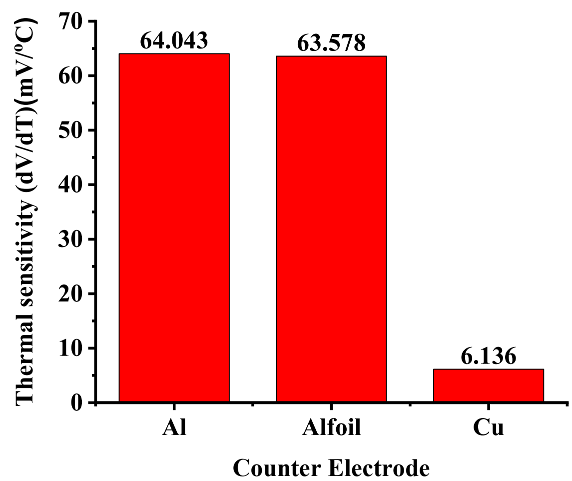


Fig. 8. Thermal sensitivity of counter electrodes

The average amount of voltage (dV/dT) was calculated based on the difference in average voltage divided by the average temperature increase in the range of temperature increase. The average thermal sensitivity of the voltage (dV/dT) generated by the water electrolyte was higher compared to thermoelectric material [22].

6. Discussion of results of voltage generation using bamboo-based activated carbon with water electrolyte in three types of electrode

6. 1. Discussion of results of voltage generation of bamboo-based activated carbon with injecting water electrolyte into the models and providing heat

In Fig. 6, the voltage difference of aluminum, aluminum foil, and copper counter electrodes can be seen increasing as both the heating time and the temperature increase. The voltage difference of the aluminum, aluminum foil, and copper counter electrodes increases for 40 seconds by heating. It is because heating can increase electron mobility and accelerate the release of electrons.

Fig. 7 shows that when the temperature increases, the voltage difference generated by aluminum, aluminum foil, and copper counter electrodes increases. The increase occurred up to a temperature of 54 °C. On the aluminum counter electrode, the voltage difference generated tended to increase. Once it was above the temperature of ΔT=45 °C, it increased significantly because the hydrogen bonds of water molecules were weakened, so the ions were easily attracted to the activated carbon to release the electrons. On the aluminum foil counter electrode, the voltage difference generated tended to increase. However, it was still lower than on aluminum since the phosphorus content in aluminum foil tended to attract electrons. Hence, it inhibited the release of electrons. While on copper, the voltage difference generated tended to increase but was lower than on aluminum and aluminum foil since its ability to release electrons was low. Thus, the difference in the results obtained from the counter electrode was influenced by the chemical composition and electron configuration of the material. Based on Table 1, the aluminum counter electrode has a chemical concentration of Al 96.5 % as well as other elements that have little effect. It has 3 valence electrons. So, aluminum tends to release 3 electrons from its orbitals. At the counter electrode, aluminum foil has a chemical concentration of Al 93.9 % and other elements that affect it, namely phosphorus, which has a chemical concentration of 2.3 %. Phosphor has 5 valence electrons with a tendency to accept 3 electrons to its orbital. So that the process of releasing electrons is disrupted since its phosphorus content tends to attract electrons. At the counter electrode, copper (Cu) has a chemical concentration of 98.68 %, with other small elements not influencing it. It has 1 valence electron and the tendency to release 1 electron. A complete explanation is given in section 6. 2.

Fig. 8 shows the average amount of thermal sensitivity of voltage (dV/dT) for the aluminum, aluminum foil, and copper counter electrodes. The amounts are 64,043 mV/°C, 63,578 mV/°C, 6,136 mV/°C, respectively. The aluminum counter electrode has the largest dV/dT because the increase in tension is more significant than aluminum foil and copper. This is because aluminum releases 3 electrons, while aluminum foil contains phosphorus, which inhibits the release of electrons, and copper only releases 1 electron.

The method used in this research is by injecting the electrolyte into the model and applying heat. The pressure due to the injection also helps release electrons. When being injected, the voltage has already increased, and when the heat is added, the voltage increases, and this process is fast. Whereas in previous studies, the method used was by immersing the model in the electrolyte and then applying heat. The results obtained by the previous method were much lower than the method that is currently used.

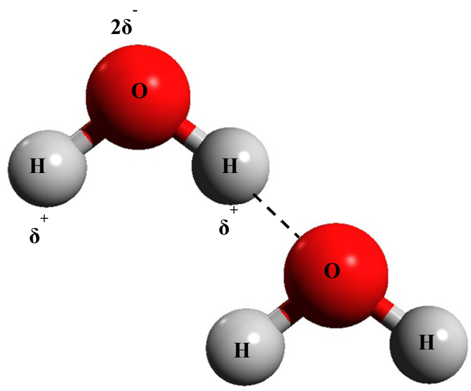
The weaknesses of our research are in determining the exact dimensions of the gap between the activated carbon and the counter electrode and in attaching the activated carbon to the surface of the counter electrode. In the future, it is necessary to consider the process of attaching activated carbon to the electrode plate.

The future development is continuous electrolyte flow.

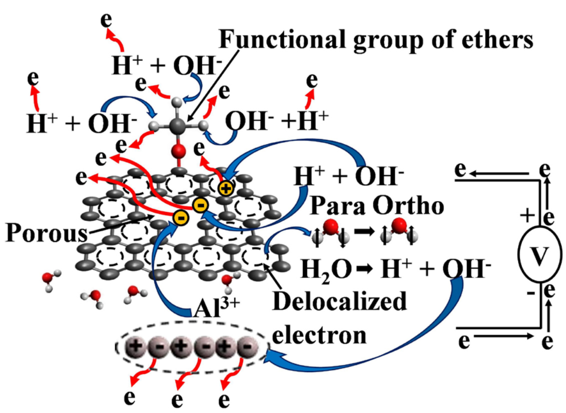
The emergence of an electrical voltage was due to the release of electrons on the surface of bamboo-based activated carbon, which consists of pores, functional groups with electrolytes and counter electrodes. When the electrolyte flowed into the model of electric energy generator and was given the heat, it released electrons. The ions from the water electrolyte interacted with the pores, functional groups and the counter electrode, causing the release of electrons. The heat applied to the model increased the mobility of ions and speeded up the electron-releasing process. As a result, when given heat, the electrical voltage generated increased very rapidly. The electron increase was also influenced by the induction of a delocalized electron from the aromatic ring, which creates a magnetic field. The delocalized electron from the aromatic ring induced ions from the electrolyte, so the electrons were easily released. The electron-releasing process is described in section 6. 1.

6. 2. Discussion of results of the electron-releasing process on the bamboo-based activated carbon

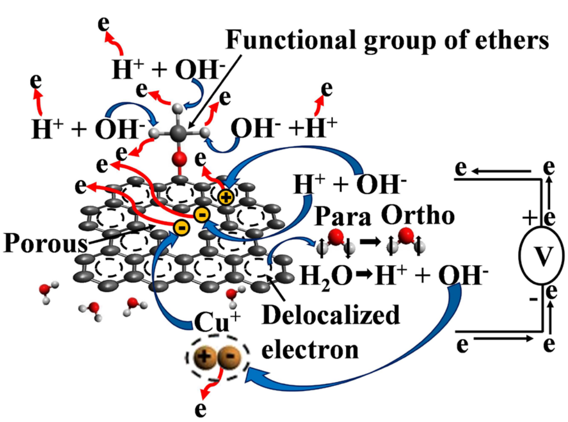
On the water electrolyte, an H_2O water molecule has two electric dipoles, each throughout the H-O bond. Each hydrogen atom bears a partial positive charge (δ^+), and the oxygen atom carries a partial negative charge that equals the amount of two partial positives ($2\delta^-$). Between H_2O and another H_2O, which has hydrogen bonds, there is an attractive electrostatic force between the oxygen atom of one water molecule and the oxygen atom of another water molecule [23], as shown in Fig. 9, *a*. To be able to interact to generate electricity, the water molecule needs to be ionized into H^+ and OH^-. The H_2O molecule can be ionized due to the influence of the magnetic field on the aromatic ring and increased following the heat distributed. The water molecule has para spin isomer (two antiparallel aligned spins). It is because the delocalized electrons from the aromatic ring produce a local magnetic field. It induces an electron spin on the water that causes the spin to increase. The spin goes away due to the centrifugal force. As a result, the orbit orientation changes into ortho spin isomer (two parallel aligned spins) whose attractive force is weak. An activated carbon surface that has pores or defects has positive and negative poles. The positive pole tends to attract an electron from H_2O, (i. e., OH^-), while the negative pole attracts a proton from H_2O (H^+). So, the release of electrons occurs. After that, the functional groups on the activated carbon surface that have poles will also interact with H^+ and OH^-; hence, the release of electrons occurs. On the ether functional group, the H_2O molecule, when being ionized into H^+ and OH^-, its electron is released for H^++e. Then, OH^- has an attractive electrostatic force with the H atom that is bonded to the ether functional group. The H atom is released from the C-H bond, and then there is a release of electrons on the H atom for H^++e. The release of the H atom bond from the C-H bond is because the energy of the C-H bond (413 kJ/mol) is smaller than that of the O-H bond (463 kJ/mol). So, the total amount of electrons released from the ether functional group is $6H^+$+e. The same electron-releasing process also works for the other functional groups such as C-H aromatic out-of-plane bend, C≡C alkyne, C≡N nitriles, C-H alkanes (stretch), carboxylic acids, N-H primary amides, and O-H phenol. The release of electrons also occurs on the counter electrode where OH^- from the ionization result of H_2O experiences attraction with the aluminum counter electrode that releases 3 electrons. Hence, the aluminum is charged with Al^{+3}. Then, Al^{+3} experiences attraction with the pores on the negatively charged activated carbon. After that, the release of electrons occurred. While on copper, the release of electrons happening is 1 electron, so the copper contains Cu^+. Then, Cu^+ experiences attraction with the negatively charged pores, so the release of electrons occurs. Aluminum releases electrons more easily compared to copper since it has lower ionization energy (578 kJ/mol) compared to copper (745 kJ/mol). All electrons released stream from the negative charge to the positive charge on the measurement tool explaining the amount of electrical voltage. While for aluminum foil, the electron-releasing process is the same as for aluminum, the only difference is in its chemical composition, as shown in Table 1. The electron-releasing process on the aluminum counter electrode is shown in Fig. 9, *b*. Fig. 9, *c* is for copper. The negatively charged pores can be explained from the SEM image processed with image J, as shown in Fig. 10.



a



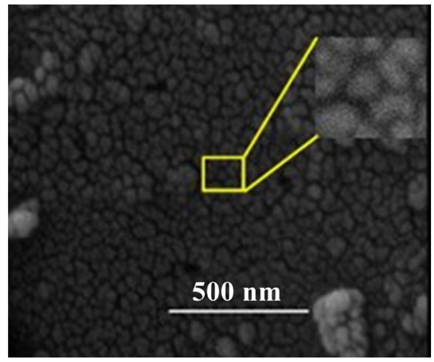
b



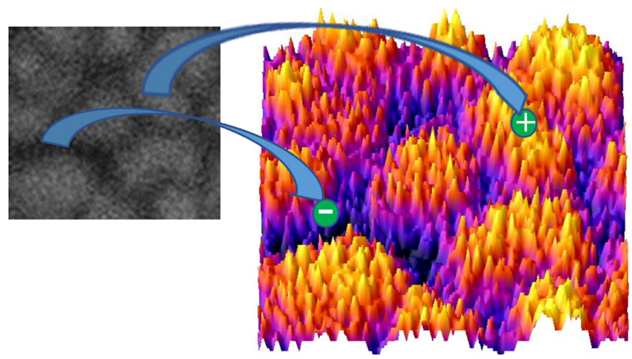
c

Fig. 9. Electron-releasing process: *a* – hydrogen bonds; *b* – process of electron release on the activated carbon with water electrolyte and aluminum counter electrode (Al); *c* – with copper (Cu)

The SEM test results show that there are pores in the form of nano cracks on the bamboo-based activated nanocarbon surface, as described inside the yellow box in Fig. 10, *a*. It is then processed using the software Image J using a fire LUT surface plot, as shown in Fig. 10, *b*. In the SEM test, an electron is emitted on the activated carbon surface. In Fig. 10, *b*, the dark-colored pores (dark blue) represent electrons emitted by SEM tending to be repelled by the carbon, so it tends to be negatively charged (–). Meanwhile, the farther it is from the light-colored pores (e. g., yellow), it shows that the electrons emitted by SEM tend to be attracted by the carbon surface, so it tends to be positively charged (+).



a



b

Fig. 10. Determining positive and negative contents on the active carbon surface: *a* – SEM test results; *b* – color spectrum of the counter surface, the result of processing with image J showing positive and negative contents

6. 3. Discussion of the results of the effect of chemical composition and electron configuration of material on the counter electrode toward the electrical voltage generated

The chemical composition and electron configuration of the counter electrode material affect the voltage generated differently. Based on the X-Ray Fluorescence (XRF) test, the chemical composition of the material from the counter electrode is obtained, as shown in Table 1.

The aluminum counter electrode has a chemical concentration of Al 96.5 % as well as other elements that have little effect. The electron configuration of aluminum (Al) is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$ and it has 3 valence electrons. So, aluminum tends to release 3 electrons from its orbitals. At the counter electrode, aluminum foil has a chemical concentration of Al 93.9 %, and other elements that affect it, namely phosphorus, which has a chemical concentration of 2.3 % with an electron configuration of $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$. Therefore, phosphor has 5 valence electrons with a tendency to accept 3 electrons to its orbital. So, the process of releasing electrons is disrupted since its phosphorus content tends to attract electrons. At the counter electrode, copper (Cu) has a chemical concentration of 98.68%, with other small elements not influencing it. It has an electron configuration of $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^1\,3d^{10}$; 1 valence electron, and the tendency to release 1 electron. Therefore, aluminum produces a higher thermal sensitivity from the electric voltage (dV/dT) than aluminum foil and copper because aluminum can release more electrons.

Table 1

Chemical composition of counter electrode materials

Counter Electrode					
Copper		Aluminum		Aluminum foil	
Compound	Conc.%	Compound	Conc.%	Compound	Conc.%
P	0.41	Al	96.5	Al	93.9
Ca	0.31	P	0.77	P	2.3
Sc	0.065	Ca	0.39	Ca	1.21
V	0.03	Sc	0.14	Ti	0.082
Cr	0.036	Ti	0.058	V	0.17
Fe	0.22	Mn	0.08	Cr	0.1
Ni	0.14	Fe	1.18	Mn	0.084
Cu	98.68	Ni	0.023	Fe	1.42
Ce	0.11	Cu	0.245	Ni	0.085
–	–	Ga	0.028	Cu	0.11
–	–	Cs	0.4	Zn	0.02
–	–	Ba	0.12	Ga	0.03
–	–	Os	0.065	Eu	0.24
–	–	Ir	0.03	Yb	0.13
–	–	–	–	Re	0.11

7. Conclusions

1. The voltage generation model with bamboo activated carbon electrodes and various counter electrodes can increase the voltage. Because the ions from the electrolyte and the counter electrode are absorbed by bamboo activated carbon to interact with the functional groups, the pores of bamboo activated carbon have nanoparticle size.

2. By injecting electrolyte and applying heat to the model, the voltage can be generated quickly and in a high amount. It is because the injection can accelerate the electron release process and increase electron mobility.

3. The voltage generated at the counter electrode of aluminum is higher than that of aluminum foil and much higher than that of copper, the magnitudes of which are 64,043 mV/°C, 63,578 mV/°C, 6,136 mV/°C, respectively. This is due to the fact that aluminum chemical composition and electron configuration are able to release the most electrons, namely 3 electrons. Meanwhile, aluminum foil has the phosphorus content that tends to inhibit the release of electrons, and copper only releases 1 electron.

Acknowledgments

The author expresses his gratitude to the Endowment Fund for Education (LPDP) of the Ministry of Finance of the Republic of Indonesia in which its Excellence Scholarship for Indonesian Lecturers – Domestic Program (BUDI-DN) has supported this research. His gratitude is also due to Dr. Ngafwan for his contribution to the discussion of the electron-releasing process on functional groups.

Reference

1. Shah, J., Jan, M. R., Mabood, F., Shahid, M. (2006). Conversion of Waste Tyres into Carbon Black and their Utilization as Adsorbent. Journal of the Chinese Chemical Society, 53 (5), 1085–1089. doi: https://doi.org/10.1002/jccs.200600144
2. Lazkano, I., Nøstbakken, L., Pelli, M. (2017). From fossil fuels to renewables: The role of electricity storage. European Economic Review, 99, 113–129. doi: https://doi.org/10.1016/j.euroecorev.2017.03.013
3. Yang, C.-S., Jang, Y. S., Jeong, H. K. (2014). Bamboo-based activated carbon for supercapacitor applications. Current Applied Physics, 14 (12), 1616–1620. doi: https://doi.org/10.1016/j.cap.2014.09.021
4. Ye, X., Yang, Q., Zheng, Y., Mo, W., Hu, J., Huang, W. (2014). Biotemplate synthesis of carbon nanostructures using bamboo as both the template and the carbon source. Materials Research Bulletin, 51, 366–371. doi: https://doi.org/10.1016/j.materresbull.2013.12.032
5. Tavakkoli, S., Lokare, O. R., Vidic, R. D., Khanna, V. (2016). Systems-Level Analysis of Waste Heat Recovery Opportunities from Natural Gas Compressor Stations in the United States. ACS Sustainable Chemistry & Engineering, 4 (7), 3618–3626. doi: https://doi.org/10.1021/acssuschemeng.5b01685
6. Xie, M., Dunn, S., Boulbar, E. L., Bowen, C. R. (2017). Pyroelectric energy harvesting for water splitting. International Journal of Hydrogen Energy, 42 (37), 23437–23445. doi: https://doi.org/10.1016/j.ijhydene.2017.02.086
7. Macías-García, A., Torrejón-Martín, D., Díaz-Díez, M. Á., Carrasco-Amador, J. P. (2019). Study of the influence of particle size of activate carbon for the manufacture of electrodes for supercapacitors. Journal of Energy Storage, 25, 100829. doi: https://doi.org/10.1016/j.est.2019.100829
8. B Xu, B., Liu, L., Lim, H., Qiao, Y., Chen, X. (2012). Harvesting energy from low-grade heat based on nanofluids. Nano Energy, 1 (6), 805–811. doi: https://doi.org/10.1016/j.nanoen.2012.07.013
9. Siddique, A. R. M., Mahmud, S., Heyst, B. V. (2017). A review of the state of the science on wearable thermoelectric power generators (TEGs) and their existing challenges. Renewable and Sustainable Energy Reviews, 73, 730–744. doi: https://doi.org/10.1016/j.rser.2017.01.177
10. Du, L., Shi, G., Zhao, J. (2014). Review of Micro Magnetic Generator. Sensors & Transducers, 176 (8) 1–12. Available at: https://pdfs.semanticscholar.org/aeca/67ab520d7279c6dd7ac636e51b9492b1d5c5.pdf?
11. Lim, H., Shi, Y., Wang, M., Qiao, Y. (2015). Effects of work function on thermal sensitivity of electrode potential. Applied Physics Letters, 106 (22), 223901. doi: https://doi.org/10.1063/1.4921769

12. Sun, F., Wang, L., Peng, Y., Gao, J., Pi, X., Qu, Z. et. al. (2018). Converting biomass waste into microporous carbon with simultaneously high surface area and carbon purity as advanced electrochemical energy storage materials. Applied Surface Science, 436, 486–494. doi: https://doi.org/10.1016/j.apsusc.2017.12.067
13. Wang, Q., Yan, J., Fan, Z. (2016). Carbon materials for high volumetric performance supercapacitors: design, progress, challenges and opportunities. Energy & Environmental Science, 9 (3), 729–762. doi: https://doi.org/10.1039/c5ee03109e
14. Li, L., Quinlivan, P. A., Knappe, D. R. U. (2002). Effects of activated carbon surface chemistry and pore structure on the adsorption of organic contaminants from aqueous solution. Carbon, 40 (12), 2085–2100. doi: https://doi.org/10.1016/s0008-6223(02)00069-6
15. Wang, J., Feng, S.-P., Yang, Y., Hau, N. Y., Munro, M., Ferreira-Yang, E., Chen, G. (2015). "Thermal Charging" Phenomenon in Electrical Double Layer Capacitors. Nano Letters, 15 (9), 5784–5790. doi: https://doi.org/10.1021/acs.nanolett.5b01761
16. Qiao, Y., Punyamurtual, V. K., Han, A., Lim, H. (2008). Thermal-to-electric energy conversion of a nanoporous carbon. Journal of Power Sources, 183 (1), 403–405. doi: https://doi.org/10.1016/j.jpowsour.2008.05.008
17. Lim, H., Shi, Y., Qiao, Y. (2016). Thermally chargeable supercapacitor working in a homogeneous, changing temperature field. Applied Physics A, 122 (4). doi: https://doi.org/10.1007/s00339-016-9981-2
18. Lim, H., Shi, Y., Qiao, Y. (2017). Thermally chargeable supercapacitor based on nickel-coated nanoporous carbon. International Journal of Green Energy, 15 (2), 53–56. doi: https://doi.org/10.1080/15435075.2017.1313737
19. Liu, K., Ding, T., Li, J., Chen, Q., Xue, G., Yang, P. et. al. (2018). Thermal-Electric Nanogenerator Based on the Electrokinetic Effect in Porous Carbon Film. Advanced Energy Materials, 8 (13), 1702481. doi: https://doi.org/10.1002/aenm.201702481
20. Yahya, M. A., Al-Qodah, Z., Ngah, C. W. Z. (2015). Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: A review. Renewable and Sustainable Energy Reviews, 46, 218–235. doi: https://doi.org/10.1016/j.rser.2015.02.051
21. Ngafwan, N., Wardana, I. N. G., Wijayanti, W., Siswanto, E. (2018). The role of NaOH and papaya latex bio-activator during production of carbon nanoparticle from rice husks. Advances in Natural Sciences: Nanoscience and Nanotechnology, 9 (4), 045011. doi: https://doi.org/10.1088/2043-6254/aaf3af
22. Zhang, X., Zhao, L.-D. (2015). Thermoelectric materials: Energy conversion between heat and electricity. Journal of Materiomics, 1 (2), 92–105. doi: https://doi.org/10.1016/j.jmat.2015.01.001
23. Brini, E., Fennell, C. J., Fernandez-Serra, M., Hribar-Lee, B., Lukšič, M., Dill, K. A. (2017). How Water's Properties Are Encoded in Its Molecular Structure and Energies. Chemical Reviews, 117 (19), 12385–12414. doi: https://doi.org/10.1021/acs.chemrev.7b00259