COASTAL AND OCEAN JOURNAL

Article

Performance Enhancement of Microbial Fuel Cells from Fishery Wastewater Using Boost Converter Device

Bustami Ibrahim [1,*], Uju [1], I Dewa Made Subrata [2], and Rahmat Agung Ramadhan [1]

[1] Department of Aquatic Product Technology, Faculty of Fisheries and Marine Sciences, IPB University, Bogor 16680, Indonesia
[2] Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor 16680, Indonesia
* Correspondence: bibrahim@apps.ipb.ac.id

Citation: Ibrahim, B.; Uju.; Subrata, IDM.; Ramadhan, RA., 2024. Performance Enhancement of Microbial Fuel Cells from Fishery Wastewater Using Boost Converter Device. *Coastal and Ocean Journal*, (8)2: 52-68.

Received: 30-05-2024
Accepted: 17-12-2024
Published: 20-12-2024

Publisher's Note: Coastal and Ocean Journal (COJ) stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: Electricity is a fundamental need in daily life. Fossil energy is commonly used to generate electricity; however, as a non-renewable resource, it will eventually be depleted without innovations involving renewable energy. Fishery wastewater can generate electricity using the Microbial Fuel Cell (MFC) system. However, the electricity produced is relatively low. This study aims to increase the electrical voltage generated from *pindang* fish wastewater in an MFC system by integrating a boost converter circuit. The research was conducted using five MFC systems connected in series and linked to a boost converter. The electrical output of the MFC system with the boost converter circuit showed a voltage of 12.13±0.87 V, a current of 0.86±0.20 mA, and a power output of 10.50±3.11 mW. In contrast, the system without the boost converter produced a voltage of 2.24±0.26 V, a current of 0.17±0.03 mA, and a power output of 0.38±0.11 mW. The increase in electricity output demonstrates the functionality of the boost converter circuit. Additionally, the MFC system effectively reduced BOD, COD, and TAN values in the fishery wastewater.

Keywords: boost converter; electricity; fishery processing industry wastewater; microbial fuel cell

1. Introduction

Electricity is a fundamental necessity in daily life, and the demand for electrical energy in Indonesia continues to rise annually in line with economic growth. Currently, electricity generation predominantly relies on fossil fuels. The demand for fossil fuels increases by an average of 5.9% per year (Sugiyono et al., 2019). However, the availability of petroleum in Indonesia declined by 0.27% in 2018 compared to 2017, while natural gas availability decreased by 5.02%. In contrast, coal reserves in 2018 stood at 39.89 billion tons, but with a production rate of 558 million tons per year, it is estimated to be depleted within 71 years (Sugiyono et al., 2019). Given that fossil fuels are non-renewable energy sources, innovative solutions involving renewable energy are essential for long-term sustainability. According to the National Energy Policy outlined in the 2018–2027 RUPTL, renewable energy is expected to contribute at least 23% of Indonesia's energy mix by 2025 and 31% by 2050, while the reliance on oil, coal, and natural gas is projected to decline (Decree of the Minister of Energy and Mineral Resources, 2018). By 2025, the demand for electrical energy will primarily come from the transportation sector (35%), whereas by 2050, it will be dominated by the industrial sector (37–42%) (National Energy Council, 2019).

The industrial sector is anticipated to require the largest amount of electricity in 2050, with various industries, including food processing and automotive, playing a significant role. Among these, the fisheries industry contributes both valuable products and substantial waste. Improper management of fishery waste can negatively impact the environment. Fishery waste consists of two types: solid waste and liquid waste. Notably, liquid fishery waste has the potential to generate electricity. According to Ibrahim et al. (2014), liquid waste can serve as a substrate in microbial electrochemical cells, offering an alternative energy source through the Microbial Fuel Cell (MFC) system.

MFC technology is a renewable energy innovation that generates electricity from biomass using microorganisms, such as bacteria. In the MFC system, bacteria oxidize organic and inorganic compounds, releasing electrons and protons. The electrons flow through an external circuit (resistor) to the cathode, while protons migrate to the cathode via a membrane, resulting in electricity generation (Logan, 2008). The electrical power (Watts) produced depends on the potential difference (Volts) and electron flow (Amperes) between the anode and cathode (Sitorus, 2010). MFC systems can be designed using either a single-chamber (one-vessel) or double-chamber (two-vessel) configuration.

Previous research by Ibrahim et al. (2017) demonstrated that electrode material influences electricity production in MFC systems. Aluminum electrodes produced the highest voltage at 0.36 V, followed by iron (0.30 V) and carbon (0.29 V). Similarly, Rosmalawati (2014) showed that connecting multiple MFC systems in series can increase electrical output. However, the electricity generated remains relatively low. To address this limitation, additional tools such as a boost converter, an electric voltage amplifier, are required to enhance the output voltage (Rashid, 2003). This study highlights the potential of utilizing liquid fishery waste in MFC systems as a renewable energy source and explores strategies to improve electrical output, supporting the transition toward sustainable energy solutions.

2. Methods

2.1. Time and Location

The study was conducted from September to November 2023. *Pindang* fish wastewater samples were collected from *CV Cindy Group* in Parung, Bogor, West Java, while active sludge was obtained from the wastewater treatment plant (WWTP) of *PP Samudera Nizam Zachman* in North Jakarta. The experimental work was carried out at the By-Product Processing and Waste

Handling Laboratory, Department of Aquatic Product Technology, Faculty of Fisheries and Marine Sciences, IPB University. The characterization of *pindang* fish wastewater was performed at the Environmental Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University.

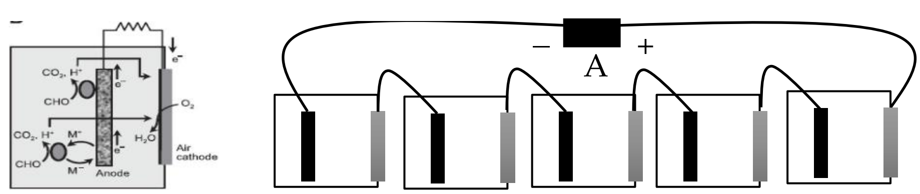
2.2. Materials and Tools

The materials used in this study were wastewater from CV Cindy Group Parung *pindang* fish processing, distilled water, glass, plastic board, 0.05 N HCl, 45% NaOH, H_2SO_4, Ag_2SO_4, $HgSO_4$, $K_2Cr_2O_7$, KH_2PO_4, $MgSO_4.7H_2O$, $FeCl_3$, NH_4Cl. The materials used to assemble the boost converter were NPN STN851 transistor, 25V/1 μF polar capacitor, 25V/6800 μF capacitor, 1N4001 rectifier diode, 1 kΩ resistor, 10 kΩ resistor, breadboard, and cable.

The tools used are jerry cans, aluminum foil, micropipettes, Whatman 42 paper, aerator (500-AP), measuring cups, digital scales, pH meters, UV lamps, UV-Vis spectrophotometers (Shimadzu), beakers, microscopes, digital multimeters, and alligator clamps, digital scales, measuring cups, petri dishes, test tubes, pipettes, glass bottles, reflux bottles, incubation bottles, thermometers, glue guns, tissues, carbon graphite, copper, scissors, incubators, cool boxes, COD reactors HI 839800, DO meters LT Lutron DO-5510, burettes (BOD), stopwatches, and gloves.

2.3. Microbial Fuel Cell System Tool Design

The Microbial fuel cell system in this study was adapted from the research of Liu and Logan (2004), employing a single-vessel configuration without a membrane. The distance between the cathode and anode was set at 6 cm, as established by Ibrahim et al. (2017). A series connection of five MFC systems was implemented, as electrodes connected in series have been shown to produce higher electrical outputs compared to parallel configurations (Ibrahim et al., 2014). The experiment was conducted in triplicate to ensure reliability and reproducibility of the results. The experimental procedure consisted of the following stages: (1) constructing vessels with dimensions of 7 × 10 × 10 cm, (2) installing a pair of electrodes in each vessel with a 6 cm separation, (3) setting up a stirrer in each vessel to facilitate uniform mixing, and (4) assembling the five MFC systems in series using electrical cables. The design layout of the MFC system utilized in this study is illustrated in Figure 1.



(I) (II)

Figure 1. (I) Design of MFC system in a vessel (Liu dan Logan 2004); (II) Design of five MFC systems in a vessel connected in series, (A) multimeter.

2.4. Boost Converter Toolkit

The Boost Converter circuit in the MFC system is a modification of the boost converter circuit (Rashid 2003) which uses several components including the NPN STN851 transistor, 25V/1 μF polar capacitor, 25V/6800 μF capacitor, 1N4001 rectifier diode, 1 kΩ resistor, 10 kΩ resistor, breadboard, and cables. These components are assembled on a breadboard. The boost converter circuit can be seen in Figure 2.

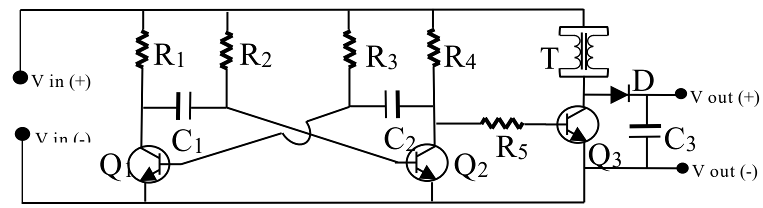


Figure 2. The schematic diagram of the boost converter circuit: (V in) voltage from the MFC system, (R1, R4) 1 KΩ resistors, (R2, R3, R5) 10 KΩ resistors, (C1, C2) 25V/1μF capacitors, (C3) 25V/6800 μF capacitor, (Q2, Q3, Q5) NPN transistors STN851, (T) single-winding transformer, (D) diode, (V out) output voltage.

2.5. Measurement of pH of Pindang Fish Wastewater

The pH value represents the degree of acidity of a liquid. The determination of the pH value was conducted using a pH meter. The pH of the waste was measured before treatment and after treatment.

2.6. Chemical Oxygen Demand (COD) Analysis (APHA 2012)

COD analysis was carried out by diluting the sample 25 times with distilled water. The sample was put into a reflux tube as much as 2.5 mL with the addition of 1.5 mL of digester solution and 3.5 mL of sulfuric acid reagent. The reflux tube used was previously washed with 20% H2SO4. The standard solution was made with two solutions, namely 1.5 mL of digester solution and 3.5 mL of sulfuric acid reagent. The standard solution was then put into a reflux tube. The reflux tube was placed on a COD reactor that had been heated at a temperature of 150℃ for 2 hours. The sample was then cooled and the solution absorbance was read with a UV-VIS spectrophotometer at a wavelength of 600 nm. The COD value can be calculated using the following formula:

$$\text{COD (mg/L)} = C \times Fp$$

Where:
C = levels obtained from measurement results with a calibration curve
Fp = dilution factor

2.7. Biochemical Oxygen Demand (BOD) Analysis (APHA 2012)

The BOD analysis was conducted by placing the sample into an Erlenmeyer flask and diluting it with 20 to 200 mL of distilled water. Following dilution, the sample was aerated for 30 minutes and then divided into two BOD bottles. One bottle was incubated, while the other was used to measure the DO in the solution. The incubated bottle was prepared without air bubbles and utilized a specialized BOD bottle. The sample was incubated for five days at 20°C in the dark. The DO values of the incubated and control samples were calculated, and the BOD value was determined using the following formula:

$$BOD\ (mg/L) = (DO - DO_5) \times Fp$$

Where:
DO = Dissolved oxygen content of sample t=0
DO_5 = Dissolved oxygen content of sample t=5

2.8. Total Ammonia Nitrogen (TAN) Analysis (APHA 2012)

TAN analysis was carried out by pipetting 25 samples and putting them into a 50 mL Erlenmeyer flask. Then 1 mL of phenol solution was added to the sample and homogenized. Then 1 mL of sodium nitroprusside was added to the sample and homogenized. Next, 2.5 mL of oxidizing solution was added and homogenized. The oxidizing solution was made by mixing 100 mL of alkaline citrate solution with 25 mL of sodium hypochlorite. The sample in the Erlenmeyer flask was then covered using plastic or paraffin film. The sample was left for 1 hour until a color formed. The sample was inserted into a cuvette on a spectrophotometer with a wavelength of 640 nm. The TAN value was obtained from the following formula:

$$TAN\ (mg\ N/L) = C \times Fp$$

Where:
C = The levels obtained from the measurement results with the calibration curve
Fp = Diluting factor

2.9. Electrical Values Analysis of Microbial Fuel Cell

The analysis of MFC electrical values was carried out using a digital multimeter to determine the voltage and electric current. Observations were made every hour for 48 hours. Each electrode was connected with a cable and connected to a multimeter. Measurements were made with 3 repetitions. Measurement of voltage values in the MFC system can be seen in Figure 3.

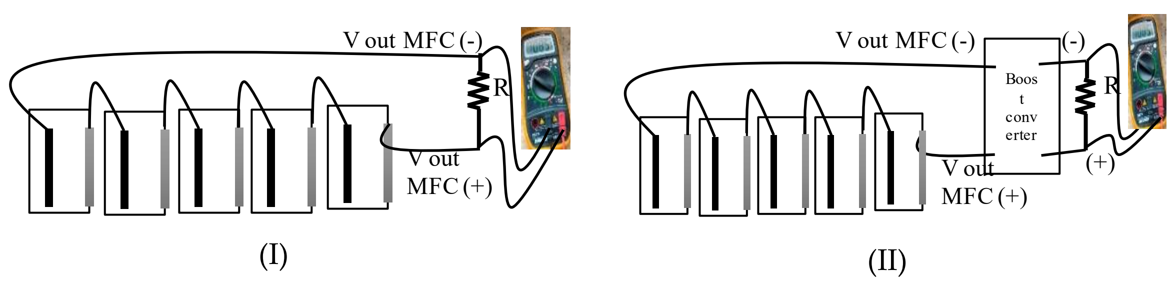


Figure 3. Voltage value measurement method, (R) 1 KΩ resistor; (I) measurement without boost converter, (II) measurement with boost converter.

The voltage measurement in the MFC system was conducted using a digital multimeter. In the MFC system without a boost converter, a load in the form of a 1 kΩ resistor was connected in parallel prior to measuring the voltage with the multimeter. Conversely, in the MFC system utilizing a boost converter, the load was applied after the circuit was connected in parallel and before the voltage measurement with the multimeter. The measurement of the current in the MFC system is illustrated in Figure 4.

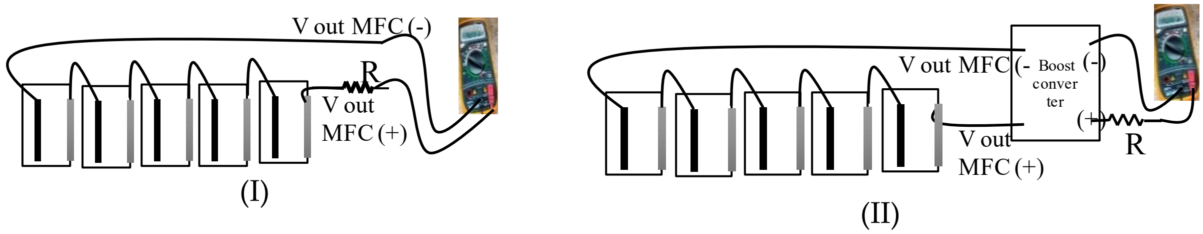


Figure 4. Current measurement method, (R) 1 KΩ resistor; (I) measurement without boost converter, (II) measurement with boost converter.

For the MFC system without a boost converter, a load in the form of a 1 kΩ resistor was connected in series with another resistor to the positive pole before being connected to the multimeter. In contrast, for the MFC system utilizing a boost converter, the load was applied after the series circuit on the positive pole and prior to connection with the multimeter.

2.10. Data Processing

Data processing in this study employed a descriptive analysis method, conducted using the Excel application. The obtained data were analyzed using a t-test. Specifically, the independent sample t-test was used, which is suitable for analyzing data sets that are not interrelated or paired. The hypothesis formulated in this study is as follows:

$$H_o = \mu_1 - \mu_2 = 0 \text{ or } \mu_1 = \mu_2$$
$$H_a = \mu_1 - \mu_2 \neq 0 \text{ or } \mu_1 \neq \mu_2$$

H_a states that the difference in the average of the two data groups is not equal to zero. The formula for the independent sample t-test is as follows:

$$t_{test} = \frac{X_1 - X_2}{\sqrt{\frac{n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}(\frac{1}{n_1}+\frac{1}{n_2})}}$$

Where:

$\overline{X_1}$ = average of the first sample group
$\overline{X_2}$ = average of the second sample group
n_1 = group size of the first sample group
n_2 = group size of the second sample group
S_1 = standard deviation of the first sample group
S_2 = standard deviation of the second sample group

Interpretation of the t-test can be done in several stages, namely, first, determining the significance value = alpha (α) 0.05. Second, comparing the t_{test} value with t_{tab} and if the value:
$t_{test} \geq t_{tab}$ or p-value $\leq \alpha(0,05)$ then it is significantly different (H_0 is rejected)
$t_{test} < t_{tab}$ or p-value $> \alpha(0,05)$ then there is no significant difference (H_0 is accepted)

3. Results and Discussion

Microbial Fuel Cell (MFC) is one method that can produce electrical energy. Electrical energy is formed from microorganisms that act as biocatalysts that convert organic materials bio-converted into electricity (Logan et al. 2006). The electrical energy produced from the MFC method according to Ibrahim et al. (2017) is relatively small, namely between 0.29 volts to 0.36 volts. The increase in electrical energy from MFC can be increased by assembling several MFC systems in series (Ibrahim et al. 2014) and using an additional boost converter circuit.

The MFC method was carried out with one vessel (single chamber) containing *pindang* fish wastewater and activated sludge with a ratio of 10: 1. The type of electrode used was carbon graphite as a positively charged cathode and copper as a negatively charged anode. The distance between the two electrodes was 6 cm, according to Ibrahim et al. 2017. The MFC prototype used 5 MFC vessels connected in series. The treatment used was the addition of a boost converter circuit. The boost converter circuit in this study can be seen in Figure 5.

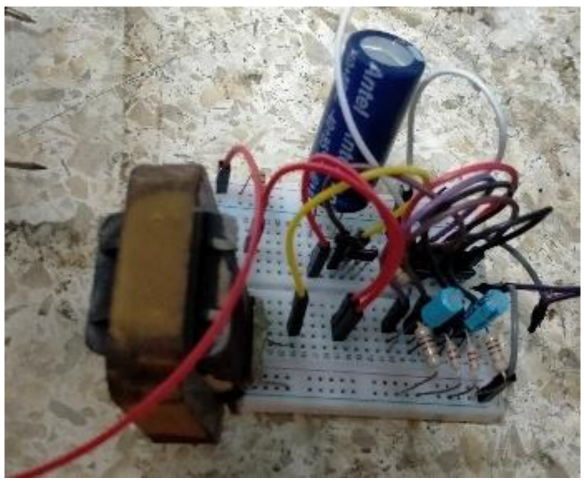


Figure 5. Boost converter device circuit.

Pindang or "*pemindangan*," is a traditional method of fish preservation that combines salting/ marinating and boiling processes over a specific duration. Common fish species used in this method include milkfish (*Chanos chanos*), mackerel tuna (*Euthynnus affinis*), Indian mackerel (*Rastrelliger kanagurta*), skipjack tuna (*Katsuwonus pelamis*), Nile tilapia (*Oreochromis niloticus*), scad (*Decapterus spp.*), and common carp (*Cyprinus carpio*), as noted by Budiman (2004). The fish *pindang* process generates wastewater as a by-product. This waste, resulting from the salting/ marinating and boiling steps, contains various chemical compounds. According to Astuti (2014), the wastewater from fish *pindang* process comprises 1.69 mg/L of protein, 13.44 mg/L of oil and fat, 0.08% ash content, 3.52% salt content, and 93.50% water content.

3.1. Working Principle of Microbial Fuel Cell (MFC)

Microbial Fuel Cell (MFC) can produce electrical energy by converting organic materials through bio-conversion (Logan et al. 2006). Microorganisms use organic substrates as an energy source and consume them to produce ATP through metabolic processes. ATP is used to produce electricity through electrochemical processes between electrodes. Microbial activity and the type of substrate used affect the performance of the MFC system in producing electrical energy (Kothapalli 2013).

The process of forming electrical energy in the MFC system is that microorganisms degrade organic materials which produce protons, electrons, and water. The cathode on the MFC will capture protons and electrons flowing to the anode. Electrons on the anode are flowed using a conductivity device to the cathode which will produce a potential difference (Logan et al. 2006). The potential difference or often called voltage is the electrical energy produced by the MFC. The substrate used in the MFC system is liquid waste from screening. The composition of the liquid waste from the Astuti (2014) scanning process has a fairly high protein content, so that the added bacteria will decompose organic compounds, namely protein, into ammonia nitrogen (NH_3-N) and then react with water to form ammonium nitrogen (NH_4-N) (Marta et al. 2021). The reactions that occur in the MFC system are:

$$\text{Anode: Protein + Bacteria} \rightarrow NH_4^+ + e^-$$
$$NH_4^+ + OH^- \rightarrow NH_4OH$$
$$\text{Cathode: } 2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$$

MFC systems connected in series can produce higher voltage values than those connected in parallel (Ibrahim et al. 2004). Series circuits have the same current on each load, the voltage source is divided by the number of series resistances if the resistance is the same, and if one of the circuits is broken, the current will stop. While in parallel circuits, the voltage on each load is the same as the voltage source, the current flowing on each load is different, the total current is the total amount of current flowing on each load and if it is broken, the current that stops is only on the disconnected load (Rosman et al. 2020).

3.2. Working Principle of Boost Converter

Boost converter is a DC-to-DC circuit used to increase the electrical voltage from the input source. The working principle of the boost converter uses the working principle of the switch, namely two on and off states or called the working principle of the step-up DC chopper (Mulyanto 2016). The boost converter circuit schematic according to Rashid (2003) can be seen in Figure 6.

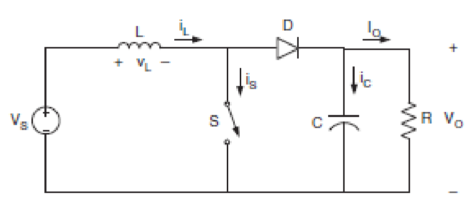


Figure 6. Schematic of the boost converter circuit.

The boost converter circuit consists of a DC input voltage source (Vs), inductor (L), control switch or transistor (S), diode (D), capacitor (C), and load resistance or resistor (R). The condition when the switch (S) is on for time t1, the current in the inductor will increase and energy is stored in the inductor. The condition of the switch is off for time t2, then the energy stored in the inductor will move to the resistor or load through the diode (Mulyanto 2016). Switching (on or off) in the boost converter circuit generally uses a microcontroller, while in this study a flip-flop circuit is used as a substitute for a microcontroller which functions to produce a square wave to control the transistor on-off. (Mulyanto 2016).

3.3. Electricity in Microbial Fuel Cell (MFC)

Electricity in MFC was measured using a tool, namely a digital multimeter. Electrical measurements in MFC included voltage, current, and power. Voltage and electric current were measured using a digital multimeter, while electric power was calculated using the voltage and current equations.

3.1.1. Voltage in MFC Systems

Voltage or potential difference according to Rosman et al. (2020) is an activity to move one charge (one coulomb) from one pole to another. The voltage on the MFC prototype was measured using a digital multimeter with the position of the tool on the voltage indicator. Observations were carried out for 48 hours and observed every hour. The treatment given was the addition of boost converter tools aimed at increasing the voltage produced. The results of measuring the voltage value on the MFC prototype can be seen in Figure 7.

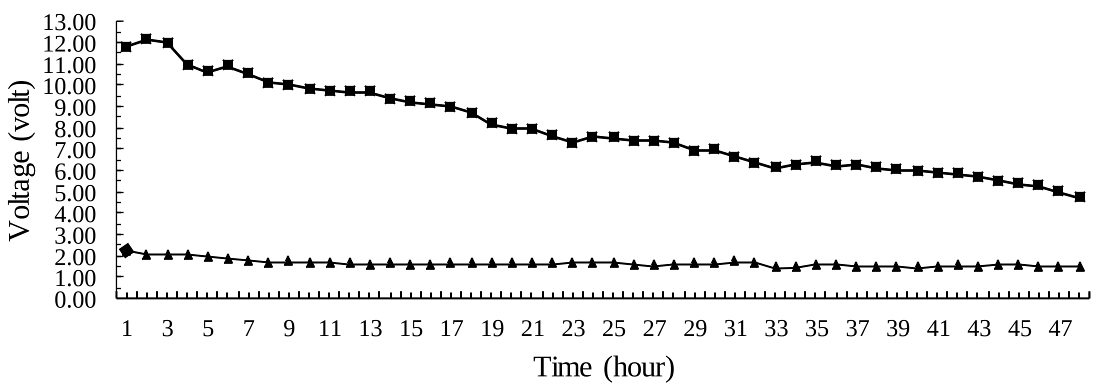


Figure 7. Results of measuring electrical voltage in MFC, (-■-) electrical voltage with boost converter; and (-▲-) electrical voltage without boost converter.

The results of the electrical voltage measurement in the MFC system for 48 hours obtained a fluctuating voltage value, but tended to decrease. The measurement of electrical voltage is divided into two, namely with or without a boost converter tool. The voltage value in the MFC system without the addition of a boost converter tool was the highest, namely 2.24 ± 0.26 volts at the 1st hour and the smallest was 1.43 ± 0.30 volts at the 40th hour. While the electrical voltage in the MFC system with the addition of a boost converter tool was 12.13 ± 0.87 volts at the second hour and the smallest voltage was at the 48th hour, 4.70 ± 0.24 volts.

The MFC system is assembled in series according to Ibrahim et al. (2014) produces higher electrical values than when assembled in parallel. The result of the voltage measurement in the MFC system of 2.24 ± 0.26 volts was higher than the research of Ibrahim et al. (2017) which only used one MFC system, namely 0.36 volts. This study used a series of 5 MFC systems, this is in accordance with the statement of Ibrahim et al. (2014) namely that assembling the MFC system in series can increase the electrical value.

A boost converter is an electronic circuit used to increase an electrical voltage. The results of the study demonstrated that the use of a boost converter significantly increased the electrical voltage, achieving a maximum voltage of 12.13 ± 0.87 volts. Based on the t-test analysis, the p-value obtained was smaller than the alpha value (0.05), indicating that the boost converter had a significant effect on the voltage output of the MFC system. The MFC system uses a boost converter circuit as carried out by Koffi and Okabe (2020) stating that the electricity of the MFC can be increased by using a boost converter, namely 0.40 volts to 4.35 volts to 5.20 volts. The voltage value in the study decreased over time. The increase in voltage only occurred in the second hour measurement, namely in the 1st hour it was 11.80 ± 0.89 volts to 12.13 ± 0.87 volts and in the 3rd hour it decreased to the 48th hour the voltage value was 4.70 ± 0.24 volts. The decrease in voltage in the MFC system with a boost converter can occur because the voltage produced by the MFC system decreases, this can be seen in the measurement of the MFC system without using a boost converter, the voltage produced was above 2 volts only in the 1st to 4th hour and after that below 2 volts until the end of the measurement. The boost converter circuit consists of several electronic components and these electronic components require energy (voltage) to activate or these components can work optimally (Azzarkasyi et al. 2020).

The fluctuating voltage observed in the MFC system was influenced by the activity of bacteria present within the system. According to Sari and Hidaya (2017) fluctuating electricity results are caused by competition between bacteria in degrading organic compounds in wastewater. In addition, according to Suyanto et al. (2010) the more time the nutrients contained in the substrate will decrease because they are used by bacteria for the metabolic process. As time goes by, the biofilm formed on the anode becomes thicker so that it can affect the performance of the MFC system (Saragih and Melaca 2018).

3.1.2. Current in MFC System

Electrical current is the movement of an electric charge through a conductor that moves from a positive charge (positive pole) to a negative charge (negative pole). The current in the MFC system was measured using a digital multimeter with the indicator position on the current. Current measurement used a load in the form of a 1 KΩ resistor connected in series. The results of current measurements in the MFC system can be seen in Figure 8.

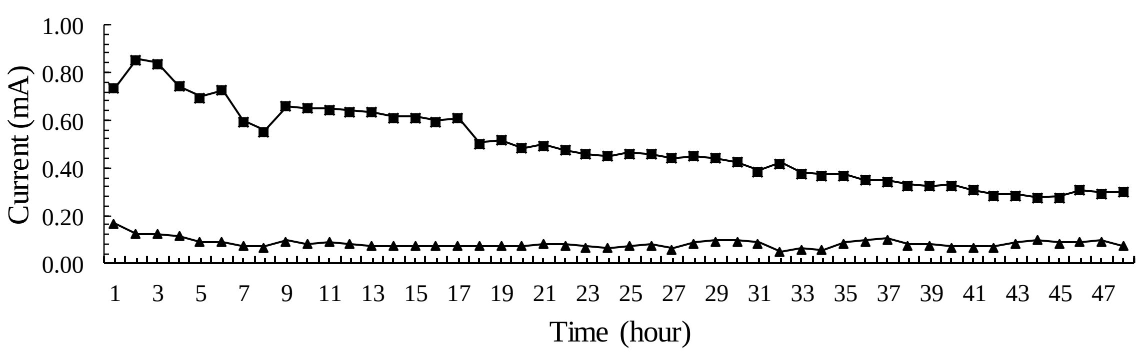


Figure 8. Results of measuring electrical current in MFC, (■) electrical current with boost converter; and (▲) electrical current without boost converter.

The results of the electrical current measurement in the MFC system for 48 hours obtained fluctuating current results. The current in the MFC system without using a boost converter was highest at hour 1 of 0.17 ± 0.03 mA, while the lowest current value was at hour 32 of 0.05 ± 0.03 mA. Meanwhile, the current in the MFC system using a boost converter had the highest current value at hour 2 of 0.86 ± 0.20 mA and the lowest current value at hour 44 of 0.28 ± 0.14 mA and hour 45 of 0.28 ± 0.11 mA. The measured current was relatively fluctuating, tending to decrease in both MFC systems. The current in the MFC system with a boost converter was higher than the electric current in the MFC system without a tool, namely with a tool of 0.86 ± 0.20 mA, while without a tool it was 0.17 ± 0.03 mA. The use of a boost converter has a significant effect on the electric current produced ($p < 0.05$).

The electronic components found in the boost converter circuit include resistors, diodes, transformers, capacitors, and transistors. The component that acts as a current enhancer is the transistor. Transistors have several functions, one of which is switching and amplifier. Switching functions as a switch, namely when there is an on and off state in a circuit, while an amplifier is something that strengthens in an electronic circuit, namely strengthening the current and voltage (Rahmad et al. 2007). The current generated by the MFC system in this study was increased through the use of the tool, which leverages the function of the transistor within the circuit. The current produced by the MFC system without the tool was 0.17 ± 0.03 mA, while with the tool, it increased to 0.86 ± 0.20 mA, demonstrating the circuit's ability to amplify the current by a factor of five.

3.1.3. Power in MFC System

Electrical power is electrical energy produced in a certain time system. This is related to the magnitude of the electrical voltage and electric current flowing in a circuit of electrical devices. The power produced from the MFC system is the result of multiplying the voltage value by the electric current value. The electrical power produced from the MFC system depends on the voltage and electric current produced. The results of power measurements in the MFC system can be seen in Figure 9.

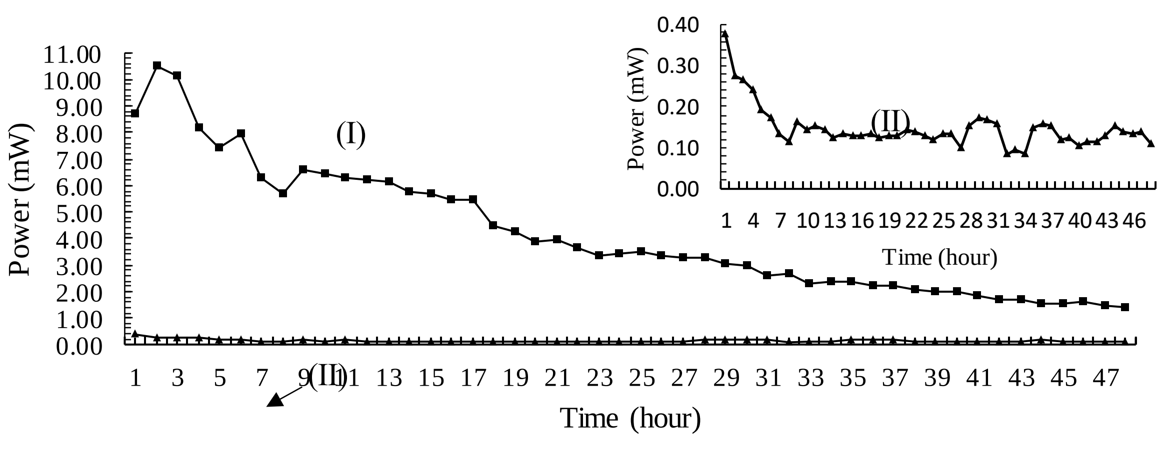


Figure 9. Results of electrical power measurements in MFC, (I) results of MFC system power with and without a boost converter, (II) MFC system power without a boost converter, (■) electrical current with boost converter; and (▲) electrical current without boost converter.

The power generated by the MFC system fluctuated and tended to decrease over time. Power, calculated as the product of voltage and electric current, is directly proportional to both these parameters. In the MFC system without a boost converter, the highest power measurement was recorded at hour 1, with a value of 0.38 ± 0.11 mW, while the lowest power values were observed at hour 32 (0.08 ± 0.05 mW) and hour 34 (0.08 ± 0.07 mW). In contrast, in the MFC system utilizing a boost converter, the highest power output was recorded at hour 2, with a value of 10.50 ± 3.11 mW, and the lowest at hour 48, with a value of 1.41 ± 0.21 mW. Based on the t-test results ($p < 0.05$), it was determined that the boost converter had a significant effect on the electric power generated by the MFC system.

3.4. Initial and Final Characteristics of Pindang Fish Wastewater

The characteristics parameters of *pindang* fish wastewater that were tested included 4 parameters, namely pH value, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Ammonium Nitrogen (TAN). The test was carried out before and after the MFC system process. The purpose of analyzing fish smoking wastewater was to observe changes in the organic load value in *pindang* fish wastewater during the MFC process. The MFC system, in addition to being able to produce electrical energy, is expected to reduce the organic load in wastewater which reduces water pollution. The results of the initial and final fish smoking wastewater characterization can be seen in Table 1.

Table 1. Characterization results of pindang fish wastewater.

Parameter	Unit	*Pindang* fish wastewater		*Pindang* fish wastewater (literature)*	
		Before	After	Before	After
pH	-	6,5	7,9±0,2	5,76±0,81	7,2±0,21
BOD	mg/L	64,00	62,00±13,11	577,28±27,51	518,37±1,13
COD	mg/L	1680,00	1413,33±122,33	6056,82±49,51	4829,52±45,33
TAN	mg/L	1,94	1,57±0,41	1,65±0,10	1,52±0,59

*Source: (Itqiyyah 2022)

3.4.1. The Value of pH

The pH value or hydrogen potential is the degree of acidity that describes the level of acidity or alkalinity of a solution. The pH scale starts from 0 to 14, the smaller the pH value, the solution is categorized as an acidic solution, while the larger the pH value is called a more basic solution and a pH value of 7 is stated as a neutral pH. The purpose of measuring pH is as one of the parameters of water quality because it can control the type and speed of reaction of several materials in water (Pamungkas 2016). Changes in pH value can describe microorganisms degrading organic compounds (Cagayana et al. 2018).

The results of the characterization of the pH value at the beginning of the fish smoking wastewater was 6.5 and after the MFC system process the pH value increased to 7.9 ± 0.20. The pH standard for fishery waste according to Regulation of the Minister of Environment No. 24 of

2014 ranges from 6 to 9, so that the pH value of *pindang* fish wastewater is in accordance with applicable standards. The pH value according to Alwahab (2017) that allows microbes to grow is around 6-8, while the pH value in a good MFC system according to Kaushik and Chetal (2013) is 7 to 9. The increase in pH value is caused by alkaline compounds resulting from the degradation of organic compounds such as trimethylamine and volatiles (Retnosari and Shovitri 2013). The increase in pH value according to Zhang et al. (2020) is caused by the reduced amount of oxygen used by bacteria for the decomposition process of organic matter. OH- ions that accumulate from the oxygen reduction process at the cathode are one of the causes of the increase in pH value (Ni'am et al. 2007). During the MFC process, the pH value not only increases, but also decreases. The factor that affects the pH value is the concentration of hydrogen ions (H +) produced by the microbial biocatalysis process in the MFC system. The decrease in pH value occurs because the concentration of H + increases (Kurniati et al. 2019).

3.4.2. The Value of Biological Oxygen Demand (BOD_5)

Biological Oxygen Demand (BOD_5) is one of the parameters to determine water quality. The BOD5 value is the amount of dissolved oxygen to decompose organic matter in aerobic conditions by microorganisms (Boyd 1990). The BOD5 value in fish smoking wastewater before and after the MFC system process can be seen in Table 1.

The results of the BOD5 value characterization in smoking wastewater changed after the MFC system process. The BOD5 value of *pindang* fish wastewater was 64.00 mg/L and after the MFC system process it was 62.00±13.11 mg/L. The BOD5 value after the MFC system process decreased by 3.13%. The small percentage decrease in the BOD5 value indicates that the degradation process that occurs in the processing of wastewater is relatively small and slow (Paramita et al. 2012). Factors that influence the degradation process by microbes in wastewater are the rate of microbial metabolism, the density of compound particles, and the environmental atmosphere (Berliana 2016). Itqiyyah's research (2022) stated that the MFC process can reduce the BOD5 value which is still relatively small, namely the initial waste of 577.28 mg/L to 518.37 mg/L. The high BOD_5 value is caused by the high organic content in the wastewater (Astuti and Rosemalia 2022). The BOD_5 value of the *pindang* fish wastewater in the MFC system is still below the fishery wastewater quality standard according to the Ministry of Environment (2014), which is a maximum of 75 mg/L. The decrease in the BOD_5 value in the MFC system occurs due to the decomposition process of organic material contained in the wastewater carried out by microorganisms. Bacteria in activated sludge will multiply and consume organic material as food so that it breaks down into CO_2 and H_2O (Salimin and Rachmadetin 2011). This decomposition process decomposes organic material and releases electrons which become a source of electrical energy (Hermayanti and Nugraha 2014).

3.4.3. The Value of Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is one of the parameters that can be used to determine the quality of water. COD value is the amount of oxygen needed to oxidize organic chemical compounds in water. In addition, COD is used as an indicator of the total amount of inorganic materials that can be degraded by microorganisms and inorganic materials that cannot be degraded. The COD value decreases along with the decrease in the concentration of organic compounds in the water (Harahap et al. 2020). The results of the characterization of the COD value of *pindang* fish wastewater before and after the MFC system can be seen in Table 1.

The characterization of the COD value in *pindang* fish wastewater decreased by 15.87%, namely the initial COD value of 1680.00 mg/L and after the MFC system process it became 1413.33 ± 122.33 mg/L. The decrease in COD in *pindang* fish wastewater was still not in accordance with the provisions of the Ministry of Environment (2014) which is a maximum of 150 mg/L. The decrease in COD in the MFC system occurs due to the biological process carried out by bacteria living in the MFC system. The MFC system uses bacteria to reduce COD levels in wastewater. The decrease in COD is caused by the process of decomposing organic compounds contained in wastewater. The reduction in organic compounds in wastewater causes the need for oxygen by bacteria to decrease, so that the COD value will decrease (Safitri et al. 2020). A COD value that is higher than BOD illustrates that the waste has a high organic compound content, organic and inorganic compounds cannot be decomposed by microorganisms. Wastewater contains compounds that cannot be decomposed biologically, indicated by a COD value higher than BOD (Lestari and Ain 2014).

3.4.4. The Value of Total Ammonium Nitrogen (TAN)

Total Ammonium Nitrogen (TAN) can be a parameter to determine the quality of water. TAN is a measure of the total concentration of ammonia and ammonium ions in a solution. The total ammonia contained in wastewater is the result of the washing, melting, and cooking processes that cause water-soluble proteins to be discharged into the waste reservoir (Ibrahim 2005).

The results of the characterization of TAN values in *pindang* fish wastewater can be seen in Table 1. The TAN value of *pindang* fish wastewater in the study decreased by 19.07%. The TAN value of *pindang* fish wastewater was initially 1.94 mg/L to 1.57±0.41 mg/L. The TAN value decreased because the ammonia compound degraded into nitrite and nitrate. Active sludge in *pindang* fish wastewater is thought to increase the number of microorganisms, so that active sludge flocs become a place for autotrophic bacteria such as Nitrosomonas and Nitrobacter to gather which are able to convert ammonia into nitrate (Ibrahim et al. 2017).

4. Conclusions

The microbial fuel cell (MFC) system in the study was able to produce electrical energy for 48 hours. The addition of a boost converter device was able to increase the voltage, current, and power. The maximum voltage, current, and power values without using a boost converter device were 2.24 ± 0.26 volts, 0.17 ± 0.03 mA, and 0.38 ± 0.11 mW, respectively. Meanwhile, the maximum voltage, current, and power values using a boost converter device were 12.13 ± 0.87 V, 0.86 ± 0.20 mA, and 10.50 ± 3.11 mW, respectively. The MFC system can reduce the pollutant load in *pindang* fish wastewater as seen in the decrease in BOD¬5, COD, and TAN values. Meanwhile, the pH value increased.

Recommendation

Further research can incorporate a Microbial Fuel Cell system into the series circuit, with the aim of sustaining the voltage output for a longer duration. Additional components, such as electrical power storage systems, can be integrated into the device to stabilize the generated voltage before it is delivered to the load. Furthermore, the use of alternative boost converter designs could be explored as a comparative approach to enhance the efficiency of electricity generation.

References

Alwahab, 2017. Profil Energi Listrik Terbarukan melalui Teknologi Microbial Fuel Cell dari Beberapa Substrat Potensial [thesis]. Kendari: Universitas Halu Oleo.

[APHA] American Public Health Asociation. 2012. Standard Methods for the Examination of Water and Wastewater 20th Edition. American Public Health Association, New York.

Astuti, A.D., 2014. Pemanfaatan Limbah Cair Pemindangan Ikan. Jurnal Litbang. 10(2), 114-122.

Astuti, A.D., Rosemalia, I., 2022. Review: Penurunan BOD (Biological Oxygen Demand) Limbah Cair Domestik dengan Teknik Fitoremediasi. Jurnal Unitek. 15(1), 59-72.

Azzarkasyi, M., Rizal, S., Fatmaliana, A., 2020. Elektronika Dasar (Teori, Komponen, dan Penerapan). Natural Aceh, Aceh.

Berliana, A., 2016. Biodegradabilitas Bakteri Isolat Lokal Pendegradasi Lipid [undergraduate thesis]. Bandar Lampung: Universitas Lampung.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Agricultural Experiment Station, Alabama.

Budiman, S., 2004. Proses Pemindangan. Departemen Pendidikan Nasional, Jakarta.

Cagayana, Samudro, G., Hadiwidodo, M., 2018. Penentuan Pengadukan Optimum berdasaran Pengomposan dan Produksi Listrik dalam CSMFCS (Compost Solid Phase Microbial Fuel Cells). Jurnal Sains dan Teknologi Lingkungan. 10(2), 88-100.

Dewan Energi Nasional, 2019. Outlook Energi Indonesia (OEI). [was accessed on 22 March 2022]. https://www.esdm.go.id/assets/media/content/content-outlook-energi-indonesia-2019-bahasa-indonesia.pdf

Harahap, M.R., Amanda, L.D., Matondang, A.H., 2020. Analisis Kadar COD (Chemical Oxygen Demand) dan TSS (Total Suspended Solid) pada Limbah Cair dengan Menggunakan Spektrofotometer. AMINA. 2(2), 79-83.

Hermayanti, A., Nugraha, I., 2014. Potensi Perolehan Energi Listrik dari Limbah Cair Industri Tahu dengan Metode Salt Bridge Microbial Fuel Cell. Jurnal Sains Dasar. 3(2), 162-168.

Ibrahim, B., 2005. Kaji Ulang Sistem Pengolahan Limbah Cair Industri Hasil Perikanan Secara Biologis dengan Lumpur Aktif. Buletin Teknologi Hasil Perikanan. 8(1), 31-41.

Ibrahim, B., Suptijah, P., Adjani, Z.N., 2017. Kinerja Microbial Fuel Cell Penghasil Biolistrik Dengan Perbedaan Jenis Elektroda pada Limbah Cair Industri Perikanan. Jurnal Pengolahan Hasil Perikanan Indonesia. 20(2), 296-304.

Ibrahim, B., Suptijah, P., Rosmalawati, S., 2014. Kinerja Rangkaian Seri Sistem Microbial Fuel Cell Sebagai Penghasil Biolistrik dari Limbah Cair Perikanan. Jurnal Pengolahan Hasil Perikanan Indonesia. 17(1), 71-79.

Itqiyyah, S., 2022. Biolistrik Pada Microalgae-Microbial Fuel Cell (MMFC) Menggunakan Limbah Cair Pemindangan dan Spirulina Platensis Dengan Salinitas Berbeda [undergraduate thesis]. Bogor: IPB University.

Kaushik, A., Chetal, A., 2013. Power Generation in Microbial Fuel Cell Fed with Post Methanation Distillery Effluent as A Function of pH Microenvironment. Bioresource Technology. 147, 77-83.

[KEPMEN-RI] Keputusan Menteri Republik Indonesia. 2018. Keputusan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 1567 K/21/MEM/2018 Tentang Pengesahan Rencana Usaha Penyediaan Tenaga Listrik PT Perusahaan Listrik Negara (PERSERO) Tahun 2018 s.d 2027. Jakarta(ID): Kementrian Energi dan Sumber Daya Mineral Republik Indonesia

Koffi, N.J., Okabe, S., 2020. Domestic Wastewater Treatment and Energy Harvesting by Serpentine Up-Flow Mfcs Equipped with PVDF-Base Activated Carbon Air-Chatodes and A Low Voltage Booster. Chemical Engineering Journal. 380, 1-9.

Kothapalli, A.L., 2013. Sediment Microbial Fuel Cell as Sustainable Power Resource [thesis]. Milwaukee: University of Wisconsin Milwaukee.

Kurniati, E., Haji, A.T.S., Permatasari, C.A., 2019. Pengaruh Penambahan EM4 dan Jarak Elektroda terhadap Listrik yang dihasilkan MFC (Air Lindi). Jurnal Sumberdaya Alam dan Lingkungan. 6(3), 19-30.

Lestari, A.P, Ain, C., 2014. Karakteristik dan Toksisitas Limbah Cair dari Kegiatanperikanan di Pasar Kobong, Semarang terhadap Chlorella sp. Management of Aquatic Resources Journal. 3(4), 201– 207.

Liu, H., Logan, B.E., 2004. Electricity Generation Using an Air-Cathode Single Chamber Microbial Fuel Cell in The Presence and Absence of a Proton Exchange Membrane. Environmental Science and Technology. 38(14): 4040-4046.

Logan, B.E., 2008. Microbial Fuel Cells. Hoboken, Wiley.

Logan, B.E., Hamelers, B., Rozendal, R., Schronder, U., Keller, J., Freguia, S., Aelterman, P., Verstraete, W., Rabaey, K., 2006. Microbial Fuel Cells: Methodology and Technology. Environmental Science & Technology. 40(17), 5181-5192.

Marta, M.B., Yahya, Nursyam, H., 2021. Pengolahan Limbah Cair Industri Pembekuan Ikan Kaca Piring (*Sillago sihama*) menggunakan Kombinasi Bakteri *Acinetobacter baumannii*, B*acillus megaterium*, *Nitrococcus* Sp. dan *Pseudomonas putida* Secara Aerob. Jurnal of Tropical AgriFood. 3(1), 49-62.

Mulyanto, N.D., 2016. Boost Converter sebagai Pengatur Tegangan untuk Motor Listrik DC Magnet Permanen [undergraduate thesis]. Jember: Universitas Jember.

Ni'am, M.F., Othman, F., Sohaili, J., Fauzia, Z., 2007. Removal of COD and Turbidity to Improve Wastewater Quality Using Electrocoagulation Technique. The Malaysian of Journal Analytical Sciences. 11(1), 198-205.

Pamungkas, M.T.O.A., 2016. Studi Pencemaran Limbah Cair dengan Parameter BOD5 dan Ph di Pasar Ikan Tradisional dan Pasar Modern di Kota Semarang. Jurnal Kesehatan Masyarakat. 4(2), 166-175.

Paramita, P., Shovitri, M., Kuswytasari, N.D., 2012. Biodegradasi Limbah Organik Pasar Dengan Menggunakan Mikroorganisme Alami Tangki Septik. Jurnal Sains dan Seni ITS. 1(1), 23-26.

[PERMEN-LH] Peraturan Menteri Lingkungan Hidup. 2014. Peraturan Menteri Lingkungan Hidup Republik Indonesia Nomor 5 Tahun 2014 Tentang Baku Mutu Air Limbah. Jakarta (ID): Kementerian Lingkungan Hidup Republik Indonesia.

Rahmad, M., Angelia, Y., Sahal, M., 2007. Perancangan Rangkaian Aplikasi Dasar Transistor Bopolar. Jurnal Geliga Sains. 1(1), 38-44.

Rashid, M.H., 2003. Power Electronics Handbook Third Edition. Elsevier, United States.

Retnosari, A.A., Shovitri, M., 2013. Kemampuan Isolat *Bacillus* sp. dalam Mendegradasi Limbah Tangki Septik. Jurnal Sains dan Seni ITS. 2(1), 7-11.

Rosmalawati, S., 2014. Kinerja Rangkaian Seri pada Sistem Microbial Fuel Cell sebagai Penghasil Biolistrik dari Limbah Cair Perikanan [undergraduate thesis]. Bogor: IPB Universitu.

Rosman, N.A., Risdayana, Yuliani, E., Vovi, 2020. Karakteristik Arus dan Tegangan pada Rangkaian Seri dan Rangkaian Parallel dengan Menggunakan Resistor. Jurnal Ilmiah D'Computare. 9(7), 40-43.

Safitri, U.N., Anggo, A.D., Fahmi, A.S., 2020. Kinerja Sedimen Microbial Fuel Cell Penghasil Listrik dengan Nutrien Limbah Industri Filet Ikan. Jurnal Ilmu dan Teknologi Perikanan. 2(1), 20-28.

Salimin, Z., Rachmadetin, J., 2011. Denitrifikasi Limbah Radioaktif Cair yang Mengandung Asam Nitrat dengan Proses Biooksidasi. In: Martono, H. [Eds]. Prosiding Seminar Nasional Teknologi Pengelolaan Limbah IX, Tangerang, Indonesia, October 5, 2011. 149-157.

Saragih, V., Melaca, K.M., 2018. Pengaruh Eksternal Resistensi dan Penambahan Molasseses pada Lumpur Lapindo Untuk Menghasilkan Biolistrik [undergraduate thesis]. Surabaya: Institut Teknologi Sepuluh Nopember.

Sari, D.R., Hidaya, C., 2017. Studi Pemanfaatan Lumpur sebagai Sumber Alternatif Energi dengan Menggunakan Microbial Fuel Cells (MFCs) [undergraduate thesis]. Surabaya: Institut Teknologi Sepuluh Nopember.

Sitorus, B., 2010. Diversifikasi Sumber Energi Terbarukan melalui Penggunaan Air Buangan dalam Sel Elektrokimia Berbasis Mikroba. Jurnal ELKHA. 2(1), 10-15.

Sugiyono, A., Anindhita, Fitriana, I., Wahid, L.O., Adiarso, 2019. Dampak Peningkatan Pemanfaatan Energi Terbarukan Terhadap Perekonomian Nasional. Badan Pengkajian dan Penerapan Teknologi, Jakarta.

Suyanto, E., Mayangsari, A., Wahyuni, A., Zuhro, F., Isa, S., Sutariningsih, S.E., Retnaningrum, E., 2010. Pemanfaatan Limbah Cair Domestic IPAL Kricak sebagai Substrat Generator Elektrisitas melalui Teknologi Microbial Fuel Cell Ramah Lingkungan. Seminar Nasional Biologi, Yogyakarta, Indonesia, September 24- September 25, 2010.

Zhang, Y., Xu, Q., Huang, G., Zhang, L., Liu, Y., 2020. Effect of Dissolved Oxygen Concentration on Nitrogen Removal and Electricity Generation in Self pH-Buffer Microbial Fuel Cell. International Journal of Hydrogen Energy. 45(58), 34099-34109.