SODIUM HYDROXIDE EFFECT ON OIL PALM WASTE IN BIO-BATTERIES

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Abstract
The plentiful palm solid waste generated by the palm oil industry can be transformed into environmentally beneficial alternative energy, comprising cellulose, ash, lignin, and hemicellulose. This material possesses significant potential as the primary raw component for eco-friendly and sustainable bio-batteries. This study was to determine the impact and optimal amount of sodium hydroxide for enhancing electrical energy from frond, empty bunches, and shells of oil palm, with sodium hydroxide variations of 5%, 10%, and 15%. This study employed an experimental methodology with a two-factorial, fully randomised design. The findings indicated that the optimal treatment involved empty bunch with 15% sodium hydroxide, yielding a voltage of 2.61 V, a current of 69.53 mA, a power of 181.48 mW, a resistance of 0.038 Ω, and an electrical energy of 3.87Wh. These results provide valuable insights for developing efficient, sustainable bio-battery technology from palm oil waste.

Key words: *oil palm waste; sodium hydroxide; alternative electrical energy; bio-battery.*

INTRODUCTION

Palm oil has become a dominant force in the global oils and fats market, with production increasing dramatically because it is applicable in many different industries, such as food, cosmetics, pharmaceuticals, and biofuels. In 2022, Indonesia leads global production with approximately 25 billion liters annually, followed by Malaysia *(Abd-Aziz, Gozan, Ibrahim, & Phang, 2022)*. According to data from the Central Statistics Agency (Badan Pusat Statistik, BPS), Indonesia had approximately 15.4 million hectares of oil palm plantations in 2023 and contributed about 59% of the total global palm oil production, which reached around 47.084 million tons *(BPS, 2024).*

On another hand, the increasing production of palm oil has led to a rise in palm oil waste, including oil palm fronds, shells, and empty fruit bunches (EFBs). These wastes contain toxic compounds and tannins, which can hinder plant growth and disrupt ecosystems *(Jarujareet, Nakkanong, Luepromchai, & Suttinun, 2019; Phonepaseuth, Rakkiatsakul, Kachenchart, Suttinun, & Luepromchai, 2019)*. Moreover, palm oil waste, particularly, EFBs are rich in cellulose, hemicellulose, and lignin, which are difficult to biodegrade naturally and require long decomposition periods *(Castano, Crespo, & Torres, 2019)*. Improper disposal can cause foul odors, breeding grounds for insects *(Kahar et al., 2022)*, and greenhouse gas emissions *(Pulingam et al., 2022)*.

However, palm oil waste presents a significant opportunity for valorisation into high-value products. One promising application is converting the cellulose content in palm solid waste into activated carbon, which can be used as an electrode material in bio-batteries *(Liu et al., 2025; Sonawane & Kandasubramanian, 2025)*, a renewable and environmentally friendly energy source *(Hou et al., 2023; Nasir et al., 2019; Sobri & Haris, 2025)*. The process involves breaking glycosidic bonds and releasing volatile compounds such as water (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), and small hydrocarbons *(Mettler et al., 2012; Zhu, Krumm, Facas, Neurock, & Dauenhauer, 2017)*.

Recent studies show that sodium hydroxide (NaOH) can enhance bio-batteries, hydrovoltaic energy harvesting, and other energy harvesting technologies, improving performance, durability, and efficiency in coffee grounds *(Haliq, Kan, & Ismail, 2022), and wood (Garemark et al., 2023)*. According to *(Shan et al., 2018; Wu et al., 2016)*, sodium hydroxide plays a critical role in the activation process by forming pore structures in the carbon material and enhancing its electrical conductivity. Higher concentrations of sodium hydroxide result in better current output due to increased surface area, micro- and mesopore development, and the removal of insulating impurities. Sodium hydroxide's designation as a strong electrolyte renders it a possible bio battery. Completely ionised ions can enhance electrical conductivity in the bio-battery electrolyte and expedite charge transfer between the anode and cathode. Sodium hydroxide diminishes internal resistance in the battery, enhancing electron transport between electrodes and substantially augmenting the voltage and current generated *(Huang et al., 2024)*. Therefore, this study aims to investigate the influence of sodium hydroxide concentration on the production of bio-battery electrical energy from palm oil solid waste and determine the optimal percentage for maximum performance.

MATERIALS AND METHODS

This study utilized 5 kg each of mature oil palm fronds (L1), empty oil palm bunches (L2), and oil palm shells (L3). Distilled water (H_2O) was used to cleanse the solid oil palm waste, while a 10% sodium hydroxide (NaOH) solution was employed as an electrolyte enhancer to improve the conductivity of the sample.

The solid waste used in this study was collected from oil palm fields in the Tanjung Morawa subdistrict of Deli Serdang Regency, North Sumatra, Indonesia. This waste, which includes palm fronds, empty palm bunches, and palm shells, is a byproduct of oil palm processing. The palm frond debris and discarded palm fruit bunches were initially rinsed with running water, then chopped into small segments (about 2 cm) to aid the succeeding procedure. The items are subsequently dried in an oven for one hour at a temperature of 100°C.

In the production of activated carbon, was employed the pyrolysis technique, a method chosen for its ability to yield high-quality activated carbon. This approach involves individually incorporating samples of palm fronds, shells, and desiccated palm fruit clusters, heating them to 500 °C, and conducting the pyrolysis process for 3 hours. The resulting pyrolysis products, specifically activated carbon derived from oil palm fronds and empty fruit bunches, are then pulverised to a 90-mesh size. We further enhance the electrolyte with sodium hydroxide, including it at concentrations of 5% (P1), 10% (P2), and 15% (P3) of the total mass.

The product design, a unique medium that stores activated carbon from solid palm oil waste originating from used batteries, was developed. This medium was tested for its electrical characteristics. The used batteries were ABC AA Blue Heavy Duty, measuring 14.5 mm in diameter (⌀) and 50.5 mm in height (h) (Fig. 1).

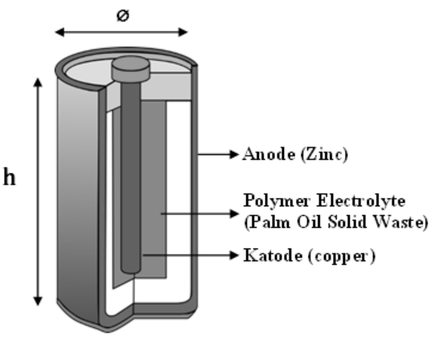


Fig. 1. Bio-Battery Prototype

The testing of the device is a meticulous process that involves inserting the carbon derived from solid palm oil waste into an empty battery, which is then tested with a green LED load. This test was used to evaluate how long the LED light could remain ON. Voltage and current were measured using a digital multimeter until no more electricity was generated, as evidenced by the light turning OFF. Power was calculated by multiplying current and voltage, while energy was derived by multiplying power by the duration the LED was ON. The device circuit in this study used two bio-batteries connected in series. The study was replicated three times, and data were analysed using a robust statistical method, the Analysis of Variance with α=1% and α=5% using SPSS software, to ensure the reliability of the impact of sodium hydroxide on solid palm oil waste results.

RESULTS AND DISCUSSION

Tab.s. 1 and 2 present the influence of waste type on the electrical parameters of bio-batteries. The variations in solid palm oil waste types have a profound impact on bio-battery performance. Each type of solid palm oil waste, with its unique chemical composition and physical structure, directly affects the efficiency of electrochemical reactions in the bio-battery system. For instance, empty palm oil fruit bunches, with their fibrous structure and high cellulose content, produce higher voltage and current, thereby increasing the power and electrical energy generated (Figs. 2a and 3b). In contrast, oil palm fronds and shells, with their stiffer and denser structure and higher lignin content, exhibit lower bio-battery performance. These findings highlight the significant role of waste type in determining energy conversion efficiency in bio-batteries.

Tab. 1 and Tab. 2 demonstrate that the interaction between waste types and sodium hydroxide concentration significantly impacts bio-battery performance. The experiments, which varied waste type and sodium hydroxide concentration, measured LED ON duration, voltage, current, power, energy, and electrical resistance. The best performance was recorded for empty oil palm fruit bunches combined with 15% sodium hydroxide (L2P3), producing high voltage and current that directly enhanced power and electrical energy. Conversely, palm oil fronds with 5% sodium hydroxide (L1P1) produced the lowest values in almost all parameters, indicating suboptimal activation of carbon. This underscores that both waste type and sodium hydroxide percentage are key factors influencing energy conversion efficiency in bio-batteries.

Tab. 1. The voltage, current, power, electrical resistance, LED ON duration and energy values on NaOH percentages in palm oil waste types

	Elec. voltage (V)	Elec. current (mA)	Elec. resistance (Ohm)	Elec. power (mW)	LED light ON duration (h)	Elec. energy (Wh)
L1P1	2.02	51.29	0.039	103.58	11.67	1.21
L1P2	2.46	55.60	0.044	136.95	16.83	2.31
L1P3	2.45	54.79	0.045	134.39	17.50	2.35
L2P1	2.46	61.56	0.040	151.19	19.83	3.00
L2P2	2.59	65.25	0.040	168.97	18.83	3.18
L2P3	2.61	69.53	0.038	181.48	21.33	3.87
L3P1	2.18	52.55	0.042	114.79	13.67	1.57
L3P2	2.42	54.17	0.045	131.08	16.67	2.18
L3P3	2.47	54.95	0.045	135.54	20.17	2.73

Description: L1 = Frond. L2 = Empty Bunch. L3 = Shell; P1 = 5% NaOH. P2 = 10% NaOH. P3 = 15% NaOH

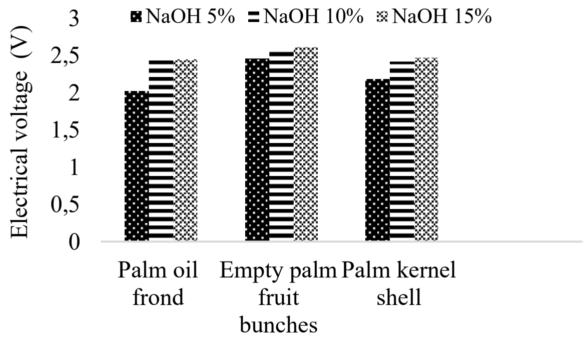
Fig. 1a and Tab. 2 show that voltage output varies with both waste type and sodium hydroxide addition. The highest voltage was obtained from empty palm oil fruit bunches (2.61 V), followed by shells, with fronds producing the lowest voltage (2.02 V). This may be attributed to the higher cellulose content and open porous fibre structure of empty bunches, which enhance conductivity and electron transfer. Shells, though carbon-rich, have denser structures that hinder conductivity, while fronds' lower carbon content and less effective conductive pathways result in lower performance. Sodium hydroxide concentration also significantly influenced voltage, with 15% addition yielding the highest voltage and 5% the lowest (Fig. 1). This aligns with previous findings *(Demir & Doguscu, 2022; Hérou, Crespo, & Titirici, 2020; Hu & Hsieh, 2017)* that sodium hydroxide improves microporosity and surface area, enhancing electrode–electrolyte contact and accelerating electrochemical reactions.

The current output followed a similar trend to voltage. Empty bunches produced the highest current (69.53 mA), followed by shells, with fronds at the lowest (51.29 mA). Higher fixed carbon content and microporosity in empty bunches enable better electron flow, increasing current. Sodium hydroxide concentration had a positive effect (Tab. 2 and Fig. 2a), with 15% addition producing the highest current, as sodium hydroxide enhances pore formation and removes insulating materials *(Liu, Shi, Xiang, Liu, & Ramamurty, 2024; Zuo & Ye, 2018)*. The best combination was L2P3 (69.53 mA), while L1P1 produced the lowest current (51.29 mA).

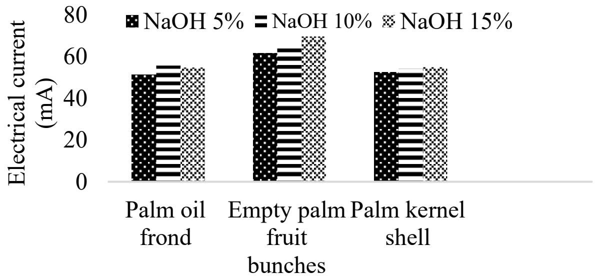
Electrical resistance decreased with increasing sodium hydroxide concentration, due to improved ionisation and conductive pathways. Empty bunches (L2) recorded the lowest resistance, attributed to their high carbon content, while shells (L3) had the highest (Fig. 2a). However, excessively high sodium hydroxide concentrations may leave sodium residues, potentially increasing resistance despite greater surface area *(Modenbach & Nokes, 2014)*. The lowest resistance was observed for L2P3 (0.038 Ω), and the highest for L1P3 and L3P3 (0.045 Ω).

Tab. 2. Analysis of variance of treatment on electrical voltage. electrical current. electrical resistance. electrical power. electrical energy. and LED light duration

	Statistical significance					
	Elec. voltage	Elec. current	Elec. resistance	Elec. power	Elec. energy	LED light ON duration
Type of solid oil palm waste (L; L1. L2 and L3)	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$
Percentage of NaOH (P; P1. P2 and P3)	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$
Interaction between L and P (LP)	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$



(a)



(b)

Fig. 1. Relationship between waste type and Sodium hydroxide addition on the electrical voltage (a) and current (b) of bio-batteries

Electrical power, a function of both voltage and current, was highest for empty bunches (L2) and lowest for fronds (L1). Sodium hydroxide addition significantly increased power, with 15% addition producing the highest output. The optimal combination, L2P3, yielded 181.48 mW, compared to only 103.58 mW for L1P1. This result reflects the synergistic effect of high carbon content and enhanced porosity on improving conductivity and electrochemical efficiency.

LED ON duration time reflects the practical applicability of the bio-battery. Empty bunches achieved the longest time, followed by shells and fronds. Sodium hydroxide addition extended LED illumination, with 15% producing the longest duration and 5% the shortest (Tab. 1 and Fig. 3a). The best result was for L2P3 (21.33 hours), while L1P1 produced the shortest (11.67 hours). This is consistent with the relationship between higher voltage/current and longer LED operation.

Electrical energy values followed trends similar to voltage and current. Empty bunches produced the highest energy, with fronds at the lowest. Increasing sodium hydroxide concentration improved energy yield, with 15% and 5% (Fig. 3b).. The optimal treatment, L2P3, reached 3.87 Wh, while L1P1 produced only 1.21 Wh. Higher sodium hydroxide concentrations enhance pore development, surface area, and conductivity, improving charge transfer efficiency and electrochemical performance.

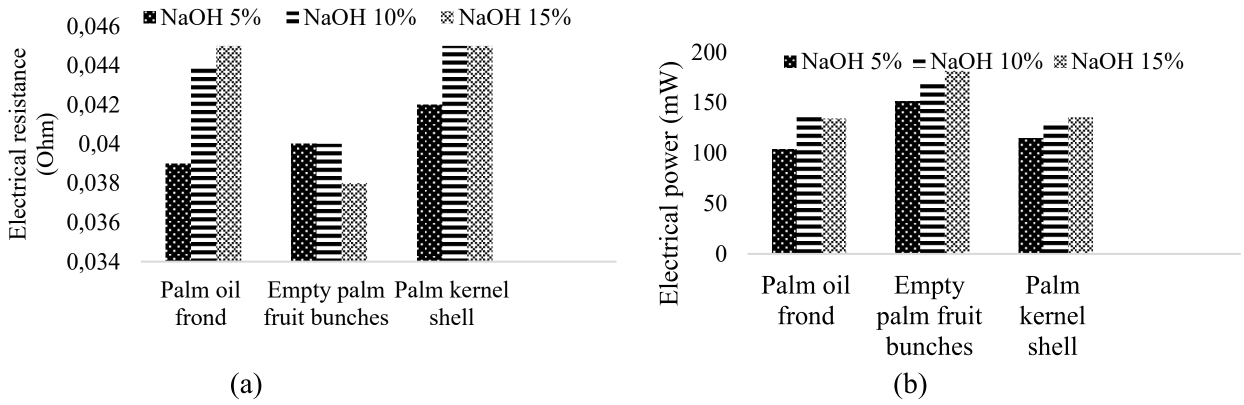


Fig. 2. Relationship between waste type and Sodium hydroxide addition on the electrical resistance (a) and power (b) of bio-batteries

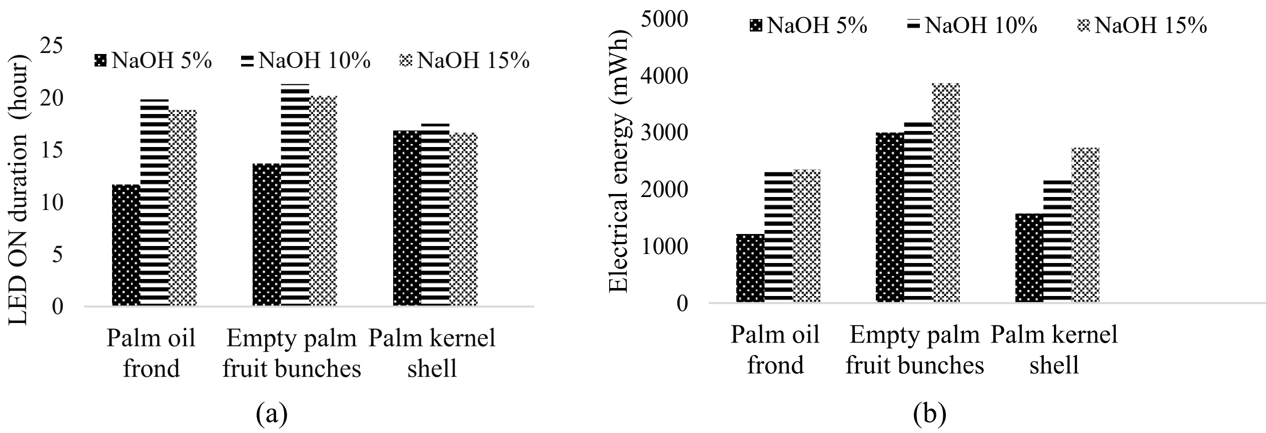


Fig. 3. Relationship between waste type and Sodium hydroxide addition on LED ON duration (a) and the electrical energy (b) of bio-batteries

CONCLUSIONS

Across all parameters—voltage, current, resistance, power, energy, and LED ON duration—the L2P3 combination (empty palm oil fruit bunches + 15% sodium hydroxide) consistently delivered the best performance. This treatment optimises fixed carbon content, microporosity, and conductivity, resulting in superior energy conversion efficiency. Conversely, palm oil fronds with low carbon content and insufficient activation (L1P1) consistently underperformed. These results provide valuable insights for developing efficient, sustainable bio-battery technology from palm oil waste.

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