BIOELECTRICITY GENERATION OF GLYCERINE WASTE IN MICROBIAL FUEL CELL

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DECLARATION

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LIST OF ABBREVIATIONS

PACF	Polyacrylonitrile Carbon Felt
POME	Palm Oil Mill Effluent
PME	Proton Membrane Exchange
DOM	Dissolved Organic Matter
MFC	Microbial Fuel Cell
KCL	Potassium Chloride

ABSTRAK

Gliserin, ataupun dikenali sebagai gliserol, adalah hasil sampingan pengeluaran sabun dan salah satu biojisim. Untuk setiap 100 paun sabun yang dibuat, 10 paun gliserin telah dihasilkan, dan gliserin sering dibuang. Ini mewujudkan lebihan sisa dari masa ke masa dan berbahaya kepada alam sekitar. Dengan memproses sisa gliserin menjadi gliserol mentah, sebahagian daripada sisa gliserin boleh ditukar menjadi produk yang berguna. Kos memproses terlalu mahal untuk dilakukan.

"Microbial Fuel Cell" boleh menggunakan sisa gliserin dengan menukarkannya kepada tenaga. Menggunakan proses pengurangan dan pengoksidaan yang berlaku akibat bakteria yang terkandung dalam gliserin, tenaga boleh dihasilkan. Kajian ini bertujuan untuk menambah baik penjanaan kuasa dengan menggunakan parameter berbeza untuk "Microbial Fuel Cell" dan bahan yang digunakan pada sel tersebut. Beberapa parameter ialah kesan kepekatan gliserin, kesan aditif, kesan suhu dan perbezaan keelektronegatifan elektrod. Kepekatan gliserin ditetapkan pada kepekatan 50% untuk setiap eksperimen.

Dalam kajian ini , keelektronegatifan bahan mempunyai pengaruh paling besar dalam hasil voltan maksimum di mana ia meningkatkan voltan maksimum daripada 0.29V kepada 0.786V. Penjanaan voltan bertambah baik dengan menukar bahan elektrod di mana aluminium, kuprum dan karbon digunakan dan hasil voltan maksimum ialah 0.596V, 0.354 dan 0.29 masing-masing

Nilai pH larutan dalam ruang anod dan katod mula berubah mengikut masa apabila MFC dikendalikan selama beberapa hari di mana pada anod larutan menjadi lebih asas dan pada katod larutan mula berasid kerana kehadiran hidrogen. ion dalam larutan

Walaupun parameter telah meningkatkan penjanaan voltan, tetapi penjanaan kuasa masih rendah dan tidak sesuai untuk dikomersialkan ke dunia sebenar dan lebih banyak kajian perlu dilakukan terhadap reka bentuk MFC.

ABSTRACT

Glycerin, commonly known as glycerol, is a byproduct of soap production and one of the biomasses. For every 100 pounds of soap made, 10 pounds of glycerine were generated, and the glycerine was often discarded. This creates an excess of waste over time and is harmful to the environment. By refining the waste glycerine into crude glycerol, some of the waste glycerine can be converted into a valuable product. The cost of refining is too expensive to be processed.

A Microbial Fuel Cell may utilize the glycerine waste by converting it into energy. Utilizing the reduction and oxidation that occur as a result of the bacteria present in the glycerin, energy may be produced. In this study, a Dual Chamber This study aims to improve the power generation by using different parameter for the Microbial Fuel Cell and the material used on the cell. Some of the parameters are effect of concentration, effect of additive, effect of temperature and difference in electronegativity of the electrodes. The biofuel default concentration is set at 50% concentration.

In this study , the electronegativity of material has the most influence in the maximum voltage yield where it improves the maximum voltage from 0.29V to 0.786V . The voltage generation improve by changing the electrode material where aluminium , copper and carbon are utilized and the maximum voltage yield are 0.596V , 0.354 and 0.29 repectively

The pH value of the solution in the anode and cathode chamber start to change by time when the MFC is operated by several days where at the anode the solution become more basic and at the cathode the solution starts to become acidic due to the presence of hydrogen ion in the solution

Although the parameters have improved the voltage generation , but the power generation is still low and not suitable to be commercialized into the real world and more study needs to be done on the design of the MFC

ACKNOWLEDGEMENT

Without the assistance of numerous people, this thesis could not have been finished. Firstly, I would like to let my supervisor, Dr Teoh Yew Heng know how grateful I am for his assistance. I was able to complete this job to the best of my ability because to his ongoing assistance and advice. He always advise me on what to include in my final year report and always reminding me to update on the current progress of the project.

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I owe my parents a debt of gratitude that will last forever because they have been the cornerstones in my life, providing both material and emotional support. I've been able to pursue my goals and do what I enjoy in life thanks to the freedom they've given me.

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CHAPTER 1

INTRODUCTION

1.1 Overview

The world has pushed more on the research of power generation as the demand for power increases with the increasing population in the world. Energy production can't rely much on fossil fuels such as petroleum to generate power as it is unsustainable, and the sources are depleting and will be gone in a couple of decades. With the current climate change, the pressure to reduce the greenhouse effect increases, and researchers have shifted their research to renewable energy sources which are carbon neutral free. The energy crisis has concerned the world with the demands of the limited natural resources that are used to generate energy. The limited natural resources are diminishing, and the demand rises. The energy crisis and environmental concerns raised the necessity for new biofuels.

Biomass which is mostly a waste product is now considered an alternative energy resource as it can be renewable, environmentally friendly, and cost-effective (Alidrisi and Demirbas, 2016). Biomass can be converted to ethanol by the fermentation process, hydrogen fuel, and can be used in a microbial fuel cell. Glycerol (also referred to as glycerine) is a significant by product of biodiesel manufacturing. Approximately 1 pounds of crude glycerol are produced for every 10 pounds of biodiesel produced. Due to the biodiesel industry's rapid expansion, a surplus of crude glycerol is being produced. Biodiesel producers have made much research on the disposal options due to the high cost of refining the glycerol for usage in the food, pharmaceutical, and cosmetics sectors. Numerous efforts have been attempted to dispose and utilise this crude glycerol, including combustion, composting, anaerobic digestion, animal feeds, and thermochemical/biological conversions to value-added products.

Due to the high viscosity of raw glycerine, there is a challenge in using it in a combustion engine. The process of converting biomass into ethanol and hydrogen fuel is not cost-effective as it takes a lot of processes to produce the fuel. This is where the MFC takes the role to generate energy by using microbes present in the biofuel to generate electricity. Microbial fuel cells (MFCs) are bio-electrochemical devices that effectively convert organic material into electrical energy using the power of respiring microbes. In a microbial fuel cell, a huge number of microorganisms can help generate power. Researchers have found a new metabolic class of electronic microbes that can use self-sustaining microbial fuel cells to convert a wide range of organic chemicals into energy. Electrician organisms have the capacity to iodize organic molecules. At its foundation, the MFC is a fuel cell that exploits oxidation-reduction reactions to transform chemical energy to electrical energy. MFC is considered long-lasting and ecological due to its non-carbon emission The MFC consists of an anode, cathode, exchange membrane, or sometimes a salt bridge. To store the fuel, an anaerobic anode chamber and an aerobic cathode chamber are used. Only protons are able to diffuse over the exchange membrane, which links the two chambers it is either a cation exchange membrane or a proton exchange membrane. Electrons are transferred from the anode chamber to the cathode chamber through an external electrical circuit in order to create electrical energy. At the cathode, protons and electrons react with oxygen (O2) to generate water molecules.

Commonly employed as a water waste treatment, the MFC eliminates and recovers impurities such as chemical oxygen demand (COD), heavy metals, and ammonia (NH_3).

The majority of MFC research centred on waste treatment, such as waste sludge. Do et al. (2018) identified several MFC-related obstacles for wastewater treatment applications. In addition, bio-electrochemical processes offer great promise for the recovery of high-value products such as power, heavy metals, fertilisers, and hydrogen. MFCs are a growing technology to produce sustainable energy from wastewater, and bio-electrochemical processes have a high potential for the recovery of high-value products such as electricity, heavy metals, fertilisers, and hydrogen.

Due of its low power output, the MFC is not yet marketed, and it is not yet fully optimised. MFC can behave like a lithium battery, however its power output cannot approach that of lithium batteries. Numerous research has been conducted to enhance the MFC's power production.

1.2 Research Background

A microbial Fuel Cell is a cell that generates power by taking advantage of the presence of microbes present in the biofuel. The microbes will decompose the organic matter and oxidize which will release electrons and it will be transferred to an external load to generate electricity. The oxidation will form water and oxygen as its product. The microbes will oxidize at the anode the electrons will be transferred to the cathode and the protons will be transferred by a salt bridge or a proton bridge.

From the study (Parkash, 2016a) the study mainly focuses on the behavioural of the microbes present in the biofuel. The study analysed the parameter that influences the productivity and the life cycle of the microbes. The study found out that the oxygen flow rate, pH value, concentration of biofuel could affect the microbe's productivity. The experiment was conducted with different oxygen flow rates, pH values, biofuel, and concentrations of biofuel.

In the study, the experiment uses agar as the salt bridge to transfer the proton to the cathode chamber. The cons of using agar as a salt bridge are that it is not a good salt bridge-like HCl and KmNO4. This will cause the proton to be abundant in the anode chamber and transfer of proton will not be as smooth as using HCl as the proton bridge. The pros of using agar as the proton bridge compared to HCl is that the agar can work as a proton bridge longer than the HCl. This is due to the HCl will be dried after a few hours running the Microbial Fuel Cell and the cell will operate without a proton bridge after a few hours. Due to the time the researcher runs the Microbial Fuel Cell, the agar bridge is the best for the experiment,

From (Gajda et al., 2020) the experiment was conducted with stacked carbon electrodes to increase the power generation. The stack Microbial Fuel Cell equipped with modified anodes (produced up to 37.9 mW in comparison to the control (CV) which consists of only one electrode on each chamber, reached 21.4 mW. The experiment conducted, shows that the power increased to 77%. The stacked electrodes allow more electrons to be transferred due to the higher surface area to move the electrodes to the load.

1.3 Problem Statement

MFC is considered an alternative energy source and has been the subject of extensive research in order to promote clean, renewable energy. The MFC is not commonly employed to create power in the actual world, and the MFC technology is not fully optimized to generate electricity to its maximum potential. Numerous studies have revealed that many parameters must be examined to optimize the MFC. The objective of the project is to optimize the energy produced by studying the behaviour, life cycle, optimal conditions for microbial presence, and utilized materials.

1.5 Objective

1) To investigate the microbial behaviour to optimized MFC energy generation
2) To design and analyse power generated by the Microbial Fuel Cell
3) To determine the power generated by using different electrode material for Microbial Fuel Cell

1.6 Scope of work

This research is to conduct an experiment to generate electricity by using biofuel as the source. The power will be generated by using a Microbial Fuel Cell as shown in Figure 1. There are some apparatus and materials that need to be used to conduct the experiment such as anode, cathode, chamber, and glycerin. The microcontroller will be used as a data logger to measure the current generated. The software that will be used for this experiment is Arduino IDE and some programming need to be done. The experiment will be set up as shown in Figure 1 and the current generated will be observed

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Microbial Fuel Cell

(Baranitharan et al. 2013) Microbial fuel cells (MFC) have risen to become one of the most promising long-lasting technologies because they utilize microorganisms to filter wastewater and convert its biochemical energy into useable electrical energy. In microbial fuel cells, most of the time, materials such as graphite rods, graphite fibre brush, carbon cloth, carbon paper, and carbon felt are often used as the electrodes. Simple substance or compound such as glucose ($C_6H_{12}O_6$) and acetate (CH_3COOH) have been extensively researched as the biofuel and shows great power generation, while complex substances like swine wastewater, starch factory sludge, and domestic wastewater have also been researched. Among conventional technologies, anaerobic digestion followed by aerobic biological processes is the most prevalent due to their benefits, such as low biomass production and high volumetric organic loading. Typically, one-third of the biogas produced is converted with a high level of energy (generating 220 V electricity) and the other third is converted with a low level of energy (creating 60-80 °C heat).

MFCs directly convert the energy from the biomass to electricity (Pham et al. 2006). MFC might be a potential alternative to conventional wastewater treatment since it runs at lower temperatures and yields less biomass while still producing bioelectricity. MFC is not commercially viable due to its low power output and coulombic efficiency. The research examined the performance of MFC in anode and cathode chambers with polyacrylonitrile carbon felt (PACF) as the electrodes.

From the study, it is found that the Palm Oil Mill Effluent (POME) will forms some extensive biofilm on the electrode surface where it can prevent transfer of electrons that was produce by the microbes to the electrode surface, which could be the reason of the low power density produced by MFCs by using POME. Higher internal resistance induced by the presence of a membrane and the large distance between the anode and cathode electrodes may also contribute to the decreased power density.

The power density of raw palm oil mill effluent (POME) was found to be substantially greater than the diluted biofuel. When pure POME instead of diluted biofuel was utilised in the MFC system, chemical oxygen demand and ammoniacal nitrogen removal efficiency were around (45 and 56 percent).

MFCs may serve a market need as a standalone energy source and for wastewater treatment. With raw POME (60,600 mg/L), the maximum power density in MFC was at (45 mW/m2). When a high initial chemical oxygen requirement was employed, the MFC's power output was reduced.

2.2 Different parameter used for Microbial Fuel Cell

(Parkash 2016)As the world transitions to sustainable energy sources, MFC are getting popular globally. As a pre-treatment technology, the microbial fuel cell can be utilised to remove dissolved organic matter (DOM) from polluted lake water while at the same time generating electricity.

Various parameters were examined during the experiment, including pH, biofuel concentration, oxygen flow rate, and biofuel kind. The maximum voltage yield of 2500mV was obtained using sewage sludge with a pH of 8.5. Because of changes in the active site's ionic form, pH had an impact on voltage generation. The activity of the cellulosic nature of biomass reduces as the pH value lowers, which is why pH values must not go below 7.

Because the amount of organic matter in biomass varies, the concentration of substrate has an impact on power generation. The higher the power generation, the higher the concentration of the subtract. This is because the microbial activity in the microbial fuel cell is affected by the concentration.

From the experiment, the MFC utilised several biofuels, including sewage sludge, carbo manure, cow manure, and water waste. Sewage sludge created the most power, with a power production of (2500 mV/L). The other biomasses yield lower power output due to organic matter content in the subtract, which has a lower concentration of glucose than sewage sludge.

After 15d operation, the total removal and efficiency of cells reached (40.8-9.0%) and (19.4-4.3%), respectively. Fermentation process of 9 day with temperature of 30 °C reduced the total suspended matter from 26.1g/L to 16.5g/L, but did not significantly affect the power output of MFC. The sludge's total chemical oxygen (TCOD) was decreased by 46.4%. when an initial 10.850mg/l was added to the MFC cathode chamber. When sludge was sterilized or base pre-treated, MFC output increased from

0.30-0.32V and 19.9-22.6mW/m2\r (raw sludge) to 0.43V and 37.8-40.8mW /m2 (sterilized sludge), respectively. MFC power output was not affected much on process parameters such as substance concentration, pH, or Catholyte concentration, or anodic pH.

(Feng et al. 2011) In the study, In a laboratory-scale reactor, biodiesel and biowastw were created by combining waste bean oil, methanol, and solid alkaline. The mixture was

trans-esterified for about 40 minutes with temperature of 55 °C with overhead stirrer before being cooled to ambient temperature in a separating funnel to get product esters. This method was repeated three times, and a biodiesel, mostly methyl ester of long chain fatty acids formed the top layers and BW comprising glycerin and by-products was formed bottom layers. These products were separated.

Typically, biodiesel is produced by transesterification of lipids (e.g., vegetable oil, animal fat, etc.) with alcohol. In the study, biodiesel production waste (BW) created during this procedure comprises glycerine in addition to residual ester and other by-products. This waste material must be repurposed for the efficient use of biomass as an alternative energy source. Waste from biodiesel production and microbial fuel cells (MFC) has been used to generate electricity for the first time in a laboratory-scale reactor, but we are the first to use it as fuel for MFCs powered by non-biodegradable organic matter. Carbon brushes for the MFC were prepared by soaking them in pure acetone for one night and in an acidic mixed solution for 15 minutes before heating them at 450 degrees Celsius for 30 minutes in a muffle furnace.

The finding revealed that the greatest power density produced with BW as a medium was 487 mW/m2, which was less than with glycerin as the medium (533 mW/m2). MFCs fed with BW as medium have a lower Coulombic efficiency (CE) (9.0 0.5%) than MFCs fed with glycerin as medium (10.5 0.2%).

The study was conducted again with a carbon brush and heated carbon brush as the anode. The result found out that heated carbon brush yield higher power generation with 556 ± 4 mV and 530 ± 6 mV for the carbon brush. The chemical and physical treatment improve the carbon properties and the electron transfer. The treatment was proved to increase the performance of the MFC.

2.3 Stacked Microbial Fuel Cell

(Gajda, Greenman, and Ieropoulos 2020) The electrical power from the Microbial Fuel Cell is too low and the study stressed out this is one of the reasons that MFC can't be practically used to generate electricity in the real world. One approach that has been taken to scale up the power generation is through stacking and multiplying the anode and cathode of the MFC. The stacking of anode and cathode influence the energy efficiency due to the lower ohmic losses. Adding powdered activated carbon to the fibres of the anodic carbon veil scaffold is intended to be a simple and cost-effective modification of the scaffold. The experiment generates power using urine as its biofuel. According to the study, after 500 hours of operation, urine's chemical energy may be successfully converted into direct electricity by utilizing Microbial Fuel Cell stacks, resulting in deployable power levels and a decentralised power source in remote areas. To obtain higher electrochemical performance over the course of 500 days of operation, a unique type of anode electrode was created by applying powdered activated carbon to the carbon fibre scaffold in the ceramic MFC stack. In comparison to the control, the stack with changed anodes generated up to 37.9 mW (21.1 W m3), a 77 percent increase in power generation. The result is a promising anode electrocatalyst for high-performance MFC stacks, given its low cost and ease of manufacture, as well as its exceptional electrochemical activity during long-term operation.

2.4 Glycerin pitch

(Nasarudin et al., 2020) Glycerine pitch is a brown to dark brown liquid with a pH of more than 10 that is highly alkaline. The constituents of glycerin pitch are glycerol (55–65 percent), diglycerol (15–25 percent), fatty acids, and inorganic salts. The combination of carrier material and microorganisms permits simple handling, long-term storage, and high biofertilizer performance. Overall, peat is the most effective transporter, but it is not economically viable. As alternate carrier materials, other clays, animal dung, and composted plant components could potentially be investigated. Widespread production of liquid biofertilizers for enhancing the soil ecosystem and supplying plants with vital nutrients has been developed. Several variables, such as carriers and inoculants, must be considered. Fermentation of the carrier material with the inoculant bacterium is required to create either liquid or solid fertilizer.

This work focuses on the conversion of glycerol into liquid biofertilizer using Lactobacillus inoculant and glycerin pitch as a medium. Glycerin pitch can be used as a medium for the production of liquid biofertilizer that is beneficial to the growth of cucumber plants. The study utilized Lactobacillus inoculant and glycerin pitch to make bio-fertilised cucumber seeds.

The outcome was the successful use of Lactobacillus inoculant and glycerin pitch as a medium for the synthesis of liquid biofertilizer. In comparison to the conventional fertiliser, the combination of the two nearly doubled the height of the plant's growth.

2.5 Microbial Fuel Cell with different types of waste

(Pant et al. 2010) The study was carried out to analyse the current and electric generation using a different types of waste. Any biosynthesis needs a substrate because it provides a supply of carbon (nutrition) and energy. In MFC, in anaerobic conditions, microorganisms oxidise organic material to produce electrons and protons. Electrons transfer via the external circuit to the cathode chamber, where electrons, protons, and electron acceptors (mainly oxygen) combine to produce water.

According to the results, the greatest energy generated seems to be connected to the substrate's complexity. With substrates such as peptone and wastewater from meat processing, less energy was produced than with a single component such as bovine albumin. The fact that xylose bioconversion in MFCs occurs at room temperature and at very low substrate concentrations could make MFCs a complementing technology to anaerobic digestion for hydrolysates.

In recent years, extensive research has been conducted on MFCs, and power generation from MFCs has increased significantly. However, generating high power density remains a formidable problem. Domestic wastewater includes nearly ten times the amount of energy required for treatment (WERF, 2009). Existing constraints in MFCs could be circumvented in a variety of ways. The replacement of platinized cathodes with similarly efficient non-platinized cathodes is a significant improvement in this field. Microbial Fuel Cell (MFC) technology could be employed for a variety of purposes, including the manufacture of valuable chemicals from inexpensive substrates and medical devices that use blood sugar as fuel. MFCs have also been utilised for the anode or cathode treatment of resistant chemicals. Carbon dioxide capture and conversion to usable chemicals in an MFC is an additional profitable use that has been partially achieved in recent years. (Caoet al., 2009).

2.6 Heat Treatment of aluminium

Due to the aluminium's lightweight, softness, and low strength, pure aluminium is typically not used in structural applications. Pure aluminium can have its strength and hardness increased by alloying it with other elements. This study investigates the impact of cooling rate on the tensile strength, hardness, and microstructure of quenched aluminium. Additionally, it looks at how the solution heat treatment and addition of copper to the Al-Si-Cu-Mg alloy affect the microstructure and mechanical characteristics of the cast aluminium alloy.

The as-cast alloy is 200 mm long and 10 mm wide and was thermally treated. These prepared samples proceeded by being placed into a muffle furnace with the furnace temperature around 500°C. This is due to the heat treatment for aluminium alloys being done between 450 and 500°C [24], and the temperature was sustained at that level for 20 minutes. The cooling process begins by allowing the aluminium alloys to sit at ambient temperature for a few hours

From the process, it is noticed that there is a significant decrease in grain size and a better redistribution of grain structure. This may have enhanced tensile strength, hardness, and elongation %. The enhanced refinement and redistribution of the grain structure led to an overall improvement in the mechanical characteristics of the heat-treated specimens.

2.7 Production of Hydrogen by PEM by using glycerol

Hydrocarbon is a type of chemical compound that consists of a combination of carbon and hydrogen atom which they form a bond to produce the hydrocarbon. Hydrocarbons are widely used as the source of energy globally and the world depends on it to generate energy. Hydrocarbon has an advantage in generating energy since it has a high efficiency but, it has disadvantages such as the CO2 produced during the energy is generated.

Hydrogen has been considered as an alternative to replacing hydrocarbon to generate electricity since the CO2 released can be captured by plants and also it releases H2O as the by-product when generating electricity. Hydrogen can be produced by the process of electrolysis which uses water or by using biomass. The current process relies much on the fermentation and thermochemical process to convert biomass into hydrogen.

In the study, hydrogen was produced from glycerol by using Proton Exchange Membrane (PEM) where the glycerol was mixed with water. The PEM consists of an anode, proton, battery exchange membrane, and cathode, where the glycerol was placed at the anode and water, was placed at the cathode. The PEM can generate extra electricity by the process of oxidation and reduction of the microbes.

From the study, it is found out that the voltage produced depends on the concentration of the glycerol. The glycerol with a molar concentration of 2 mol L-1 generates electricity around 20-50 mV less than the concentration of glycerol 8.5 mol L-1. The PEM cell also can produce hydrogen at a smaller voltage compared to the electrolysis of water. The hydrogen can be produced at cell potential of 0.48V-0.7V, meanwhile, for the electrolysis of water, it requires 1.33V-1.40V. The energy efficiency of glycerol to hydrogen conversion is around 44%, where 82 percent of the energy used to create hydrogen comes from glycerol and 18 percent of the energy comes from electrical energy. Hydrogen can be produced around 10m3 per day where the energy consumption is around 1.1kWhm-3 compared to electrolysis of water where the energy consumption is higher.

CHAPTER 3

METHODOLOGY

3.1 Microbial Fuel Cell Design

3.1.1 Dual Chamber Microbial Fuel Cell

To conduct the experiment, a Dual chamber Microbial Fuel Cell was utilized as shown in the Figure 3.1. This cell featured an anode and a cathode chamber that were physically separated by a proton bridge. The anode chamber of the MFC is the negative chamber, and it is the chamber that will be filled with water. On the other hand, the cathode chamber is the positive chamber, and it is the chamber that will be filled with glycerin pitch.

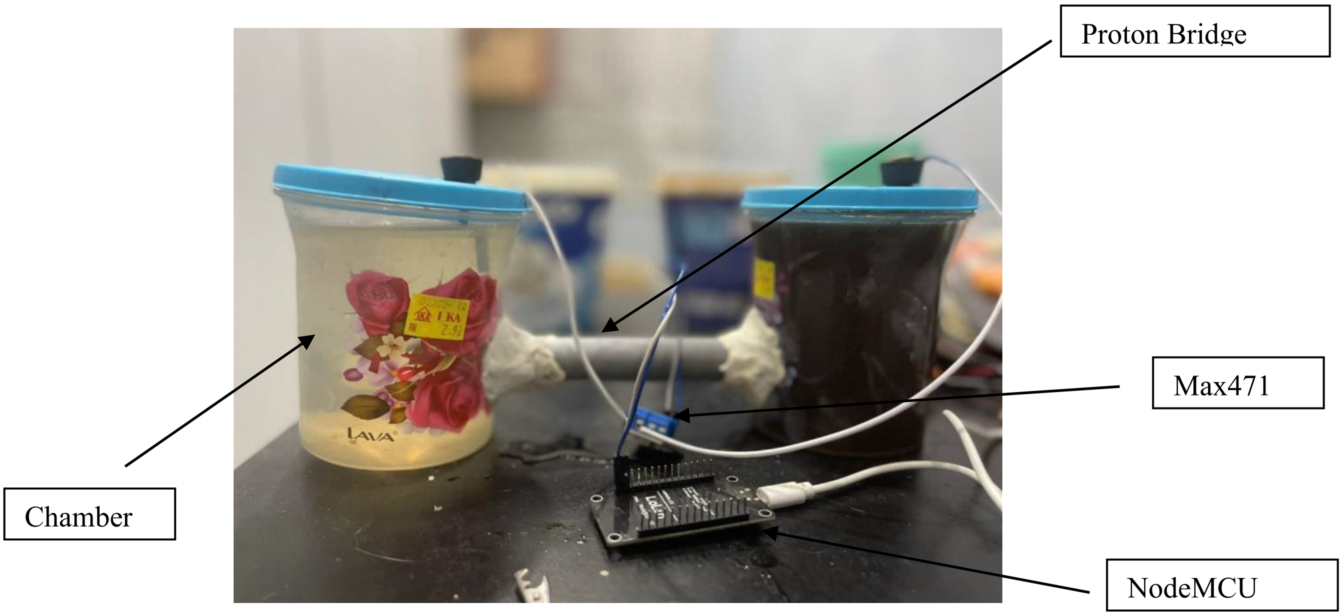

Figure 3.1 : Dual Chamber Microbial Fuel Cell Setup

3.1.2 Proton Bridge

The proton bridge or also known as an ion exchanger transports the excess positive charge in the cathode chamber to the anode chamber. Oxidations occur at the anode chamber where the subtracts losses its electron and hydrogen are break from its bond to become a positive charge ion. If there are excessive positive charge ion presence in the chamber, it will form a new bond and cause the electron flow to be disrupted

The proton bridge was prepared by pouring an agar mixture with water and 1 mol of KCL into a pipe. The agar was mixed with water and KCL solution at a temperature above 80 °C, and the mixture was stirred until no agar solid was left in the mixture. The mixture was poured into the pipe and was let cool at room temperature until the mixture solidified

3.1.3 Electrodes

In the experiment, two electrodes were employed. The electrodes were made from carbon. The electrodes were dipped into the chamber, this is to allow the surface of the electrodes to pull the electrons from the chamber and the electrons will flow through the electrodes before being transferred from the cathode chamber to the anode chamber via wire.

3.2 Data Logger

3.2.1 Hardware

The data logger consist several electronic equipment to measure the voltage produced by the MFC. The data logger consist of a microcontroller , sensors , wires and resistors . Table 3.1 shows the hardware of the data logger

Table 3. 1 : Hardware of the data logger

Component	Description
NodeMcU ESP8266	NodeMcU ESP8226 is a microcontroller that has built in Wi-Fi microchip that enable the user to connect to the internet. The microcontroller was used as a data logger where it was connected to the Blynk cloud. All the data from the sensor were detected by the microcontroller and it will be uploaded to the cloud
MAX471 Voltage and Current sensor	The sensor can be used to test the current and the voltage. Since the sensor was connected to the NodeMcu, the working voltage is 3.3v, and it can detect voltage up to 16.5V. The resolution of the sensor is 0.00489 (3.3V/1023) X5, so the minimum voltage that can be detected by the voltage is 0.015V
Ds1b820	Ds18b20 is a temperature sensor that is waterproof. It can detect digital signal 9-