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Bioelectrochemical Systems (BESs) Technology for The Production of Electrical Energy from Kepok Banana Stem

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Abstract

Bioelectrochemical Systems (BES) technology is a method for generating electric energy using bacteria as catalysts. The electricity is produced by Microbial Fuel Cells (MFCs), which represent the latest development in biological energy research. This study utilized substrates from banana stems and the bacterium *Pseudomonas* sp. The research aims to assess the potential of banana stems as a substrate in the MFC system and to determine the effects of adding a combination of an electrolyte solution and an appropriate buffering material to achieve maximum current, potential difference, and power density values. The results showed that the maximum current and potential difference achieved were 1.05 mA and 0.62 V, respectively, with a power density value of 446 mW/m². When combining the $KMnO_4$ electrolyte solution with sodium phosphate buffer, a potential difference of 0.76 V and a current of 1.75 mA were obtained, resulting in a power density value of 911 mW/m². By using the $K_3[Fe(CN)_6]$ electrolyte solution buffer with potassium phosphate buffer, a current of 1.14 mA was produced, and the power density value reached 406 mW/m².

Keywords: Banana Stems, buffer phosphate, power density, microbial fuel cells, pseudomonas sp.

INTRODUCTION

The utilization of electrical energy in Indonesia demands concrete solutions, such as exploring alternative energy sources that leverage bacteria as catalysts for electricity generation (Hayati, Nuryanto, & Suyati, 2015, Serna-Jiménez et al., 2021). The availability of fossil-based energy sources is depleting, necessitating the search for and ongoing development of alternative energy sources. This imperative encourages innovation among humans in the quest for such alternatives (Tiwari, Jain, Mungray, & Mungray, 2019). One promising alternative energy source to reduce dependency on fossil fuels is Bioelectrochemical Systems (BESs) technology. In this system, microorganisms interact with electrodes by transferring electrons, which are either released or provided, through electrical circuits. The most commonly employed form of BESs is the Microbial Fuel Cell (MFC) (Rahimnejad & Adhami, 2015). Microbial Fuel Cell (MFC) is a system that converts chemical energy into electrical energy using microorganism (Santoro, Arbizzani, Erable, & Ieropoulos, 2017).

The operational principle of the MFC system involves the breakdown of organic matter into protons (H^+), CO_2, and electrons, which are then transferred to the anode. Microbes metabolize in an anaerobic state, breaking down glucose into protons, electrons, and carbon dioxide. These byproducts can serve as a source of electric current (Konovalov, Pogharnitskaya, Rostovshchikova, & Matveenko, 2015, Bhargavi et al., 2018). The MFC presents numerous advantages, primarily its ability to generate electrical energy from organic materials. Consequently, the MFC stands as a viable alternative energy solution, capitalizing on organic matter that may otherwise end up as waste. Notably, the banana stem represents one such organic material that remains to be fully optimized for energy production (Yamshchikova & Lisetskij, 2015, Wahyuni, Heriyono, Aisyah, Baharuddin, & Patunrengi, 2022, Obileke et al., 2021)..

The banana stem boasts high-quality fibers, making it a promising resource. Considering the fiber's anatomical structure, it emerges as a potential alternative material capable of serving as a source of cellulose (Susanti, Iqbal, Sholeha, & Putri, 2022).

This cellulose, once employed as a substrate, can facilitate the decomposition of organic matter by microbes to generate energy, thereby yielding economic value through the advancement of MFC technology. However, prior to blending banana stem fibers with other components, a treatment process is essential. Alkali treatment, involving the use of substances like sodium hydroxide (NaOH), is anticipated to influence the resultant cellulose fibers. Alkali treatment plays a significant role in eliminating lignin, thus affecting the composition and properties of the cellulose fibers (Mostafa, 2021).

The output of the MFC employs cellulose extracted from banana stem waste for electricity generation. Banana stem waste stands as an economical and easily obtainable alternative raw material. By applying alkaline treatment to cellulose lignin materials, the chemical and physical structure of the fiber surface can be altered, rendering it more susceptible to microbial decomposition (Gumisiriza, Hawumba, Okure, & Hensel, 2017). Among the organisms capable of breaking down hydrocarbon compounds is *Pseudomonas sp.* This bacterium possesses the capacity to degrade organic matter present in the natural environment. Organic matter containing hydrocarbon compounds serves as a nutrient source for bacterial growth, enabling the production of energy through metabolic processes (Samarina, Skufina, Samarin, & Ushakov, 2018). Introducing the right concentrations of an electrolyte solution and buffer solution can lead to an elevation in the electrical potential within the MFC system (Konovalov et al., 2015).

Consequently, the potential of banana stems as a cellulose source, harnessed by the bacterium *Pseudomonas sp.* holds promise for generating electrical energy using Bioelectrochemical Systems (BESs) technology, particularly within Microbial Fuel Cells (MFCs).

METHODOLOGY

Materials and Instrumentals

The utilized materials consist of Banana Stem (sourced from Around Lake Mawang, Gowa Regency, South Sulawesi), aluminum foil, 1 M hydrochloric acid (HCl), *Pseudomonas* sp. isolate, 70% alcohol, distilled water (H_2O), Swallow agar, potassium phosphate buffer (K_2PO_4) at pH 7, sodium phosphate buffer (Na_2PO_4) at pH 7, 0.2 M potassium ferricyanide ($K_3Fe(CN)_6$), 0.2 M potassium permanganate ($KMnO_4$), graphite electrode, KCl salt, copper wire, nutrient agar media (NA), nutrient broth medium, and 1 M sodium hydroxide (NaOH).

The instruments used in the study included the Heracus Thermo Scientific TYP B6120 incubator, Kern ABJ analytical balance, Thermo Scientific MaxQ4000 incubator shaker, double chamber MFC bioreactor, YX 28OD autoclave sterilizer, Memmert oven, ESCO air flow laminar (LAF), Masda DT830B digital multimeter, Philips blender, Electric heater from the brand Maspion, crocodile clips, hose wire, beakers, correction tubes, 250 mL Erlenmeyer flasks, pipette scales, petri dishes, drip pipettes, cables, spatulas, and tube racks.

Construction of Bioelectrochemical Systems (BESs) MFC

The MFC system in the study consisted of an anode and a cathode with a volume of 1000 mL; a salt bridge connected each of the anode compartments and the cathode. The manufactured salt bridges are made of KCl 1M and 5% agar which is then included in PVC pipes. The electrodes used are sourced from new batteries. The electrodes were soaked with 1M NaOH and 1M HCl solutions for one day each.

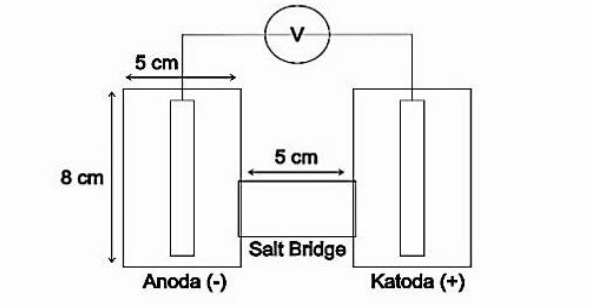

Figure 1. MFC Double Chamber Design

The electrodes are soaked with distilled water until the moment of use. The MFC bioreactor is manufactured by connecting two plastic containers connected to a salt bridge and electrode rods attached to the conducting wire on the surface of the container. MFC system design as Figure 1.

Preparation of *Pseudomonas* Bacteria s*p*

The *Pseudomonas sp* isolates are streaked onto prepared Agar Nutrient (NA) media and subsequently incubated for a duration of 24 hours. Following this, an inoculum medium is prepared by weighing 2.4 g of Nutrient Broth (NB) in 300 mL of distilled water. The mixture is then incubated for 30 minutes and subsequently transferred into a Laminar Air Flow environment. The cultivated bacteria are collected using an ose wire and introduced into an Erlenmeyer flask containing Nutrient Agar (NA) media. The inoculum is subjected to agitation for 24 hours at a

temperature of 37°C, with a rotation speed set to 125 rpm.

Preparation of Banana Stem Substrate (*Moses sp)*

Banana stems are collected from Lake Mawang in Gowa Regency, South Sulawesi. The collected Banana Stem samples are sun-dried before being blended into a mash. Subsequently, 1000 g of the mashed Banana Stem is weighed and mixed with water. This mixture is then heated to a temperature of 100°C for a duration of 30 minutes. Following this process, a banana stem substrate slurry of approximately 2000 mL is obtained, which is then stored for utilization in the MFC bioreactor.

Preparation of Electrolyte Solution $KMnO_4$

A quantity of 31.6 g of $KMnO_4$ solids is weighed and subsequently dissolved in 500 mL of distilled water. This solution is then transferred into a 1000 mL measuring flask and adjusted to the fill line. Finally, the solution is stored within a brown bottle.

Preparation of Electrolyte Solution $K_3Fe(CN)_6$

$K_3Fe(CN)_6$ solids are measured out to a quantity of 33 g and then dissolved in 500 mL of distilled water. This resultant solution is transferred into a 1000 mL measuring flask and adjusted to reach the fill line. Subsequently, the solution is stored in a brown bottle.

Preparation of Salt Bridge

Amount 5 g nutrient to be dissolved with 100 mL of distilled water then heated. Next is added 3 g of homogenized KCl. Then the solution is put into the PVC pipe and waited until it solidifies and is ready for use (Figure 2).

Figure 2. Preparation of Salt Bridge

MFC Experiments Without Electrolyte and Buffer Solutions

The prepared banana stem substrate is introduced into the anode chamber, totaling 300 mL. Following this process, 10 mL of *Pseudomonas sp*. bacteria is added to the anode chamber. For the cathode chamber, 300 mL of distilled water is introduced. Subsequently, the chamber cover is securely placed, and the setup is connected to a voltmeter using crocodile clips. Voltage and current readings are taken every hour over a period of 36 hours to monitor the generated electrical potential (Figure 3).

Figure 3. Experimental process and energy measurement

Effect of $KMnO_4$, Sodium Phosphate, and Potassium Phosphate

The banana stem substrate that has been made is put into the anode chamber as much as 300 mL and 10 ml of *Pseudomonas Sp* bacteria is added then another 5 mL of Sodium phosphate pH 7 buffer solution is added. In the cathode chamber is inserted 300 mL $KMnO_4$ 0.2 M. After that, a chamber cover is installed and connected to a voltmeter. Measures the voltage and voltage generated every hour for 36 hours. Repeated the experiment using a buffer solution of Potassium phosphate pH 7.

Effect of $K_3Fe(CN)_6$, Sodium phosphate buffer solution and Potassium Phosphate

The prepared banana stem substrate, totaling 300 mL, is placed into the anode chamber. Alongside this, 10 mL of Pseudomonas sp. bacteria is introduced into the chamber. Additionally, 5 mL of Sodium phosphate buffer solution at pH 7 is added. Within the cathode chamber, 300 mL of $K_3Fe(CN)_6$ solution is introduced.

Subsequent to these steps, the chamber cover is secured, and the setup is connected to a voltmeter using crocodile clips. The voltage and current values are measured each hour for a duration of 36 hours. This experiment is then repeated using a Potassium phosphate buffer solution at pH 7 in place of the Sodium phosphate buffer solution.

RESULTS AND DISCUSSION

The potential difference measurements of the MFC system using Pseudomonas sp. bacteria with a banana stem substrate, in the absence of an electrolyte solution and buffer material combination, are summarized in Table 1. The potential difference exhibits a progressive increase from the 8th hour to the 16th hour, reaching its peak value of 0.62 Volts. This increase is followed by a subsequent decline until the 20th hour, followed by another rise leading to the second maximum potential difference of 0.4 volts. The observed variations can be attributed to the absence of added electrolyte solutions and buffer materials. The absence of these components affects bacterial growth as they contain essential metallic elements required by bacteria for cell component synthesis and energy production, such as potassium and sodium (Gil et al., 2003).

In the MFC system, the generated current value without the inclusion of electrolyte solutions and buffer materials exhibits fluctuation. The measurement results depict variable current data, likely stemming from bacterial competition for nutrients from the substrate (Javed, Nisar, Ahmad, Yasmeen, & Zahoor, 2018). Before producing electrical energy, bacteria are required to hydrolyze lignin, cellulose, and hemicellulose into simpler sugars.

Table 1. Data on the results of measuring potential differences and currents without the addition of electrolyte solutions and buffer solutions

Time (Hours)	Voltage (Volts)	Current (mA)
0	0.10	0.02
4	0.18	0.08
8	0.58	0.07
12	0.62	0.09
16	0.52	0.04
20	0.10	0.55
24	0.29	0.46
28	0.39	1.05
32	0.04	0.08
36	0.06	0.09

As suggested by Hayati et al. (2015), the addition of a buffer serves the purpose of stabilizing pH changes. Maintaining a stable pH is crucial, as elevated pH levels can lead to the entry of OH^- ions into the anode chamber, potentially impeding the transfer of protons from the anode to the cathode. This interference could result in the multimeter not registering the potential difference.

The study's outcomes involved employing a banana stem substrate along with an electrolyte solution comprising $KMnO_4$, in conjunction with a combination of sodium phosphate and potassium phosphate buffers. The primary objective of this approach was to enhance electricity production within the MFC system. Notably, the presence of competing bacteria striving to acquire nutrients from the substrate influenced the results. Moreover, the bacterial metabolic process entails the hydrolysis of lignin, cellulose, and hemicellulose into simpler sugar molecules before the conversion of these sugars into electrical energy takes place. This intricate series of processes underpins the energy generation mechanism within the system.

The incorporation of a buffer solution serves to regulate pH fluctuations, preventing an excessive increase in pH. Elevated pH levels can lead to the influx of OH^- ions into the anode chamber, thereby obstructing the movement of protons from the anode to the cathode. This hindrance can result in the multimeter failing to register the potential difference. According to Gil et al., (2003) adding a buffer at the anode aids in pH reduction, establishing a pH range conducive to bacterial growth. The observed outcomes are presented in Table 2. A comparative analysis was conducted utilizing a $K_3Fe(CN)_6$ electrolyte solution to ascertain the impact of incorporating electrolyte solutions and phosphate buffers.

Table 2. Results of measuring potential differences and $KMnO_4$ currents with a combination of Na_3PO_4 and K_3PO_4 Buffer

Time (hour)	Substrate + $KMnO_4$			
	Buffer Na_3PO_4		Buffer K_3PO_4	
	Voltage (Volts)	Current (mA)	Voltage (Volts)	Current (mA)
0	0.04	0.02	0.06	0.02
4	0.18	1.04	0.44	0.25
8	0.55	0.10	0.04	0.04
12	0.26	0.19	0.20	0.28
16	0.76	0.08	0.04	0.11
20	0.48	1.75	0.14	1.40
24	0.06	0.06	0.19	0.78
28	0.20	0.97	0.17	1.43
32	0.10	0.16	0.06	0.12
36	0.04	0.03	0.04	0.04

The results of the research involving a banana stem substrate, coupled with the addition of a $K_3Fe(CN)_6$ electrolyte solution alongside a combination of sodium phosphate and potassium phosphate buffers, are documented in Table 3.

Table 3. Data on the results of measuring potential and current differences combination of Na buffer$_3PO_4$ and K_3PO_4

Time (Hour)	Substrate + $K_3Fe(CN)_6$			
	Buffer Na_3PO_4		Buffer K_3PO_4	
	Voltage (volts)	Current (mA)	Voltage (volts)	Current (mA)
0	0.05	0.02	0.11	0.20
4	0.70	0.31	0.35	0.98
8	0.09	0.03	0.08	0.03
12	0.06	0.51	0.11	0.27
16	0.04	0.25	0.05	0.04
20	0.12	0.30	0.20	0.03
24	0.11	0.12	0.05	1.14
28	0.05	0.59	0.19	0.08
32	0.04	0.06	0.07	0.06
36	0.07	0.08	0.52	0.19

The result of research utilizing a banana stem substrate with the addition of an electrolyte solution of $K_3Fe(CN)_6$ with a combination of sodium phosphate and potassium phosphate buffers can be seen in Table 3.

Table 4. Power density (mW/m^2) result data on each addition of electrolyte solution with buffer

Combination of electrolyte and buffer material	Power density (mW/m^2)
No Additions	446
$KMnO_4$ and Sodium Phosphate Buffer	911
$KMnO_4$ and Potassium Phosphate Buffer	421
$K_3Fe(CN)_6$ and Sodium Phosphate Buffer	287
$K_3Fe(CN)_6$ and Potassium Phosphate Buffer	406

The results of the study using banana stem substrate with the addition of electrolyte solutions $KMnO_4$ and $K_3Fe(CN)_6$ with a combination of sodium phosphate buffer and potassium phosphate obtained data on the results of voltage and current. Then a calculation of the *Power Density* value (mW/m^2) was carried out to determine the density of the power produced. It occurred when bacteria break down lignocellulose into lignin and cellulose so that bacteria directly use cellulose and hemicellulose to produce energy, hemicellulose also contains glucose. The resulting power density values can be seen in Table 4.

CONCLUSIONS

The BESs technology system generates energy, yielding potential difference values and a maximum current of 0.62 V and 1.05 mA. The utilization of an electrolyte solution comprising $KMnO_4$ combined with a Sodium Phosphate Buffer solution leads to an enhanced potential difference and maximum current, measuring 0.76 V and 1.75 mA, respectively. Incorporating the $K_3Fe(CN)_6$ electrolyte solution along with a potassium phosphate buffer yields a maximum current of 1.14 mA. Among the tested combinations, the amalgamation of the $KMnO_4$ electrolyte solution with the sodium phosphate buffer solution results in the highest Power Density (mW/m²) value, reaching 911 mW/m².

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