JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(3), 213–223
https://doi.org/10.12911/22998993/158564
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.12.09
Accepted: 2023.01.05
Published: 2023.01.15

Power and Energy Optimization of Carbon Based Lithium-Ion Battery from Water Spinach (*Ipomoea Aquatica*)

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ABSTRACT

Currently, lithium-ion batteries still use electrodes from graphite, which is a natural resource for non-metallic minerals. As a sustainable plan, research on the manufacture of lithium-ion batteries based on biomass electrodes has prospects for commercial development. In this study, carbon stems of water spinach (*Ipomoea Aquatica*) were used as electrodes on the battery. Water spinach is processed into nanocarbon by hydrothermal method and pyrolysis. The size of the nanocarbon particles from water spinach in this study was 200 mesh resulting from the grinding method. The type of battery made is a bag battery with a size of 8×12 cm by performing variable optimization by using a concentration of 50% $LiCl/Li_2SO_4$ electrolytes media, Polyurethane/Polyacrylate binder, and Triethylamine/Non-emulsifier. The highest power and energy values are generated from carbon based lithium-ion batteries from water spinach with LiCl electrolyte media, Polyurethane binder, and Triethylamine emulsion which is 5.404 W and 4.511 W·h.

Keywords: binder; carbon; electrolyte media; emulsifier; lithium-ion battery; water spinach.

INTRODUCTION

The rechargeable battery can be used many times by recharging when the power starts to run out. The most widely used type of rechargeable battery in various electronic devices is lithium-ion (Tran et al., 2021; J. Liu et al., 2022; Li et al., 2022). Compared to traditional battery technology, lithium-ion batteries charge faster (Al-Saadi et al., 2022), last longer (Yang et al., 2021), and have a higher power density for longer battery life in a lighter package (Kaliaperumal et al., 2021). A lithium-ion battery is a storage area for energy that can be used continuously by being recharged and releasing moving from the negative to the positive electrode when released. In the lithium-ion battery component, there is an electrode section. This section serves as a place to store energy and a place for chemical reactions to occur. Therefore, the basic material of an electrode greatly affects the amount of energy stored and the processes that occur in the electrode, namely electrochemical reactions (Zhou et al., 2022).

Until now, graphite has been widely used to make carbon as a constituent of electrodes in lithium-ion batteries. Unfortunately, graphite is a material that is difficult to obtain because it must be obtained from mining activities (Beaudet et al., 2020). Mining activities carried out to obtain graphite continuously harm the environment (Pigłowska et al., 2021). In addition, graphite from an economical point of view is a relatively expensive item so it has a significant impact on the overall battery price (Brückner et al., 2020).

To minimize the disadvantages of using graphite to make lithium-ion batteries, it is necessary to minimize them by looking for alternative new materials that are easier to obtain, environmentally friendly, and at lower prices.

Previous research explained that carbon from plants has the potential to be used as a supercapacitor that ranging from banana peels (Nazhipkyzy, Yeleuov, et al., 2022), grass (She et al., 2018), soybeans (Chung et al., 2020), corn stalks (Kigozi et al., 2020), coconut shell (Lee et al., 2021), and water spinach (Lin et al., 2022). Water spinach (*Ipomoea Aquatica*) is an aquatic plant that can be found in Southeast China, India, and Southeast Asia that can easily grow in water areas such as rivers, rice fields, and swamps by forming large colonies (Yu et al., 2018; Ma et al., 2019; Abdul Aziz et al., 2020). Because it is easy to absorb heavy metals from the growth media, such as mercury, arsenic, zinc, copper, and nickel, water spinach is very dangerous if consumed by living things because it can cause poisoning, cancer, or other dangerous diseases (Vongdala et al., 2018; Zaheer et al., 2020; Tao et al., 2022). In addition, the presence of water spinach can damage plants that grow close to this plant so that the level of production of other plants continues to decrease (Uddin et al., 2021). Because of its large population, its toxic nature, and being a parasite to other plants around it, the use of water spinach as carbon has a major contribution from the economic, health, and environmental aspects.

The utilization of water spinach into carbon as the basic material for making electrodes in lithium-ion batteries has previously been carried out by Ingried et al (Ingried et al., 2022). This study used 10%, 20%, and 40% LiCl electrolyte media. The study showed that the use of 40% LiCl electrolyte was able to produce the greatest power and energy. It is proof that increasing electrolyte media percentage would enhance produced power and energy on carbon based lithium-ion batteries from water spinach. Also, further studies by increasing the percentage of electrolyte media on carbon based lithium-ion batteries from water spinach need to be carried out. Apart from the variation of electrolyte media presentation, the results of Ingried et al (Ingried et al., 2022) also compare the electrolyte media in the form of liquid and gel. The measurement results show that the use of electrolyte media in liquid form produces greater power and energy than electrolyte media in gel form. It can be concluded that the high percentage of electrolyte media in liquid form can maximize the power and energy generated from carbon based lithium-ion batteries from water spinach. Previous research by Lang et al. (Lang et al., 2020) has used 50% AlCl electrolyte media in form of liquid on molten batteries, but such high percentages have never been performed on carbon based lithium-ion batteries from water spinach that was explored to fill the research gap.

In addition to the percentage of electrolyte media, several other important variables that affect the produced power and energy are types of electrolyte media (Kuganathan, 2022), binders (Fitz et al., 2021), and emulsions (Cui et al., 2019). Optimization from various variables to maximizing produced power and energy is a crucial step to improve battery performance. Such efforts have previously been carried out by Vieceli (Vieceli et al., 2020), Hosseinzadeh (Hosseinzadeh et al., 2017), and Park (Park et al., 2021) for lithium-ion batteries with carbon from graphite, but carbon from water spinach has not been explored. Further effort in carbon from water spinach can close the research gap that accommodates the best potential for the utilization of water spinach as carbon in lithium-ion batteries.

The purpose of this study was to analyze the power and energy generated on carbon based lithium-ion batteries from water spinach. 50% liquid electrolyte media use has been considered based on previous research and provides an increase in terms of power and energy. The variables of the electrolyte media, binders, and emulsions will be studied further as an optimization variable.

MATERIALS AND METHODS

Carbon preparation from water spinach

The cleaned water spinach stems are cut to a size of ±5 cm, this cutting process aims to make the water spinach stems easier to dry. The process of drying water spinach stems is carried out using a conventional method, namely drying by utilizing sunlight for ±1 week. This drying aims to reduce or eliminate the water content contained in water spinach stems and determine the free water content. After drying, the water spinach stems are in a blender until smooth so that they become water spinach stem powder. A total of 40 grams of water spinach stem powder was mixed with a solution of KOH (0.08 grams of KOH in 100 ml of water) while stirring for ± 3 minutes. The results of the mixing are then fed into a hydrothermal reactor with a pressure inside the reactor of 30 bar and heated using an electric oven at a temperature of 200 °C for 16 hours. After 16 hours, the reactor was cooled to room temperature and atmospheric pressure. The hydrothermal process produces brown water spinach stem powder (torrefaction material).

20 grams of torrefaction material is put into a furnace surrounded by binchotan and then microwaved for 35 minutes with 1000 W of microwave power. The temperature in the furnace increases due to molecular motion after being exposed to the microwave. The temperature rise takes place during contact with the microwave and 1-2 hours thereafter so that the temperature in the furnace reaches 800 °C. The achievement of temperatures up to 800 °C occurs due to the use of binchotan which functions as an energy absorber from the microwave and torrefaction of the material that has turned into nanocarbon. The result of this pyrolysis process is nanocarbon (Ingried et al., 2022).

Anode and cathode preparation

The anode preparation for the battery was carried out by mixing nanocarbon from the stem of water spinach with Polyurethane or Polyacrylate binder to form a paste. Then the mixture that has been in the form of a paste is coated on the copper surface. After that, it is calendered and cut. The results were obtained in the form of an anode for the battery. The cathode preparation for the battery was carried out by dissolving 8.4 grams of LiCl or Li_2SO_4 into 40 ml of deionized water. The solution is then mixed with 0.4 grams of TiO_2 and 0.1 grams of NaOH. Then, the mixture is placed into a hydrothermal reactor and heated at 180 °C in a furnace for 24 hours (Ingried et al., 2022).

Battery preparation

The manufacture of batteries with a liquid electrolyte base is carried out by adjusting the copper sheets used as separators, anodes, and cathodes, as well as applicators and dividers. When the three materials (separator, anode, and cathode) are ready, they are loaded into the sleeve until a battery without electrolyte is formed. Then the sealing is carried out without air utilizing a vacuum. After that, prepare the battery with LiCl or Li_2SO_4 electrolyte media with a concentration of 50%. Emulsion with Triethylamine was then added and another battery without emulsion. The battery is then loaded with electrolytes utilizing the electrolyte solution being injected with a glovebox and pressed (Ingried et al., 2022). And the last put aluminum foil measuring 8×12 cm and the battery into a pouch.

Variable optimization

Three variables from carbon based lithium-ion batteries from water spinach were further observed to maximize the produced power and energy, there are electrolyte media, binders, and emulsions. For each variable using two different objects, where the electrolyte media uses 50% concentration of LiCl and Li_2SO_4, the binder uses Polyurethane and Polyacrylate, and the emulsion uses Triethylamine and Non-emulsifier making there are eight different variations on the carbon based lithium-ion battery from water spinach in current study described in Table 1. The selection of each object on each variable is based on the rationalization of widely adopted carbon based lithium-ion battery from graphite (Reddy et al., 2020; Zhao et al., 2021), relatively affordable prices (Peters et al., 2019; Doose et al., 2021), and availability in the market that is generally easy to obtain (Kim et al., 2020; Cholewinski et al., 2021).

RESULTS AND DISCUSSION

Carbon characterization based on water spinach stems

Scanning Electron Microscope (SEM) is widely used to observe morphological structures sample surface at high magnification using a beam high energy electrons (Nazhipkyzy, Maltay, et al., 2022). SEM characterization was carried out on carbon rods water spinach. The results obtained in the SEM characterization with magnification 5,000 times shows that the carbon of water spinach stems has dense pores needed to capture and release Li^+ ions. The pores in carbon have varying sizes. In Figure 1, the size of the pores formed is between 0.7–5 μm in size. These pores are needed to capture and release Li^+ ions. The formation of these pores occurs due to the influence of heat during the pyrolysis process, resulting in the decomposition of organic compounds on carbon. The carbon produced in the pyrolysis process was also tested for its content presented

Table 1. Variation of carbon based lithium-ion battery from water spinach

Variations	Electrolyte concentration	Electrolyte media	Binder	Emulsion
1st	50%	LiCl (liquid)	Polyurethane	Triethylamine
2nd		Li_2SO_4 (liquid)		
3rd		LiCl (liquid)	Polyacrylate	
4th		Li_2SO_4 (liquid)		
5th		LiCl (liquid)	Polyurethane	Non-emulsifier
6th		Li_2SO_4 (liquid)		
7th		LiCl (liquid)	Polyacrylate	
8th		Li_2SO_4 (liquid)		

in Table 2. The carbon content from the stems of water spinach was analyzed using EDX which is part of the SEM tool.

Furthermore, X-Ray Diffraction Method (XRD) aims to characterize the crystallography of a sample through the peaks formed at an angle of 2θ diffractogram (Volkov et al., 2022). In this study, the 2θ angle read in the formation of the peak ranged from 0° to 80° shown in Figure 2. The results of the XRD spectrum on water spinach stem carbon obtained peaks indicating the presence of a crystal structure formed in the water spinach carbon sample. Based on XRD spectra on

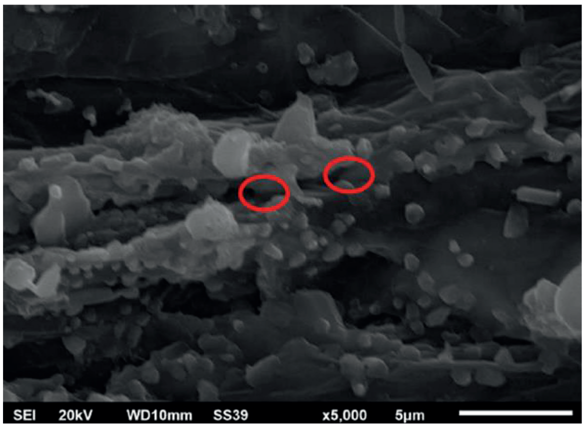

Figure 1. SEM characterization of water spinach stems carbon

Table 2. Atomic elements analysis of water spinach stem

Elements	Atom (%)
Carbon (C)	79.45
Oxygen (O)	13.28
Sodium (Na)	0.63
Magnesium (Mg)	0.29
Silicone (Si)	0.28
Chlorine (Cl)	1.56
Potassium (K)	3.53
Calsium (Ca)	0.96

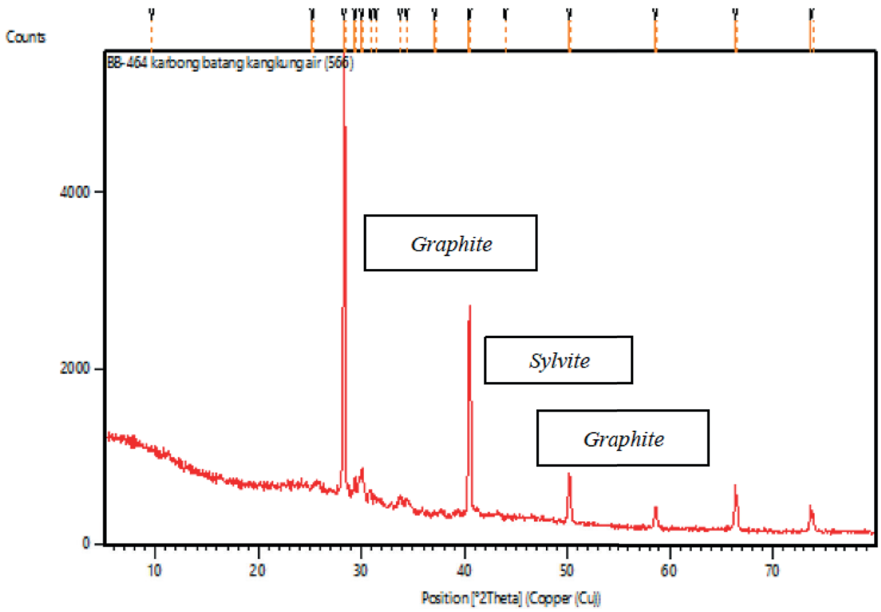

Figure 2. Water spinach stem carbon diffractogram image

water spinach stem carbon, it produced the highest peaks at the 1st, 2nd, and 3rd peaks. The 1st peak at an angle of 28.3083° produces a peak height of 3717 cts, the 2nd peak at an angle of 40,475° produces a peak height of 1795 cts, and the 3rd peak at an angle of 50.137° produces a peak height of 483 cts Based on JCPDS-ICDD data, the peaks formed are the crystal structures of graphite and sylvite.

Next, Fourier Transfer Infra-Red Method (FT-IR) aims to characterize the functional groups in a sample (Hamza et al., 2022). The peaks formed on the FT-IR spectrophotometer indicate the bonds formed. In the FT-IR spectrophotometer, the sample used is water spinach stem carbon explained in Figure 3, the FT-IR spectrophotometer shows the presence of alcohol O – H bonds at the peak of 3300–3500 cm^{-1}, and C = C aromatic ring at the peak of the 1650 cm^{-1}. The heating process that takes place in the pyrolysis causes the breaking of the bonds formed in some of the functional groups so that the carbon only shows 2 peaks of the functional groups, this is due to the influence of high temperatures during the process.

Current and voltage analysis

Lithium-ion batteries generate electricity by converting the chemical energy present in the battery components by an electrochemical oxidation-reduction reaction (Jankowiak et al., 2019). During the charging process, there is a transfer where the lithium ions move from the positive electrode (cathode) to the negative electrode (anode) or what is commonly referred to as the oxidation peak, on the other hand, during the discharging process, the lithium-ion moves from the negative electrode (anode) to the positive electrode (cathode) which is referred to as the reduction peak (Mevawalla et al., 2020). Voltage and current values in the reduction and oxidation processes are described in Table 3.

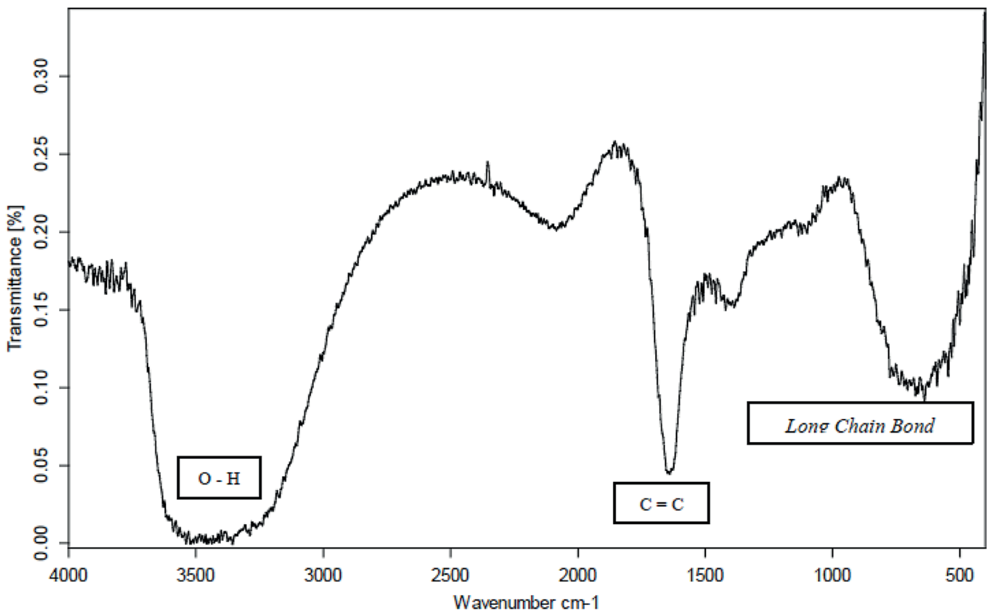

Figure 3. FT-IR characterization of water spinach stem carbon

Table 3. Current and voltage in oxidation and reduction process

Variations	Oxidation		Reduction	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
1st	3.096	7.981	0.422	5.960
2nd	3.402	6.233	0.936	4.872
3rd	3.427	6.751	1.129	4.757
4th	2.425	5.231	0.649	3.667
5th	2.513	7.527	0.581	5.835
6th	3.561	6.439	1.027	4.921
7th	3.422	6.958	1.328	5.038
8th	3.418	6.278	0.835	4.375

It is known that the highest currents for the oxidation and reduction processes were found in the 1st variation of 7.981 A and 5.960 A, respectively, while the lowest was found in the 4th variation of 5.231 A in the oxidation process and 3.667 A in the reduction process. If the current, the highest and lowest values for both processes are owned by the same variation, this is different for voltage. The highest and lowest voltages in the oxidation process were found in the 3rd variation of 3.427 V and 2.425 V, respectively. Meanwhile, the highest and lowest voltages in the reduction process were found respectively in the 7th variation of 1.328. V and the 1st variation of 0.422 V.

From the exposure of the measurement results of voltage and current from the oxidation and reduction process, the electrolyte media has a dominant role in the measurement results obtained, especially in the current where the LiCl electrolyte media in the 1st variation gives the highest current value, while Li_2SO_4 in the 4th variation, gives the lowest current value, even though both the 1st and 4th variations use Polyurethane binder and Triethylamine emulsifier. In general, LiCl electrolyte media makes the current in the oxidation and reduction process larger than Li_2SO_4. This shows the ability of LiCl to be a better medium to accommodate the movement of lithium ions. LiCl and Li_2SO_4 are salt-type electrolytes that are more stable to increase in pH than other acid or base electrolytes (Lamb & Burheim, 2021). When lithium ions move as a chemical energy process, the pH will be low (acid) (Paul et al., 2022). This condition makes the battery easily oxidized, causing leakage.

Power and energy analysis

Two general aspects that are seen to assess the performance of lithium-ion batteries are the produced power and energy from initial use to the need for recharging (Lemian & Bode, 2022). The results of power and energy measurements from carbon based lithium-ion batteries from water spinach in the current study are presented in Table 4. The highest power and energy values were found in the 1st variation using LiCl electrolyte media, Polyurethane binder, and Triethylamine. emulsion with a power value of 5.404 W and an energy value of 4.511 W·h. Meanwhile, the lowest power and energy values were found in the 4th variation using Li_2SO_4 electrolyte media, Polyacrylate binder, and Triethylamine emulsifier.

Table 4. Power and energy measurement results

Variations	Power (W)	Energy (W.h)
1st	5.404	4.511
2nd	3.356	2.387
3rd	4.582	3.812
4th	2.778	1.669
5th	3.269	2.343
6th	3.847	2.691
7th	4.020	2.793
8th	4.915	3.564

Although the 1st variation and 4th variation both use Triethylamine as an emulsifier, the difference between electrolyte media and binder brings a relatively significant difference with a difference of 2.626 W for power and 2.842 W·h for energy.

The function of the binder in the manufacture of carbon based lithium-ion batteries from water spinach is to bind the constituent materials of the battery, namely the cathode and anode. The nature of the binder is generally sticky and has a pungent smell, but when it is dry it is flexible like rubber (Caputo et al., 2020; Boh Podgornik et al., 2021; Kota et al., 2022). The choice of binder is based on its thermal conductivity properties only so that it does not reduce the electrical content generated by the battery (Lippke et al., 2022), therefore Polyurethane and Polyacrylate have been considered for current research as two of the easiest binder options available (Norjeli et al., 2022) with good thermal conductivity values compared to other options on the market (Yuca et al., 2022), which have a thermal conductivity value of 0.226 W/m·K for Polyurethane (Tsai et al., 2018) and 0.199 W/m·K for Polyacrylate (Wang et al., 2014). With a higher thermal conductivity value of Polyurethane compared to Polyacrylate, the use of a binder with Polyurethane has the potential to produce higher Power and Energy than the use of a Polyacrylate binder. This is consistent as described in Table 4 in the 1st and 3rd variations. With both using LiCl electrolyte media and Triethylamine emulsifier, the Power and Energy in the 1st variation using Polyurethane binder was higher than the 3rd variation using Polyacrylate binder.

Furthermore, carbon based lithium-ion batteries from water spinach were also given two different treatments with variations 1st to 4th being given a Triethylamine emulsifier and variations 5th to 8th not being given an emulsifier. The addition of an emulsifier to the battery is useful for maintaining the stability of the mixture at the cathode and anode so that each part can be mixed properly. In theory, the use of a Triethylamine emulsifier can increase the power and energy produced by the battery. Triethylamine has a role as a pH balancer (Weshahy et al., 2022). When used as an emulsifier, it can make the battery less acidic due to the chemical reactions that occur to produce energy in the battery. In addition, Triethylamine has an inert nitrogen content so it is not easy to react with oxygen and oxidation occurs (Zhang et al., 2022). However, the results of experimental measurements in the current study do not align with these explanations in some cases. As shown in Table 4 in the 2nd and 6th variations, both using Li_2SO_4 electrolyte media and Polyurethane binder, the 6th variation that did not use emulsion had greater energy than the 2nd variation which used Triethylamine emulsifier. The energy value of the two variations is 2.387 W·h for the 2nd variation using a Triethylamine emulsifier and 2.691 W·h for the 6th variation without an emulsifier. The discrepancy between the results obtained with the intended use of the emulsion can be caused by several things, such as errors due to human factors (Quintal, 2022), tool factors (Samieian et al., 2022), and environmental factors (Balasingam et al., 2020).

Results comparison with the previous study

As a follow-up study from Ingried et al (Ingried et al., 2022), the current study seeks to find the optimum combination of variables to maximize the best potential of carbon based lithium-ion batteries from water spinach by being able to produce higher power and energy than previous studies. The results of the measurement of power and energy from the current study have been compared with previous studies by Ingried et al (Ingried et al., 2022) presented in Table 5. Overall, the results of the current study were able to produce higher power and energy than previous studies. There are several explanations that this can be achieved because of the different configuration variables for making carbon based lithium-ion batteries from water spinach. First in terms of electrolyte concentration, the current study uses an electrolyte concentration of 50% higher than subsequent studies which were only 10%, 20%, and 40% (Ingried et al., 2022). Furthermore, the form of the electrolyte media from the current study focuses on liquids which have been proven from previous studies to produce higher power and energy than gels (Ingried et al., 2022). Next, the current research uses an emulsifier in the form of Triethylamine that having various positive impacts to improve overall

Table 5. Results comparison with the previous study from Ingried et al (Ingried et al., 2022)

Study	Variations	Electrolyte concentration	Electrolyte media	Binder	Emulsion	Power (W)	Energy (W·h)
Present Study	1st	50%	LiCl (Liquid)	Polyurethane	Triethylamine	5.404	4.511
	2nd		Li_2SO_4 (Liquid)			3.356	2.387
	3rd		LiCl (Liquid)	Polyacrylate		4.582	3.812
	4th		Li_2SO_4 (Liquid)			2.778	1.669
	5th		LiCl (Liquid)	Polyurethane	Non-emulsifier	3.269	2.343
	6th		Li_2SO_4 (Liquid)			3.847	2.691
	7th		LiCl (Liquid)	Polyacrylate		4.020	2.793
	8th		Li_2SO_4 (Liquid)			4.915	3.564
Ingried et al [24]	1st	10%	LiCl (Gel)	Polyurethane	Non-emulsifier	1.38×10^{-5}	4.67×10^{-7}
	2nd	20%				1.16×10^{-4}	3.91×10^{-6}
	3rd	40%				2.75×10^{-2}	9.30×10^{-4}
	4th	10%	LiCl (Liquid)			3.85×10^{-2}	1.30×10^{-3}
	5th	20%				1.43×10^{-1}	4.83×10^{-3}
	6th	40%				1.41×10^{-3}	4.77×10^{-5}

battery performance (Liu et al., 2021) and safer utilization (Wu et al., 2022) compared to non-emulsifier. And lastly, The type of battery in the current study is a pocket battery, while in the previous study it was a button battery.

Efforts to increase energy and power generated in the battery can increase the greater risk of leakage as mentioned by Gabbar et al. (2021). This is because the higher the produced power and energy, the faster the battery is heating. The heat generated over a long period can reduce overall battery quality and shorten battery life (Mo et al., 2022). In addition, the higher the heat in the battery can make the risk of leakage in the battery higher which can damage electronic devices (Liang et al., 2021). Therefore, efforts to maximize the produced energy and power in the current study also need to be accompanied by monitoring the battery temperature. Efforts to minimize battery leakage are also a form of environmental care. Leaked batteries cannot be reused or recycled so they become hazardous waste (Viruega Sevilla et al., 2022).

Limitations of the present study

The current research has two main shortcomings that need attention. First, the current study focuses on produced power and energy from a lithium-ion battery with carbon from water spinach but does not look at carbon from graphite so it is not known whether the performance of a lithium-ion battery with carbon from water spinach is better or not compared to carbon. from graphite. In addition, the current study only examines the electrolyte, binder, and emulsion media variables with two objects for each variable. Other variables with a larger number of objects need to be explored so that they can provide a more thorough understanding of variable optimization. Further studies are needed to address the current research deficiencies.

CONCLUSIONS

The current investigation has successfully explored variable electrolyte media, binders, and emulsions to maximize the produced power and energy on carbon based lith-ium-ion battery from water spinach. The 1st variation with LiCl electrolyte media, Polyurethane binder, and Triethylamine emulsion produces the highest power and energy among the current experimental results with a power of 5.404 W and an energy of 4.511 W·h. The composition of the variable with the highest produced power and energy in the current study also showed a higher value than the previous study of carbon based lithium-ion batteries from water spinach. Efforts to maximize carbon based lithium-ion battery from water spinach performance in the current study increase the risk of leakage due to the influence of heat generated. As a result, efforts to maximize produced energy and power in the current study must be accompanied by battery temperature monitoring. Efforts to reduce battery leakage are also examples of environmental stewardship. Because leaking batteries cannot be reused or recycled, they are classified as hazardous waste.

Acknowledgments

The research of this article was funded by DIPA of Public Service Agency of Universitas Sriwijaya 2022. SP DIPA-023.17.2.677515 /2022, On Desember 13, 2021. In accordance with the Rector's Decree Number: 0020/UN9/SK.LP2M/2022, On Juni 20, 2022.

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