

Optimization of CuSO_4 and Coconut Water (*Cocos nucifera*) Concentrations in a Tapioca Starch-Based Solid Electrolyte System to Enhance Bio-Battery Performance

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Abstract

Utilization of natural materials from biological resources has become a key approach in the development of sustainable energy technologies that are environmentally friendly and low in waste production. This study aims to develop an eco-friendly bio-battery by optimizing the concentration of CuSO_4 and coconut water (*Cocos nucifera*) in a tapioca starch-based solid electrolyte system to enhance its performance. The bio-battery structure comprises CuSO_4 and coconut water as ionic sources, tapioca starch as the electrolyte matrix, and graphite and aluminum as the cathode and anode electrodes, respectively. The solid electrolyte was prepared by mixing various masses of CuSO_4 into distilled water and coconut water, followed by blending with tapioca starch until a homogeneous solid was formed. The results show that bio-batteries utilizing coconut water-based electrolytes exhibit better performance than those using distilled water. The battery with distilled water yielded a maximum voltage and current of 0.620 V and 6.4 mA, respectively, at 4 grams of CuSO_4 . In contrast, the battery using coconut water as a solvent produced a maximum current of 79 mA at 6 grams of CuSO_4 , with an ionic conductivity of 1.39 S/m, indicating a tenfold increase in current output. These findings suggest that natural ions in coconut water significantly enhance the conductivity and capacitance of the electrolyte, contributing to improved bio-battery performance and stability. This research highlights the significant potential of natural materials in the development of more efficient and sustainable bio-batteries, supporting the implementation of environmentally friendly technologies toward a zero-waste society.

Keywords: CuSO_4 ; Bio-battery; Energies; Coconut water

INTRODUCTION

Global electricity demand is projected to increase substantially by 2050, with electricity accounting for an increasingly larger share of final energy consumption across residential, industrial, and transportation sectors. In the International Energy Agency (IEA) energy transition scenarios—including the Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS), and Net Zero Emissions Scenario (NZE)—electrification is considered a key strategy for decarbonizing heating, transportation, and industrial hydrogen production (IEA, 2024). Nevertheless, fossil fuels continue

to dominate global electricity generation, supplying more than 60% of worldwide electricity production (Gielen et al., 2019). This reliance has severe environmental consequences, particularly through the emission of carbon dioxide (CO_2), which is the primary driver of climate change and global warming. The energy sector, heavily dependent on coal, oil, and natural gas, is the largest contributor to greenhouse gas emissions, leading to deteriorating air quality and rising global temperatures (Ritchie & Rosado, 2017). These conditions highlight the urgent need for technological innovations that can reduce

environmental impact and support a sustainable energy transition.

One promising approach to address these challenges is the development of sustainable electrochemical systems. While conventional electrochemical systems based on fossil fuels have contributed significantly to global energy supply, they suffer from drawbacks such as high greenhouse gas emissions and relatively low energy efficiency compared to environmentally friendly technologies. As a result, the development of bio-batteries has emerged as a strategic solution to minimize environmental harm, improve energy efficiency, and support the shift toward a green economy (Hapuarachchi et al., 2020). Bio-batteries offer a more environmentally friendly alternative by utilizing microorganisms or organic materials as electrolytes. Organic waste materials—such as fruits and vegetables, banana peels, and cassava pulp—have been tested as base materials for bio-batteries. In addition to being renewable and biodegradable, these materials also offer the potential to reduce waste. However, despite their promising prospects, bio-batteries still face major challenges in terms of efficiency and stability, particularly due to their low conductivity (Fu & Zhong, 2019; Xie et al., 2013).

To improve bio-battery performance, several studies have explored the incorporation of inorganic salts as ionic enhancers within biomass-based electrolytes. Among these, copper(II) sulfate (CuSO₄) has been reported to improve ionic conductivity, facilitate charge transport, enhance interfacial stability, and increase energy storage capability, resulting in better electrochemical performance (Lee et al., 2020). Likewise, coconut water has received considerable attention as a natural electrolyte because it contains abundant potassium (K⁺), sodium (Na⁺), magnesium (Mg²⁺), calcium (Ca²⁺), and

other dissolved minerals that promote ion transport and electrochemical reactions (Valensia et al., 2021). Tapioca starch, meanwhile, serves as a matrix in the solid electrolyte due to its eco-friendly, biodegradable nature and its ability to form thin films as electrode separators, further strengthening the potential of developing a sustainable bio-battery system (Hapuarachchi et al., 2020).

Although previous studies have demonstrated the individual potential of CuSO₄, coconut water, and starch-based polymer matrices, research integrating these three components into a single solid-electrolyte bio-battery system remains very limited. Furthermore, most existing studies primarily focus on evaluating voltage and current output without systematically investigating the synergistic interaction between natural and inorganic ionic sources within a biodegradable polymer matrix. As a result, the electrochemical characteristics and performance enhancement mechanisms of such hybrid electrolyte systems are still not fully understood. This represents an important research gap that must be addressed to improve the efficiency and practical applicability of bio-batteries.

Therefore, this study develops a solid-electrolyte bio-battery based on a hybrid electrolyte consisting of tapioca starch as the biodegradable polymer matrix, CuSO₄ as the inorganic ionic enhancer, and coconut water as the natural electrolyte source, with aluminum and graphite serving as the anode and cathode, respectively. The novelty of this work lies in the integration of natural and inorganic electrolyte sources within a tapioca starch-based solid polymer electrolyte to produce an environmentally friendly bio-battery with enhanced electrochemical performance. The study systematically investigates the influence of electrolyte composition on electrical output to identify the optimum formulation for improving bio-battery

performance. The findings are expected to provide new insights into the design of sustainable solid-electrolyte bio-batteries and contribute to the advancement of low-cost, biodegradable energy storage technologies that support the global transition toward renewable energy systems.

MATERIALS AND METHODS

This research was conducted experimentally to investigate the performance of a bio-battery based on a solid electrolyte system composed of tapioca starch, CuSO₄, and coconut water. The experimental work was carried out at the Integrated Science Laboratory of MA Husnul Khotimah from October to December 2024. The instruments used in this study included a magnetic stirrer, digital balance, beaker glass, volume pipettes, digital multimeter, sample cups, electric cables, and alligator clips. The materials used consisted of graphite sheets, aluminum sheets, tapioca starch, CuSO₄, distilled water, coconut water, and alcohol for cleaning purposes.

The graphite and aluminum electrodes were cut into dimensions of 3 × 2 cm with a thickness of approximately 0.5 cm. Before use, the electrode surfaces were cleaned using alcohol and dried to ensure stable electrical contact during the electrochemical process. Coconut water was filtered to remove suspended impurities, while CuSO₄ was prepared in powder form for electrolyte preparation. This study employed a solid electrolyte system in which tapioca starch functioned as the polymer matrix, while CuSO₄ and coconut water served as ionic sources. The electrolyte was prepared by dissolving CuSO₄ into 20 mL of solvent using a magnetic stirrer

until homogeneous. Two solvent systems were investigated, namely distilled water and coconut water. After complete dissolution, 20 g of tapioca starch was gradually added and stirred continuously until a homogeneous solid electrolyte paste was formed.

The effect of CuSO₄ concentration on bio-battery performance was investigated using different CuSO₄ masses. For the distilled water electrolyte system, CuSO₄ masses of 1 g, 2 g, 3 g, 4 g, 5 g, and 6 g were tested. For the coconut water electrolyte system, CuSO₄ masses of 1 g, 2 g, 3 g, 4 g, 5 g, 6 g, 7 g, and 8 g were evaluated to determine the optimum composition. The prepared electrolyte paste was coated onto the graphite electrode surface, followed by attachment of the aluminum electrode to form the bio-battery cell. The assembled cell was clamped to maintain electrode stability and connected to a multimeter using cables and alligator clips. Electrical characterization was performed by measuring voltage, current, and resistance for each electrolyte variation.

The electrical power generated by the bio-battery was calculated using the equation:

$$P = V \times I$$

where P is power (W), V is voltage (V), and I is current (A). Electrolyte conductivity was determined based on resistance measurements using conductivity equations related to resistivity, electrode distance, and cross-sectional area. The obtained data were analyzed by comparing the influence of CuSO₄ concentration and solvent type on the electrochemical performance of the developed bio-battery system.

RESULTS AND DISCUSSION

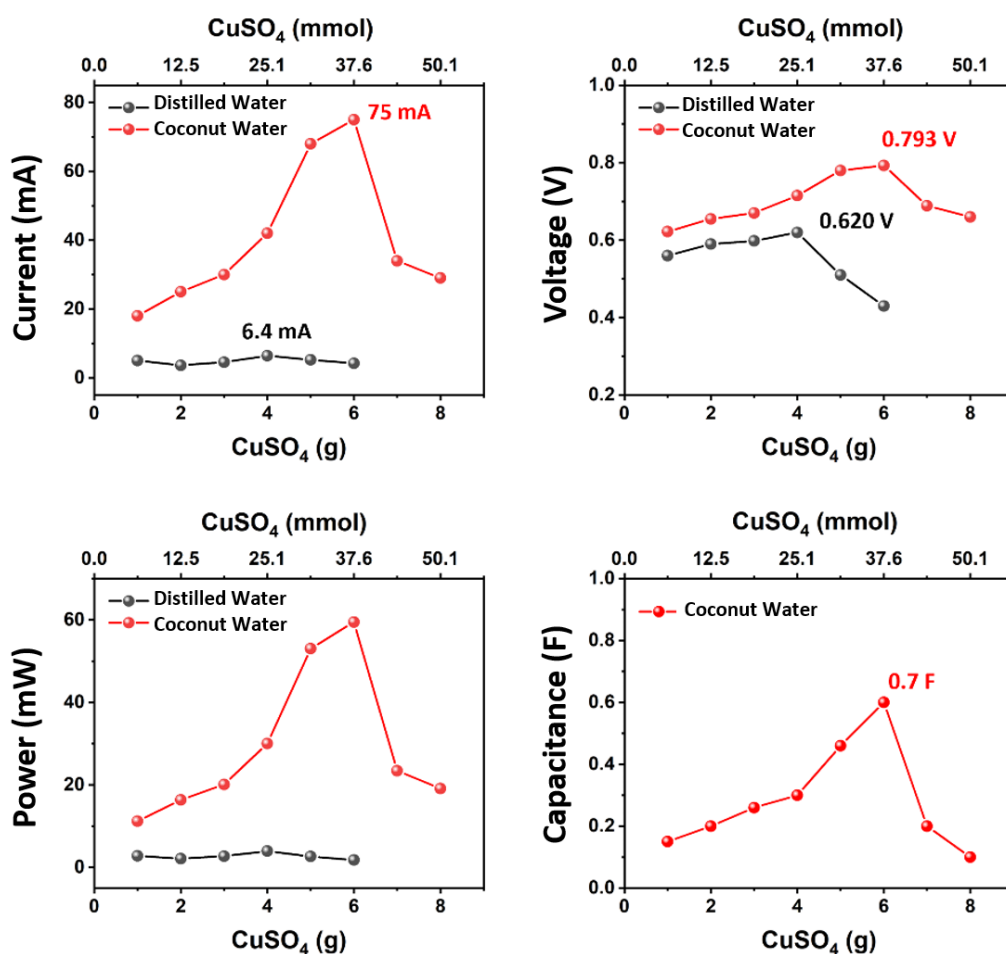


Figure 1. Electrical characteristics of bio-battery at different CuSO₄ concentrations using distilled water and coconut water electrolytes: (a) current, (b) voltage, (c) power, and (d) capacitance.

The bio-battery was fabricated using aluminum as the anode, graphite as the cathode, and a solid electrolyte composed of tapioca starch, CuSO₄, and coconut water. The developed bio-battery structure is shown in Figure 1 that presents the effect of CuSO₄ concentration on the current generated by the bio-battery using distilled water and coconut water as electrolyte solvents. For the distilled-water-based electrolyte, the current increased from 2.5 mA at 1 g CuSO₄ to a maximum value of 6.4 mA at 4 g CuSO₄. Beyond this concentration, the current gradually decreased to 5.23 mA and 4.22 mA at 5 g and 6 g CuSO₄, respectively. In contrast, the coconut-water-based

electrolyte produced substantially higher current values, reaching an optimum current of 75 mA at 6 g CuSO₄ before decreasing to 34 mA and 29 mA at 7 g and 8 g CuSO₄, respectively. These findings indicate that both the electrolyte composition and CuSO₄ concentration strongly influence the electrical performance of the developed bio-battery.

The increase in current with increasing CuSO₄ concentration can be explained by the greater number of charge carriers available in the electrolyte. When dissolved, CuSO₄ dissociates into Cu²⁺ and SO₄²⁻ ions, increasing ionic conductivity and facilitating ion migration between the electrodes. Higher ionic conductivity

reduces internal resistance, allowing oxidation and reduction reactions to occur more efficiently and resulting in greater electron flow through the external circuit. Similar behavior has been reported by Patra et al. (2023), who described that improving ion transport within bio-battery systems enhances electrochemical performance, and by Liu et al. (2016), who explained that efficient ion migration is essential for maintaining continuous electron flow during electrochemical reactions.

The electrochemical reactions occurring in the present bio-battery also support this trend. At the aluminum anode, oxidation produces Al^{3+} ions and releases electrons, while at the graphite cathode Cu^{2+} ions are reduced by accepting electrons from the external circuit. Consequently, increasing the concentration of CuSO_4 provides more Cu^{2+} ions to participate in the reduction reaction, thereby improving the overall electrochemical process. This finding agrees with Lee et al. (2020), who reported that CuSO_4 serves as an effective electrochemically active material because it supplies sufficient ionic species to sustain charge-transfer reactions.

Compared with distilled water, coconut water produced approximately ten times higher current under optimum conditions. This remarkable improvement is attributed to the naturally occurring electrolytes contained in coconut water, including potassium (K^+), sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and chloride (Cl^-) ions. These ions increase the ionic strength of the electrolyte and facilitate faster ion transport throughout the tapioca-starch matrix. Coconut water also contains naturally occurring organic compounds that contribute to electrolyte stability and improve interactions between dissolved ions and the polymer matrix. Yong et al. (2019) reported that coconut water possesses a rich electrolyte composition, while Halim et al. (2018) demonstrated that its high mineral content

significantly enhances ionic conductivity. Likewise, Valensia et al. (2021) found that coconut water effectively improves the electrical output of bio-battery systems because of its ability to facilitate electrochemical reactions.

In addition to coconut water, the tapioca starch matrix also contributed to the improved electrical performance. Tapioca starch functions not only as a biodegradable polymer but also as a medium that retains moisture and supports ion transport within the solid electrolyte. The hydroxyl groups in starch molecules interact with dissolved ions, allowing continuous ionic movement while maintaining the structural stability of the electrolyte. Hapuarachchi et al. (2020) reported that starch-based polymer electrolytes exhibit improved ionic conductivity and mechanical stability, making them suitable for environmentally friendly battery applications. Similar observations were also reported by Zhang et al. (2018), who emphasized that polymer electrolytes with enhanced ionic pathways can significantly improve electrochemical performance.

Although increasing CuSO_4 concentration enhanced current generation, concentrations exceeding the optimum value resulted in a noticeable decline in current. This phenomenon indicates that the electrolyte reached ionic saturation, where the addition of further Cu^{2+} and SO_4^{2-} ions no longer contributed effectively to charge transport. Instead, stronger electrostatic interactions among ions reduced their mobility and hindered efficient ion migration. Furthermore, excessive ionic concentration may promote precipitation and concentration polarization near the electrode surface, thereby reducing charge-transfer efficiency. Similar behavior has been observed in solid-state battery systems, where excessive ionic concentration leads to lower electrochemical performance because of increased interfacial resistance and limited ion mobility (Pervez et al.,

2019).

Overall, these results demonstrate that the performance of the developed bio-battery is governed by the balance between ion concentration and ion mobility within the electrolyte. The optimum composition of 6 g CuSO₄ dissolved in coconut water provided sufficient charge carriers while maintaining efficient ionic transport, resulting in the highest current output. This finding confirms that combining CuSO₄ with a natural electrolyte such as coconut water is an effective strategy for improving the electrical performance of biodegradable solid-electrolyte bio-batteries.

CONCLUSION

This study successfully developed a biodegradable solid-electrolyte bio-battery using tapioca starch as the polymer matrix, CuSO₄ as the ionic source, and coconut water as a natural electrolyte. The experimental results demonstrated that both the electrolyte composition and CuSO₄ concentration significantly influenced the electrical performance of the bio-battery. Increasing the CuSO₄ concentration enhanced the current, voltage, power output, and capacitance until the optimum concentration was reached. Beyond this point, further addition of CuSO₄ reduced the electrical performance because of ionic saturation, which limited ion mobility and increased internal resistance.

Among the investigated electrolyte systems, coconut water exhibited substantially better performance than

distilled water because of its naturally occurring electrolytes, including potassium, sodium, and magnesium ions, which improved ionic conductivity and facilitated charge transport within the solid electrolyte. The optimum performance was achieved using 6 g of CuSO₄ dissolved in coconut water, producing a maximum current of 75 mA, a voltage of 0.793 V, and an electrolyte conductivity of 1.39 S/m. In addition, larger electrode dimensions (3 cm × 2 cm) generated higher current and voltage with lower internal resistance than smaller electrodes, demonstrating the importance of electrode surface area in improving electrochemical efficiency.

Overall, the combination of tapioca starch, CuSO₄, and coconut water provides a promising, low-cost, and environmentally friendly approach for developing sustainable solid-electrolyte bio-batteries. These findings contribute to the development of renewable energy technologies based on biodegradable materials and highlight the potential of natural electrolytes as alternatives to conventional battery systems. Future research is recommended to investigate the long-term stability, charge-discharge cycling performance, and electrochemical characteristics of the developed bio-battery using advanced characterization techniques such as electrochemical impedance spectroscopy (EIS). In addition, further optimization of electrolyte composition, electrode materials, and polymer matrices may improve the electrical performance and broaden the practical applications of biodegradable bio-battery technology.

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