DEVELOPMENT OF INTEGRATIVE MICROBIAL FUEL CELL- FERMENTATIVE FOR BIOELETRICITY PRODUCTION FROM FOOD WASTE

NUR SAIDATUL NISA SHAKILA BINTI JAFREE

Bachelor of Engineering Technology

UNIVERSITI MALAYSIA PAHANG

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NUR SAIDATUL NISA SHAKILA BINTI JAFREE

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ABSTRAK

Pengeluaran sisa makanan (FW) berkembang selaras dengan pertambahan penduduk dan pengembangan ekonomi di seluruh dunia. Oleh itu, kerja-kerja sekarang berurusan dengan reka bentuk sel bahan api mikrob (MFC) ruang dua skala makmal untuk menjana tenaga daripada sisa organik. Eksperimen ini dijalankan untuk mencipta bioelektrik daripada sisa dapur kafeteria di Universiti Malaysia Pahang (UMP) sebagai substrat untuk MFC. Peranti ini dikendalikan dalam keadaan anaerobik di anod dan keadaan aerobik di sebelah katod pada tempoh masa penilaian 7 hari. Bacaan eksperimen direkodkan pada selang 5 jam. Prestasi penjanaan bioelektrik telah dibandingkan antara dua jenis pencairan perbezaan iaitu 70% dan 40% untuk FW Terawat dan FW Mentah telah dinilai dalam MFC. Purata penjanaan voltan maksimum FW Terawat 70% dan 40% ialah 180.225 mV dan 79.46 mV, untuk FW Mentah 70% dan 40% ialah 161.200mV dan 102.775mV. Graf yang diperolehi memerhatikan purata voltan maksimum meningkat yang dijana pada hari 1 hingga hari 2 dan penurunan dalam aliran telah dinilai pada 3 hari dan seterusnya tetapi mempunyai sedikit perubahan ketara dalam aliran peningkatan. Daripada keputusan ujian-t menunjukkan bahawa nilai p setiap sampel adalah kurang daripada α=0.05, ia mempunyai bukti kukuh untuk gagal menerima hipotesis nol dan membuat kesimpulan bahawa untuk menerima hipotesis alternatif dan sebaliknya. Berdasarkan keputusan tersebut, perbandingan FW Mentah dan FW Terawat pada 70% dan 40% adalah tidak sama dalam menghasilkan voltan, manakala perbandingan antara Terawat dan Mentah FW pada 70% menunjukkan menerima hipotesis nol yang bermaksud penghasilan voltan antara 2 sampel yang sama dan tidak mempunyai perubahan yang ketara. Ia menyimpulkan bahawa tidak perlu merawat FW dan boleh digunakan terus dalam MFC. Sebagai kesimpulan penyelidikan ini, telah ditetapkan bahawa MFC boleh digunakan untuk menjana tenaga elektrik daripada FW sambil mengurangkan pencemaran ke alam sekitar.

ABSTRACT

Food waste (FW) production is expanding in accordance with population increase and worldwide economic expansion. Therefore, the present works deal to designed of laboratory scale double chamber microbial fuel cell (MFCs) to generate the energy from the organic waste. The experiment was carried out to create bioelectricity from kitchen waste of cafeteria at University Malaysia Pahang (UMP) as a substrate for MFC. The device was operated under anaerobic condition at anode and aerobic conditions at cathode side at time duration of 7 days evaluations. The experimental reading was recorded at an interval of 5 hours. The performance of bioelectricity generation was compared between two difference type dilution which is 70% and 40% for Treated FW and Raw FW were evaluated in MFC. The maximum average voltage generation of Treated 70% and 40% were 180.225 mV and 79.46 mV, for the Raw 70% and 40% were 161.200mV and 102.775mV. The graph that obtained observed the increasing maximum average voltage generated on day 1 to day 2 and decline in trend was evaluated on 3 days onwards but have little significant changes in increase trend. From the t-test result shows that p value of each sample is less than $\alpha=0.05$, it has strong evidence for fail to accept the null hypothesis and concluded that to accept the alternatives hypothesis and vice versa. Based on the result, the comparison Raw FW and Treated FW at 70% and 40% is not same in generating the voltage, while compared between Treated and Raw FW at 70% shows to accept the null hypothesis that means the production of voltage between 2 samples same and no have a significant change. It concludes that no need to treat the FW and can be used directly in the MFCs. As a conclusion of this research, it has been established that MFCs may be utilized to generate electrical energy from FW while emitting less pollution into the environment.

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LIST OF SYMBOLS

Ω	Ohms
α	alpha
μ	mean

LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
BOD	Biochemical Oxygen Demand
CO2	Carbon Dioxide
FW	Food waste
GDL	Gas Diffusion Layer
GHG	Greenhouse Gas
MFC	Microbial Fuel Cell
PEM	Proton Exchange Membrane
PTFE	Polytetrafluoroethylene
UMP	University Malaysia Pahang

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, food waste (FW) generation is growing significantly with the increasing population and global economic growth. In many nations, food waste has been incinerated or directly deposited after quick recycling. However, such activities have been increasingly condemned because of their noticeable weaknesses. For example, combustion is highly energized when producing dangerous gases and ashes.(Xin *et al*., 2018). From the researcher's observation, it could correctly be said that per day's capital consumption of food for Malaysia is higher than in neighbouring countries because food consumption is taken more than three square meals per day. People prefer to eat at any time instead of the usual routine of breakfast, lunch, and dinner typical in most developed and developing countries (Jereme *et al*., 2016).

Food waste is one of the most critical global challenges today. A third to a half of the food produced is lost before it reaches a human's mouth. United Nations Sustainable Development Goal 12 ‘Ensure sustainable consumption and production patterns' specifies an aim to reduce global food waste per capita at retail and consumer levels by half by 2030. It also intends to minimize food losses across the supply chain (Garcia-Garcia *et al*., 2017). FW is discarded on a regular basis because of the living nature of human beings and the activities of agriculture, industry, and residential households. Food waste sources can be divided into three categories: food losses, which are food materials that are lost during the preparation, processing, and production phases of the food supply chain, unavoidable food waste, which is the inedible parts of food materials that are lost during the consumption phase (Review, 2016).

Due to the observation, categories of food preparation from the cafeteria from the university will be dramatically high according to the increasing population of students. Therefore, the researchers studied alternatives to overcome the drawback of management FW with something beneficial and more useful for all humans to achieve environmentally friendly and economically viable approaches for future FW management and use it to generate electricity. Microbial fuel cell (MFC) is a technology for sustainable bioenergy production, due to its ability to produce electricity from food waste while also treating them. The MFC using the electrons derived from the biochemical reactions catalysed by bacteria (Tremouli *et al*., 2019).

1.2 Problem statements

Worldwide, the demand for food growing is parallel to the dramatic population influence and the increasing food waste production becomes an issue. The raising of food waste consists of several reasons such as bad weather, human behaviours, manufacturing issues, overproduction and dysfunctional markets cause food loss long before it appears in a grocery store, while overbuying, poor label preparation and misunderstanding lead to food waste in stores and homes. Reducing present levels of food waste requires better waste management because of there will always be some food waste. Also, some food products are inedible and will inevitably end up non the waste stream.

There are few methods of waste disposal to control and overcome the crisis of growing production of food waste such as disposed of directly to the landfill, incineration, waste compaction, composting, recycling, and others. Therefore, due to the high production of food waste, landfill is the most popular area chosen from all people to treat and solve their problems, thus, this problem can contribute to the restricted land area. While there are numerous ways to dispose the food waste, the most typical method is landfilling, which is harmful to the environment and hazardous to human health (Garcia-Garcia *et al*., 2017).

In addition, most of the country likes to incinerate the food waste to overcome the drawback of insufficient land area for disposal. From the alternative ways that are used to dispose of the food waste, indirectly contribute impact to the pollution to the environment such as pollution to land, air, water, smell pollution, and human's health. This is because the incineration technique enhances the production of emission gases, hazardous ashes, and greenhouse effect (GHG). Food waste may generate greenhouse gases, contributing to climate change. Therefore, campaigns like the 3R (Reduce, Reuse, Recycle) have been implemented to raise public awareness. A good food waste management will efficiently reduce food waste (Review, 2016).

Food waste management and treatment in Malaysia is a difficult task and contributes to the present environmental issue by mixing with municipal solid waste that will causing greenhouse gas emissions in landfills, or through by the activities of incineration, or directly deposited after easy recycling. However, such practises have been increasingly criticised for their evident disadvantages and negative impact. Incineration, for example, is very powerful and contains toxic gases and ashes. On the other side, waste disposal is now no longer an option because of the restricted supply of land and the potential for surface and groundwater pollution. More significantly, no incineration and landfill can recover resources and electricity (Xin *et al*., 2018).

These clearly indicate that, conversion method of anaerobic digestion (AD) use for generating electricity as a solution for food waste management and resources recovery commonly uses, but the extensive research has been reported and propose of using the electro fermentative bioreactor that called MFC will directly convert the organic matter to electric energy without complex steps (Xin *et al*., 2018).

1.3 Objective

1. To design an electro fermentative bioreactor.

2. To evaluate the performance mixture of wastewater and food waste in MFC.

1.4 Scope of study

The study focused on Microbial fuel cells (MFCs) can be utilized to generate sustainable bioelectricity from FW, according to the findings. Anodic and cathodic chambers are manufactured from glass using 1 litre bottles for both and using the carbon rods as the electrodes. A proton exchange membrane (PEM) used for separates these two compartments. In the anodic chamber, which contained organic materials digested by microbes for energy production and growth while creating protons and electrons that attached to the carbon rod were used to assess the electricity production. Carbon is a well-established material that may be utilised as an electrode successfully and is available in a variety of structural and surface area configurations that are ideal for use in MFC. Carbon may be utilised in any form of MFC due to its ability to be shaped and sized to meet specific requirements. The carbon rods are used for both chambers. Anaerobic conditions were used in the anode chamber while air was exposed in the cathode chamber. A digital multi meter and resistor are linked to a cooper wire to establish an external circuit.

Next, food preparation was gathered from the University Malaysia Pahang cafeteria (UMP). The blender was used to crush 1.6 kilogram of food waste consist of rice, vegetables, chicken liver, bread, and chicken bones. FW was prepared based on the 1:1 ratio between FW and water. Through the serial dilution, four samples were prepared with 70% and 40% dilution. Two samples were used for indicating the raw FW and the other two samples were treated for 14 days and added with 10% wastewater from drainage at campus area. After that, measure the BOD and pH of the FW solution for two types of dilution. Hence, the circuit of the MFC was established and let the solution in the chamber for a few days to allow the microorganisms to do their work and produce the electricity. Following that, depending on the parameter, the effect of the different dilution and reaction of the mixture wastewater will be determined. After obtaining the electricity from the reactor, compared the result for both conditions for the maximum power and current production.

1.5 Significant of study

One of the most major advantages of MFC technology is that it is more environmentally friendly than other energy production methods such as methanogenic anaerobic digestion, fossil fuels, and others that produce carbon dioxide and contribute to global warming. As previously noted, MFC technology has a variety of uses, including the production of bioelectricity from a variety of organic sources, including solid waste biomass, food waste, household trash, and another wastewater. By incorporating these waste products into MFC technology, it becomes a more effective instrument for generating electricity sustainably.

Bioelectricity generated by bacteria has the potential to be a viable energy source that reduces dependency on fossil fuel, resulting in green energy. Due to microorganisms' ability to use a diverse spectrum of waste-derived fuels, the MFC is often regarded as a suitable technology for bioelectricity generation from renewable biomass. Anaerobic digestion of waste, contaminants, and chemicals can also be a cost-effective method of maintaining environmental purity and producing renewable energy. As a result, this MFC technology can be used as a possible source of sustainable energy.

It has been shown that the majority of MFC research is conducted for the purpose of electricity generation, which is the primary use of the technology. MFC technology can be utilised to the development of a bio-battery idea capable of recharging small-voltage appliances and devices. MFCs are mostly used to power small telemetry systems and wireless sensors that require very little power to transmit signals such as temperature to receivers at remote locations. MFCs can be used to power distributed power systems for local consumption, which is especially useful in less developed regions of the world. By utilising MFC, it is possible to overcome the issue of electricity scarcity in less developed countries such as Africa. If we look throughout the world, we see that each country has a unique power supply. Then, by implementing MFC, we can save money while also ensuring that there is always an enough supply of electricity.

Indirectly contributed to the reduction of pollution in the environment by using this strategy. Reusing food waste has also had a significant impact on the environment, as it has reduced the chances of pollution. Food waste, both untreated and recycled, was frequently deposited into the landfill. In many countries, food waste is either burnt or dumped directly into the environment after it has been recycled. Incineration, for example, generates toxic fumes and ashes. Due to the restricted availability of land and the danger for contamination of surface and ground waterways, landfill, on the other hand, is no longer an economically viable choice. In this way, MFC can serve as an alternative for the exploitation of food waste resources while also reducing the environmental damage caused by food waste.

CHAPTER 2

LITERATURE REVIEW

2.1 Food waste generation

Waste can be described as 'any product or object holder discarded, intended to be discarded or expected to be discarded' according to the European Waste Framework Directive, (Lemaire & Limbourg, 2019). According to Dalilawati Zainal and Khana Hassan (Zainal & Hassan, 2019;Theses & Abd Razak, 2017), revealed that Malaysia, which has a population of approximately 31 million, has experienced strong economic growth over the last five decades. Malaysia is ranked 41st out of 113 countries on the Global Food Security Index in terms of food security. Though Malaysia's food security remains acceptable, the country's citizens' habits of food waste have become a significant problem that must be addressed.

According to, about 3,000 tonnes until 15,000 tonnes of wasted food are potentially edible and should not be discarded. During the festive season, the quantity usually increases by 15% to 20%. As a result, it was observed that the rate of food waste reused and recycled in Malaysia is relatively low (5%) in comparison to paper (60%) and plastic (15%). Therefore, in Malaysia lack of a formal food waste disposal system can lead to the low percentage of food waste that is reused or recycled. (Jereme *et al*., 2016;Zainal & Hassan, 2019).

Table 2.1 Estimation of Food Waste Generation in Malaysia in 2018

List	Sources of food	Tonnes/day	Tonnes/year	Percent%
1.	Household	8,745	3,192,404	38.23
2.	Wet and night markets	5,592	2,040,929	24.50
3.	Food courts/ restaurant	5,319	1,941,608	23.35
4.	Hotels	1,568	572,284	6.87
5.	Food and beverages industries	854	311,564	3.41
6.	Shopping malls	298	108,678	1.30
7.	Hypermarkets	291	106,288	1.28
8.	Institutions	55	26,962	0.32
9.	Schools	45	21,808	0.30
10.	Fast food/ chain shops	2,521	808	0.26
	Total	22,793	8,331,589	100

Source: Syahirah Abd Razak et al, (2018)

As a result of the increased production of food waste, there are numerous ways to use FW as a renewable energy source and produce electricity. FW has a high energy content of organic waste and this feature of FW gives us opportunities to use FW in many biotechnological processes for energy production (Asefi *et al*., 2019).

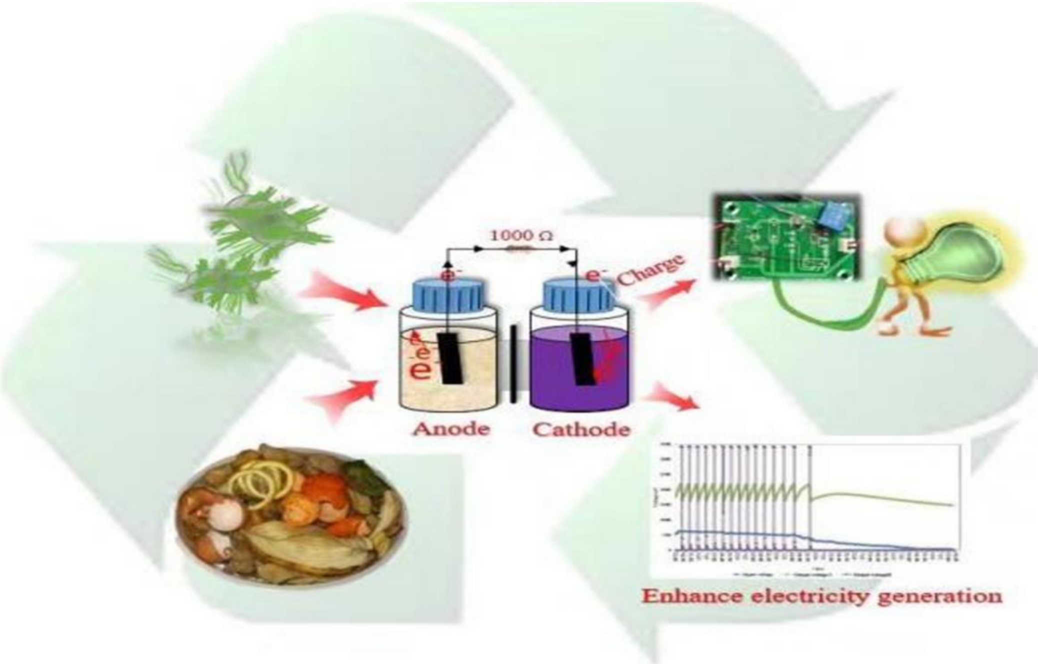

Figure 2.1   Illustrated of MFC of double chamber
Source: (Asefi et al., 2019)

MFCs can be configured to be single-chamber and two-chamber depending on application requirements. A double-chamber MFC consists of two proton exchange membranes to differentiate between these compartments, oxidation-reduction reactions are found in different sections of the process. Protons are produced in the anode compartments and transferred through the external circuit. PEM provides an anaerobic condition and improves MFC production. However, the exchange of protons inside the membrane can lead to an increase in internal resistance, thereby reducing the amount of current that is produced (Xin *et al*., 2018).

MFCs are suitable only for small- to medium-scale implementation. Single-membrane fuel cells have a single-membrane assembly, in this case, they are air-exchangeable fuel cells. The single chamber MFCs offer lower resistance, is less expensive, and are easy to configure. It is helpful in the development of potable water at the cathode. If oxygen diffusion is inhibited, then exoelectrogenic bacteria can develop more quickly, but single-chamber MFCs cannot be called aerobic. Flushing the microorganisms out of the anode and making them form biofilms on the cathode is possible in single-chamber devices. Loads of study were conducted on the microbial communities in MFCs (Ma *et al*., 2018).

2.2 Alternatives ways for FW management

The continuous increase of the world's population is turning food waste and accumulation into a major problem worldwide. The exponential increase in food waste places serious threats on our society, including contamination of the atmosphere, risk of health and lack of dumping land. Various alternative approaches for food waste production and management are currently being studied for their potential societal benefits and applications. Anaerobic digestion has emerged as one of the most environmentally sustainable and promising methods for managing food wastes, producing electricity, and producing nutrients, all of which can contribute to the world's ever-increasing renewable sources (Paritosh *et al*., 2017). Additionally, efficient production of bioelectricity, organic removal and biomass can be accomplished when organic matter is used in MFCs (Choi & Ahn, 2015).

2.2.1 Anaerobic Digestion (AD)

Anaerobic Digestion is a mechanism in which bacteria break down organic matter, such as animal waste or food waste in the absence of oxygen. According to (Slorach *et al*., 2019), mention that, in the absence of oxygen, organic matter is decomposed into biogas and digested. This technology has proven to be in use in 2015 with 17,376 biogas plants in Europe. This is normally achieved in a digester tank. This process produces fertilizers that are mainly composed of methane and can be used for farming and biogas. The biogas can be combusted for energy and heat or transformed into renewable natural gas and transport fuels.

Through Nazih Kaseem et al., 2020 revealed that some farms in New York use anaerobic digestion (AD) to manure, produce biogas (methane and CO2) for the heat and power generation process and offset for the energy consumption. However, current evidence indicates that AD has many disadvantages such as 15-20 days solid retention period, extremely complex configuration of processes that include hydrolysis, acidogenesis, acetogenesis and methanogenesis, low rates of food waste destruction, low bio-methane efficiency, broad footprint, uneasy maintenance, and an in-plant safety problem. In addition, after AD of food waste, solid residues must also be handled further by incineration or landfill (Xin *et al*., 2018).

2.2.2 Microbial fuel cell (MFC)

In contrast to Anaerobic Digestion, MFC is a promising bio electrochemical technology that uses bacteria as a catalyst to produce electricity from a variety of organic wastes (Asefi *et al*., 2019). The advantages of the MFC have been extensively investigated to convert organic matter directly to electrical energy without intermediate actions. The performance of organic matter biodegradation and electron transfer are both important factors in the generation of bioelectric energy in MFCs. The efficiency of MFCs can actually be further increased or improved by the existence of adequate anodic bacteria (ARB) at the anode (Xin *et al*., 2018).

2.3 Design of MFCs

The MFCs have been used with various materials. These materials are stacked and utilized to build reactors. The MFC design influences the system's power production, coulombic efficiency, and stability. Changing the reactor volume, oxygen supply, membrane area, and electrode spacing can improve MFC performance. A microbial fuel cell's design is critical to its success (MFC). The designs are determined by the research plan and the study's findings. New study shows the reactors were made of plastic and glass in cylindrical, cube-shaped, horseshoe-shaped, single chamber and two chamber configurations. Reactors range in size from a few square centimetres to a few square metres, with contents ranging from microliters to hundreds of litres. MFCs have electrodes, wires, glass cells, and a salt bridge. In a PEM fuel cell, a proton exchange membrane replaces a salt bridge (Flimban *et al*., 2019).

Table 2.2 MFC performance relative to configuration

Types	**Substrates**	**Electrode**		**Electron Acceptor**	**Power Density**
		Anode	Cathode		
Single chamber	Glucose	Graphite carbon fiber brush	Pt (30%) coated carbon cloth	Oxygen	2.4 W m^{-2}
Single chamber	Acetate-amended Wastewater	Graphite fiber Brush	Activated carbon catalyst on Stainless steel mesh	Oxygen	1.1 W m^{-2}
Double chamber	Glucose	Carbon paper	Carbon cloth	Permanganate	0.12 W m^{-2}
Double chamber	Glucose	Graphite plate	Graphite plate	Hexacyanoferrate	4.3 W m^{-2}
Stacked	Sodium acetate	Granular activated carbon	Granular activated carbon	Oxygen	50.9 W m^{-3}
Stacked	Neat undiluted Urine	Untreated carbon fiber veil	Coating activated carbon paste on polytetrafluoroethylene	Oxygen	0.8 W m^{-3}

Source: (Flimban et. al, 2019)

2.3.1 Double-chambered Fuel Cells

Generally, two chamber MFC designed as a basic model. A typical two chamber MFC consists of an anode chamber, a cathode chamber separated by a PEM (Bhargavi *et al*., 2018). PEM contributes to the facilitation of proton transfer from the anode to the cathode while also reducing oxygen diffusion into the anode throughout the process. This completes the reaction process and prevents the diffusion of oxygen or any other oxidizers from the cathode once it has occurred. For increased energy power output, double-chambered fuel cells are often operated in batch mode with a chemically defined medium such as acetate or glucose solution. These can also be utilized to deliver power in a variety of inaccessible conditions (Flimban *et al*., 2019).

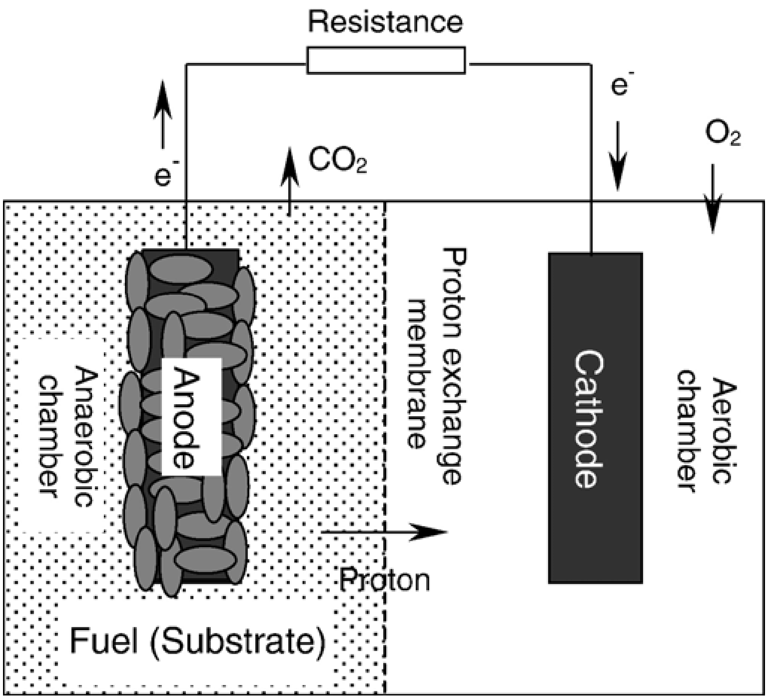

Figure 2.2 Diagrammatic representation of a typical two chamber MFC
Source: (Bhargavi et al., 2018)

2.3.2 Single-Chambered Fuel Cells

According to Ravinder *et al*, 2017 (Singh & Kalia, 2017), a single-chamber MFC has only one chamber with both anode and cathode. Single-chamber MFCs evolved from two-chamber MFCs to eliminate the membrane. The anode is separated from the cathode by PEM. They are separated by a gas diffusion layer (GDL) or a porous air-exposed cathode, which facilitates passive oxygen transport to the cathode. The electrons are then transferred to the porous cathode to complete the circuit. Not required to aerate the cathode when using oxygen as an electron acceptor led to single chamber MFCs with air cathodes. For example, the reduced electrode spacing and improved oxygen reduction rate on the cathode attract researchers. This arrangement is more adaptive because to less frequent oxidative media and aeration changes.

These fuel cells would also have a basic anode chamber with no cathode chamber and maybe no PEM. Porous cathodes use atmospheric oxygen to create one side of the cathode chamber wall and let protons pass through. Due of its simplicity, this design has lately been used in research. Cathodes are either porous carbon electrodes or a PEM combined with flexible carbon cloth electrodes. However, cathodes are typically coated with graphite, which acts as a catholyte, avoiding membrane and cathode drying. Water or enhanced fluid management in single chambered fuel cells is also a major issue.

There are numerous advantages to single chamber MFCs. One advantage is that it can reduce columbic efficiency by allowing oxygen to diffuse into the anode for a longer period. In addition, lowering the interelectrode spacing can help to lower the internal ohmic resistance of the device. Because of the connection of two chambers, it is possible to avoid the usage of catholyte while simultaneously increasing the power density. This is a straightforward and reasonably priced MFC that also produces a significant amount of power when compared to MFCs with twin chambers. There are several limitations to this chamber as well. High oxygen diffusion, liquid leakage, and evaporation are just a few of the issues that need to be addressed (Flimban *et al*., 2019).

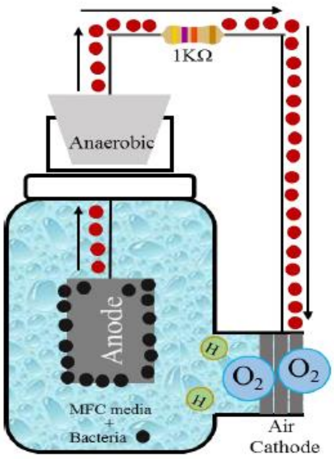

Figure 2.3 Single chamber microbial fuel cell
Source: (Flimban et. al,2019)

2.4 Working principle of MFC

The microbial fuel cell (MFC) is a device that extracts electrons from its food source, organic materials, and feeds them into an electrical circuit to produce energy. In theory, electrons are moved to the anode in MFCs following microbial oxidation of a substrate. The electron then exits the anode and travels through an external electrical circuit to the cathode, generating electricity. Finally, in an oxygen reduction reaction, these electrons react with protons and oxygen at the cathode, resulting in the formation of water as the final and pure product. As long as current flows over a potential difference, energy is produced directly through bacterial catalytic activity (Flimban et al., 2019).

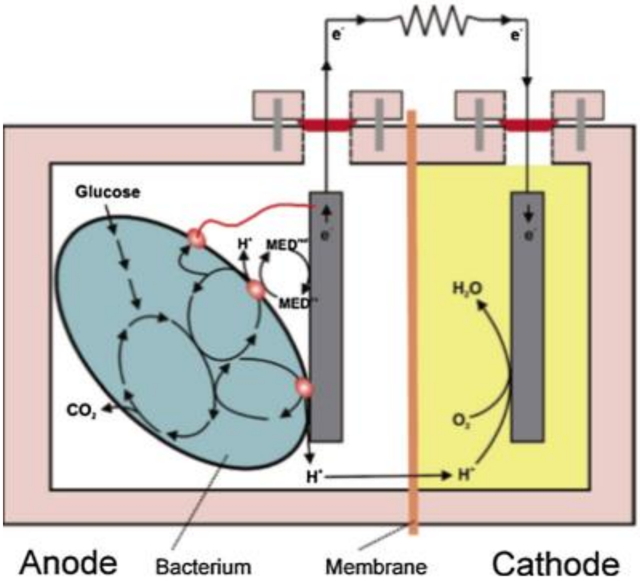

Figure 2.4 Schematic of dual-chambered Microbial Fuel Cell
Source:(Rahimnejad & Adhami, 2015)

2.4.1 Anaerobic Process at Anode

Organic matter is the fuel of MFCs in the anode chamber, and microorganisms degrade organic compounds by oxidizing (reducing other substances and losing electrons, electron donor) biodegradable substrates to create CO2, protons, and electrons. The electrons produced from the metabolic activity of microorganisms are transferred and accumulated on the electrode surface of the anode by cytochromes or redox-active proteins and then moved to the cathode, reacting through the electrical circuit (copper wire) with the electron acceptor (e.g., oxygen) (Flimban *et al.*, 2019). At the same time the protons are internally transferred to form a water molecule at the cathode via the membrane. Because of the difference in solution concentrations between anode and cathode, there is a difference in electrical potential.

The movement of electrons into the external electrical circuit generates electricity. According to Dharmalingam *et al*., 2018 revealed that an ideal anode material should be highly conductive, chemically stable in wastewater streams, biocompatible without microorganism toxicity and have a high surface area to allow the fastening and growth of microorganisms onto its surfaces. It is also beneficial for them to have good adaptability and to stay stable at room temperature and pH between 5 and 7. They should also be biofouling resistant (Dharmalingam *et al*., 2018).

Flimban *et al*.,2019, mention the effect of anode in MFCs, anode bacteria generally serve as catalysts. However, by adding an appropriate catalyst, the activation energy needed for anodic reactions can be minimized. Anode's output is also affected by the electrode content, its surface area, its equipment design, the substrate concentration, the microbial population, the nature of the anode chamber system, etc.

Anode reaction: Active Microorganism + Anaerobic Environment + Biodegradable Organics → $CO_2 + H^+ + e^-$

2.4.2 Aerobic Process at Cathode

The cathode is an electron acceptor, an electrode where protons are combined to form water with electrons and oxygen. Cathode surface area is one of the influencing factors of MFC power generation (Tharali *et al*., 2016;(Flimban et al., 2019). According to Dharmalingam et al., 2018 mention that, the cathode material should be of high conductivity, well adaptable, stable at room temperature and pH from 5 to 7, show high electrocatalytic activity against surface redoxing and resistant to chemicals present in wastewater streams and other biological by-products during an MFC operation.

Carbon materials containing platinum, activated carbon, carbon black and polytetrafluoroethylene (PTFE) pressed in stainless steel mesh are currently the most used cathode materials and catalysts used to improve the efficiency of MFCs, and are used to increase the rate of cathode catalytic oxygen reduction.

The effect reaction at cathode where protons generated in the anode chamber migrate via PEM to the cathode chamber. The electrons generated on the anode site pass through the external circuit to the cathode.

Anode: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$

Cathode: $6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Electric Energy

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology for research is the exact processes or strategies utilized for identifying, selecting, processing, and analysing the relevant information. It also refers to the entire method behind the investigation. Through this chapter, will explained briefly about the method, instrument and material used in recent study to design and develop for MFC reactor and to evaluate the performance of the MFC to generate the electricity.

3.2 MFC material prerequisites

The construction of double chamber MFC device requires the following materials and devices-

- No of 1L bottles -2
- 0.5 m crocodile wire
- No of 6x90 mm carbon rod- 2
- No of Nafion membrane- 1
- No of seal (adhesive)- 2
- No of resistor 1k Ohm -1
- Food waste sample 1.6kg consist of vegetables, rice, chicken bones, chicken liver, bread.
- volt-ohm-milliammeter (VOM) (ProsKit MT-1210 Digital Multimeter)

3.3 Methodology Flowchart

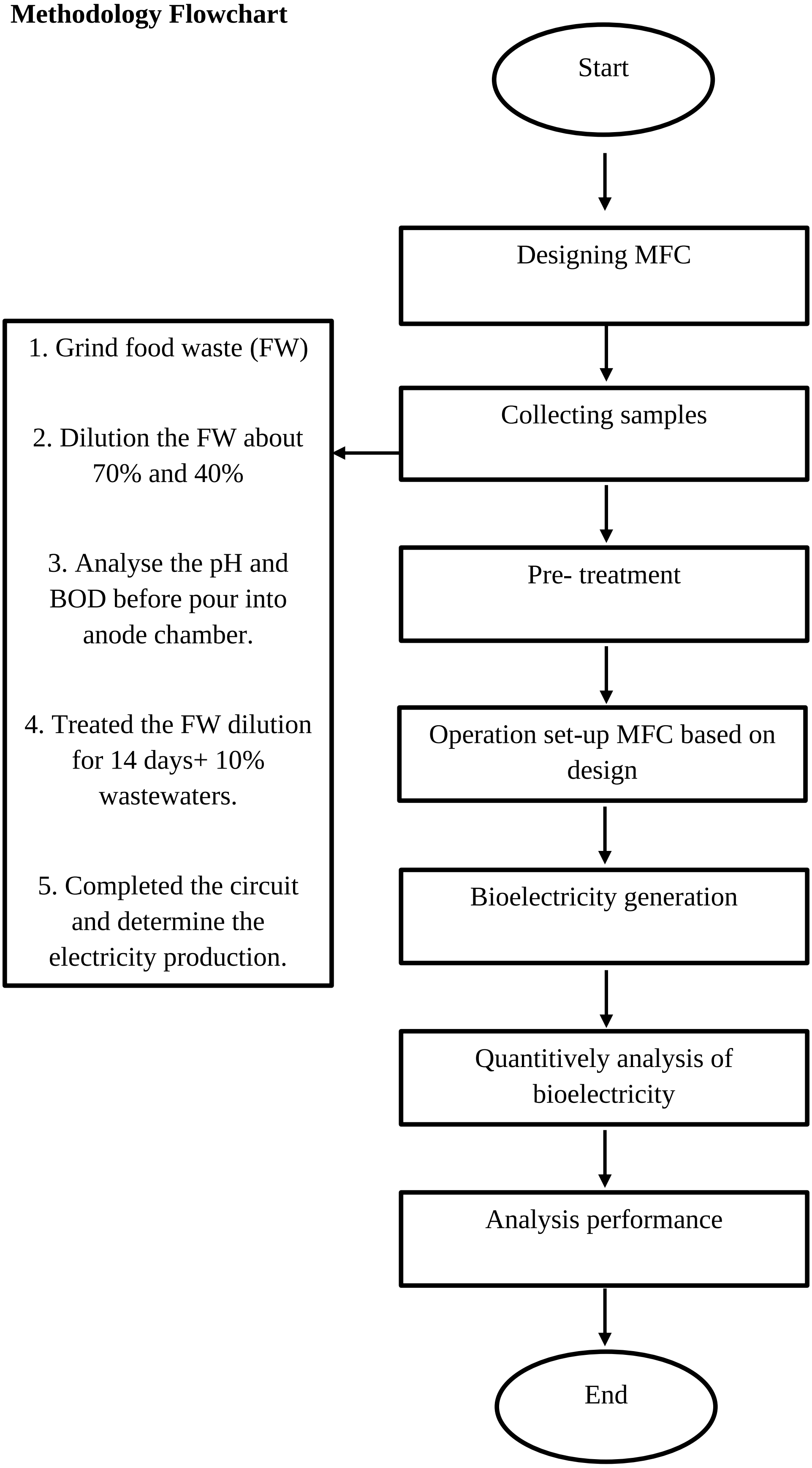

Figure 3.1 Methodology Flowchart

3.4 Sample Preparation

The food waste (FW) that has been chosen in this study as a substrate in generating the electricity comes from the cafe of residential in University Malaysia Pahang (UMP). Due to the pandemic, the sample of FW were collected and customized to prevent spreading of virus. The FW categorized from the fat, protein, and carbohydrate such as consist of 350g rice, 100g vegetables, 1kg heart chicken, 69.65g chicken bones, and 150g bread. Then, the process of the beginning with grind all the FW and dilute with 1:1 ratio of FW and water. After that, the FW is diluted into 2 samples of Treated FW and Raw FW at 70% and 40% by using formula of M1V1=M2V2.

The 10% wastewater adding in FW solution and left for 14 days with sealed the container to maintain in anaerobic conditions at room temperature called (Treated FW). Besides that, the Raw FW is a diluted FW that use directly in anode chamber MFCs. Next, chemical, and organic parameter of pH and BOD are analysed. Then, the Raw FW pour into the MFC, and the other FW sample will be store in the chiller at 3 ^{o}C to preserve sample from microbial degradation. In addition, at the lower temperature the microbial metabolism systems almost stops doing their activities.

3.5 Analysis of Data by Statistical Test

A t-Test is a type of statistical test for compares two groups' significance means. It is a commonly used statistical hypothesis test in research studies. There are two types of statistical inference: null hypothesis and alternative hypothesis. The level of significance is 0.05 that used. The data will be analysed based on the hypothesis given:

The t-Test: Paired Two Sample for Means compared the Treated FW 70% and 40% follow this hypothesis:

$$H_o : \mu_{T@70} - \mu_{T@40} = 0$$

$$H_a : \mu_{T@70} - \mu_{T@40} \neq 0$$

Next, compared the significance means of Raw FW 70% and Treated FW 70%:

$$H_o : \mu_{fw@70} - \mu_{T@70} = 0$$

$$H_a : \mu_{fw@70} - \mu_{T@70} \neq 0$$

Lastly, compared the significance means of Raw FW 40% and Treated FW 40%:

$$H_o : \mu_{fw@40} - \mu_{T@40} = 0$$

$$H_a : \mu_{fw@40} - \mu_{T@40} \neq 0$$

3.6 Measurement of pH

Most MFC investigations used a relatively neutral solution as an electrolyte, indicating that anodic bacterial strains were essentially neutrophilic. Studies on the association between the electrolyte pH value and MFC performance have also shown that these electroactive bacteria are tolerant to high pH. Low electrolyte pH frequently results in inefficient MFC performance, such as decreased power density or insufficient substrate decomposition (Linke et al., 2017).

3.7 Measurement of BOD

Biochemical oxygen demand (BOD) is one of the most essential and extensively utilized metrics for characterizing organic water and wastewater contamination estimates by measuring the oxygen level necessary for organic wastewater degradation from aerobic microorganisms. The BOD content of wastewater can be defined as the amount of oxygen required by microorganisms to biodegrade the degradable carbonaceous organic matter present in the water via their biochemical, bioprocess, and under the following reaction conditions: temperature of 20°C, retention time of five days, and darkness to avoid the presence of microscopic algae (Verma & Singh, 2013).

3.8 Material of Electrode

Carbonaceous materials are commonly utilized in MFC anodes due to their excellent biocompatibility, chemical stability, conductivity, and affordable cost. Graphite plates or sheets, carbon paper and carbon cloth are used in the laboratory for simple electrodes (Choudhury et al., 2017). Anode materials must be conductive. The material should also be eco-friendly and chemically inert to the anode electrolyte. Carbon electrodes such as graphite plates, graphite rods, graphite felt electrodes, graphite granules, carbon cloth, carbon brush, and stainless steel are frequently used in MFCs. The cathode compartment contains the cathode material, as well as a catalyst to promote the reduction of electrons and an electron acceptor, which all work together to produce electricity. The electrode materials that were used as the anode in the previous example are/can be used as the cathode as well (Singh & Kalia, 2017).

Therefore, the carbon rods materials are chosen because of the cheapest cost. This electrode will be place in anode and cathode chamber, respectively. The dimension of the carbon rod is 0.6 cm in diameter and 9.0 cm in length.

Figure 3.2 Carbon rod

3.9 Proton Exchange Membrane

An ion-selective membrane separates the anode from the cathode on both sides of the cell. While simultaneously restricting oxygen passage into the cathode, this membrane facilitates in proton transport from the anode to the cathode in an electrochemical cell (Flimban et al., 2019). It is essential to select a membrane that has a high capacity for proton transport. As a result, Nafion 117 has been selected as the proton exchange membrane in this MFC design. The Nafion measures 5 cm in length and 5 cm in height, and it weighs a total of 0.89 gram. The Nafion is located in the middle of the two chambers. The Nafion was then clamped in place and can be tightened further if necessary to ensure that it remains in place.

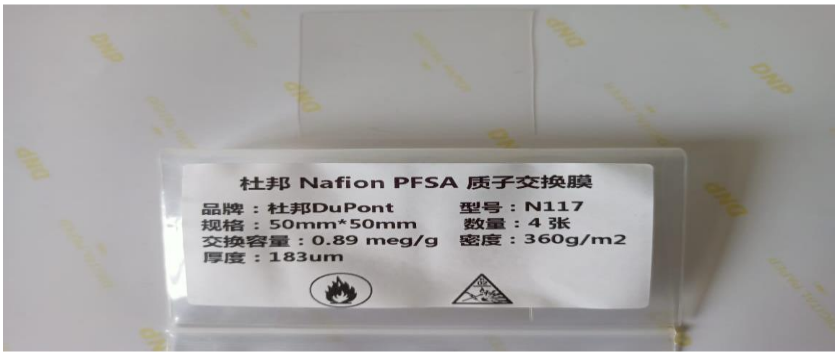

Figure 3.3 Nafion PFSA

3.10 Project Design

The construction sector relies on some fundamental components of MFCs, which are listed below. Besides electrodes and wire, a glass cell and a salt bridge are also important components of the process. PEM cells do not have a salt bridge because the proton exchange membrane (PEM) takes the role of it. However, while it raises the cost of the system, it also enhances the handling and power generation of the system, hence increasing its portability and efficiency. Additionally, fuel cells can be classified into two types based on the number of compartments or chamber that they contain (Karmakar et al., 2010).

3.10.1 Microbial Fuel Cell Design

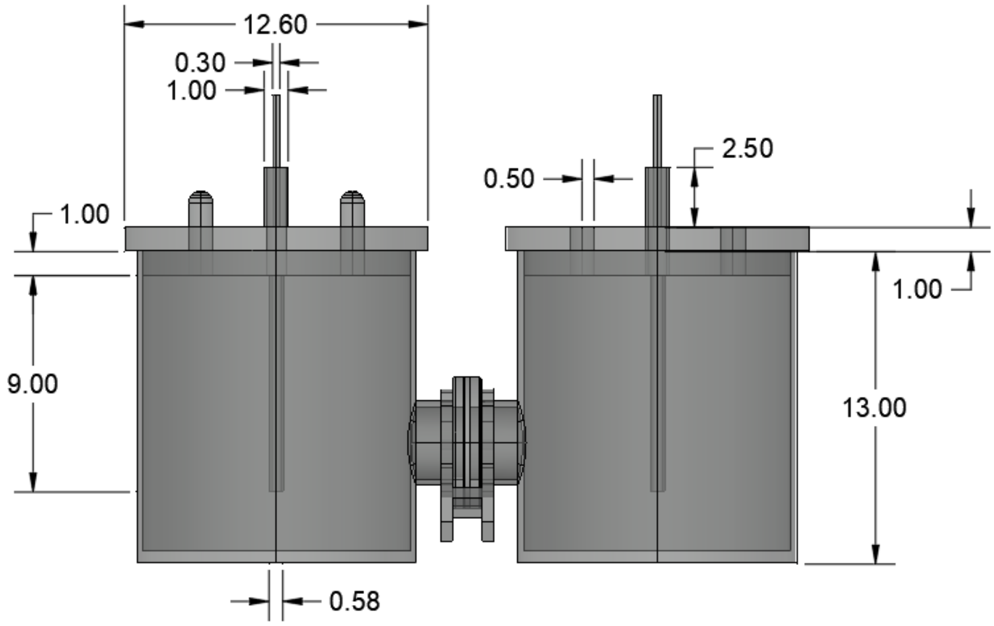

Figure 3.4 Front View dimension in cm

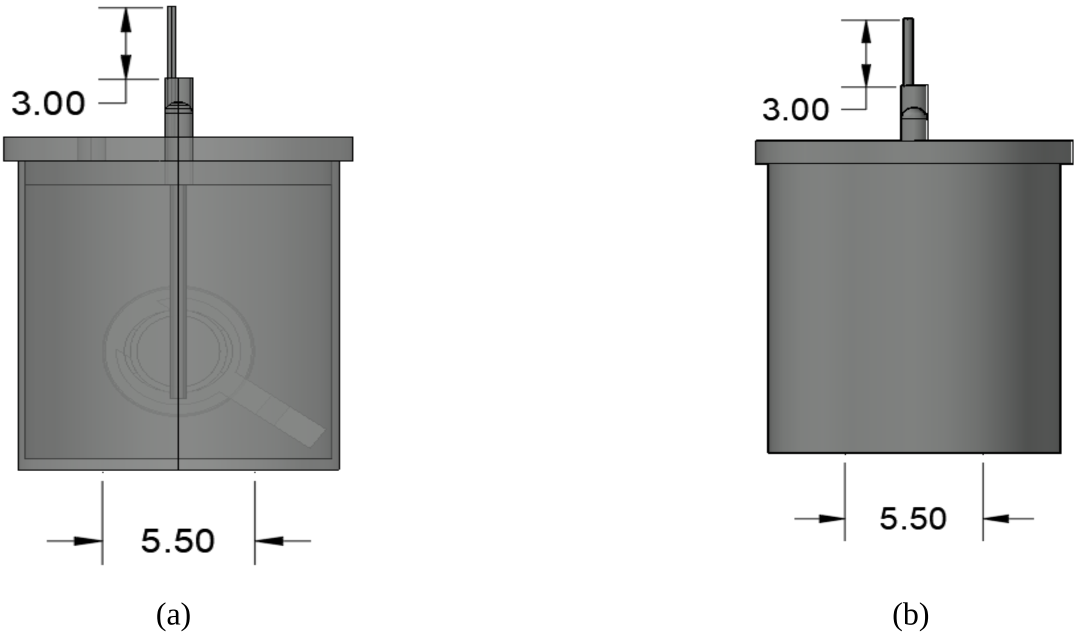

Figure 3.5 (a) Side view X-Ray style (b) Side view by shade of Gray style

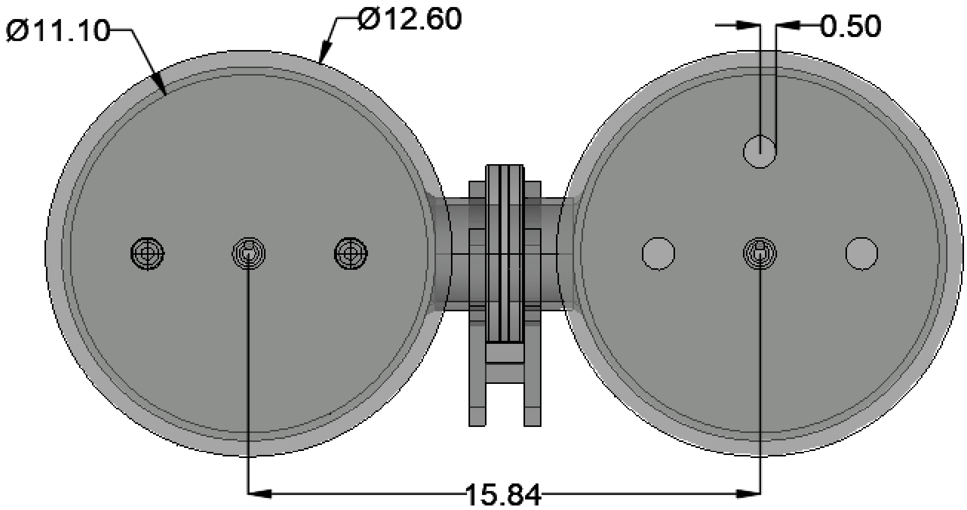

Figure 3.6 Top View

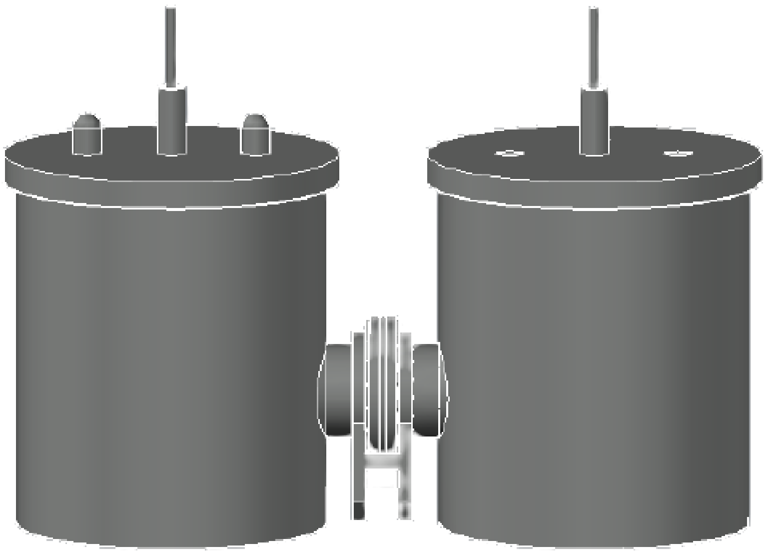

Figure 3.7 Model in 2D

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Sustainable electricity production and efficient food waste treatment are two of the most pressing issues facing the world. Natural forms of power generation are environmentally friendly, but they are not always feasible in many parts of the world. As the world's population continues to grow, food consumption will continue to rise, making it increasingly vital to develop environmentally acceptable and effective food waste treatment alternatives.

The MFCs are producing the electricity through the biological treatment to degrade the food waste under anaerobic conditions and utilize the microorganisms to degrade the organic component in aerobic conditions. Though this process, the electrons are released from anode to cathode.

4.2 MFCs Operation, Materials, and Experimental Method

The MFC system designed and the materials that were used described in the Chapter 2. The system was operated for 28 days and consisting of the conducted for treated and raw FW materials. For the treated FW, was treated for 14 days before putting in the MFCs by adding 10% of wastewater and used room temperature. Both conditions of FW were used the same MFC. The systems were evaluated every 5 hours in generated the bioelectricity (bio-E). The MFC system operation and experimental methods are provided in detail in Chapter 2 while methods are described in Chapter 3.

As described in Chapter 2, the evaluation of electrochemical performance, such as current and power production, is typically reported after being normalised to the effective surface area of the transport media used in the measurement. The MFCs were identical, with anodes having a surface area of 16.96 cm^2, cathodes having a surface area 16.96 cm^2, and proton exchange membranes having a surface area of 25cm^2.

Figure 4.1 MFCs system setup

Figure 4.1 showed the complete and finished design of microbial fuel cell after fabrication process. All the fabrication part were in good conditions to be published and presented. The essential part of circuit connection also be checked to ensure the bioelectricity generated when handling the systems.

All the evaluation process for observation for each sample were carried out at hostel and sometimes at laboratory for checked pH due to the COVID-19 pandemic and flood issues restricted to do at the proper place with using the digital multi meter. There are some problems at first due to the size of space contact area with the air at the cathode. The problem was fixed by adding the aquarium pump as a source for air to complete the reaction at cathode that come out from the cellular respiration of microbes to produce water and maintain the room temperature water bath.

4.3 Observations

The generated voltage and current were measured and recorded from the multi-meter at an interval of 5 hours for seven days. The corresponding power, while P=V.I was used to calculate the power.

4.4 Voltage Generation

<u>Result obtained for Treated FW 70%</u>

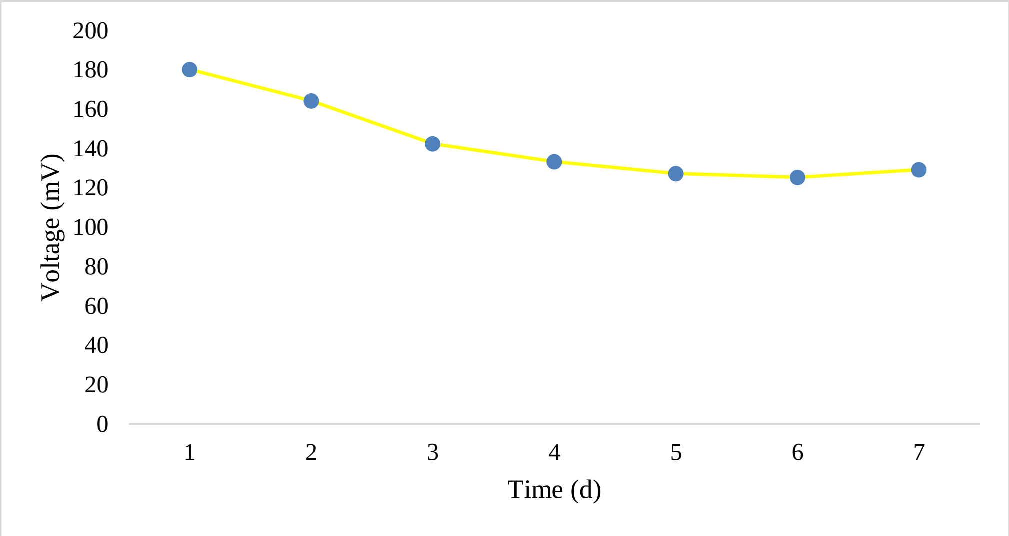

Figure 4.2 Average voltage generated for Treated FW 70%

Result obtained for Treated FW 40%

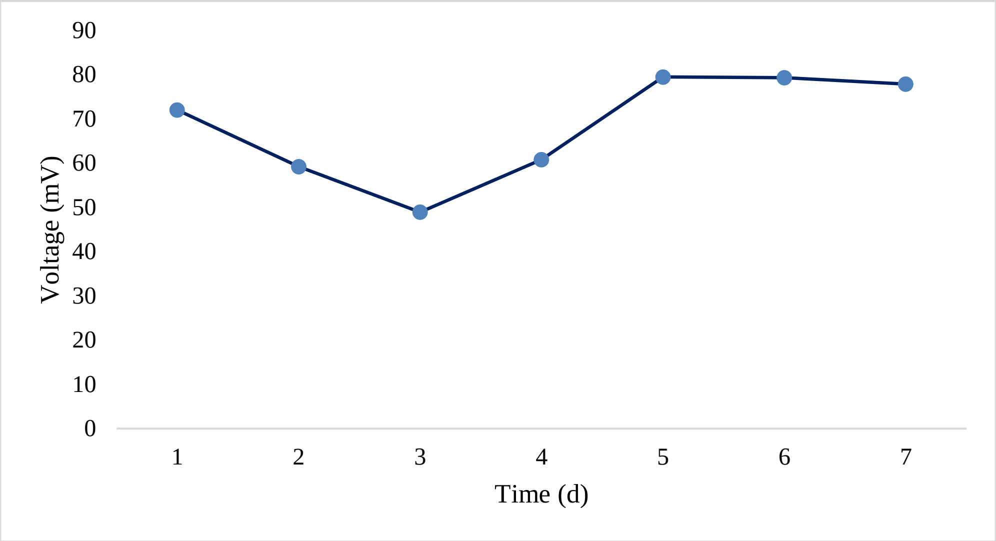

Figure 4.3 Average voltage generated for Treated FW 40%

Result obtained for Raw FW 70%

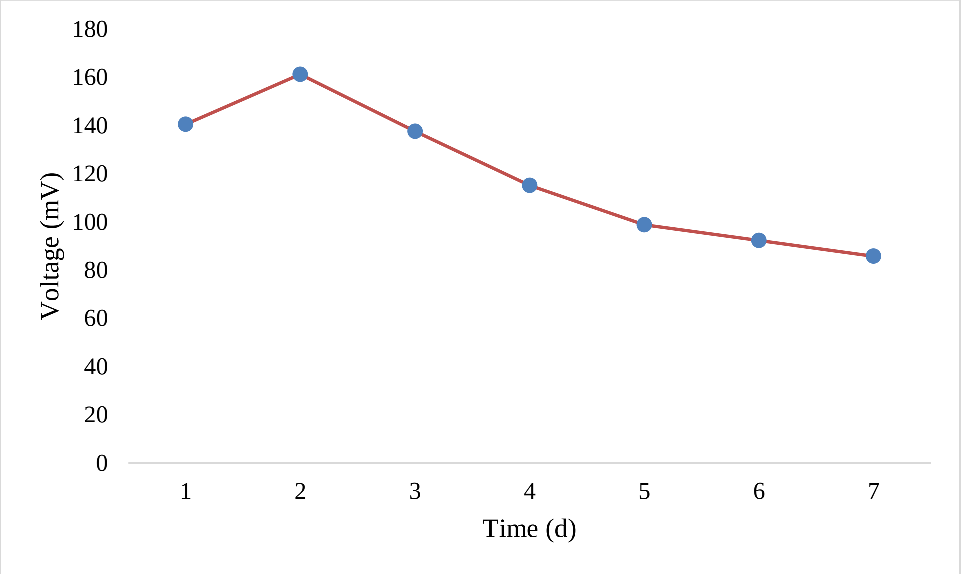

Figure 4.4 Average voltage generated for Raw FW 70%

__**Result obtained for Raw FW 40%**__

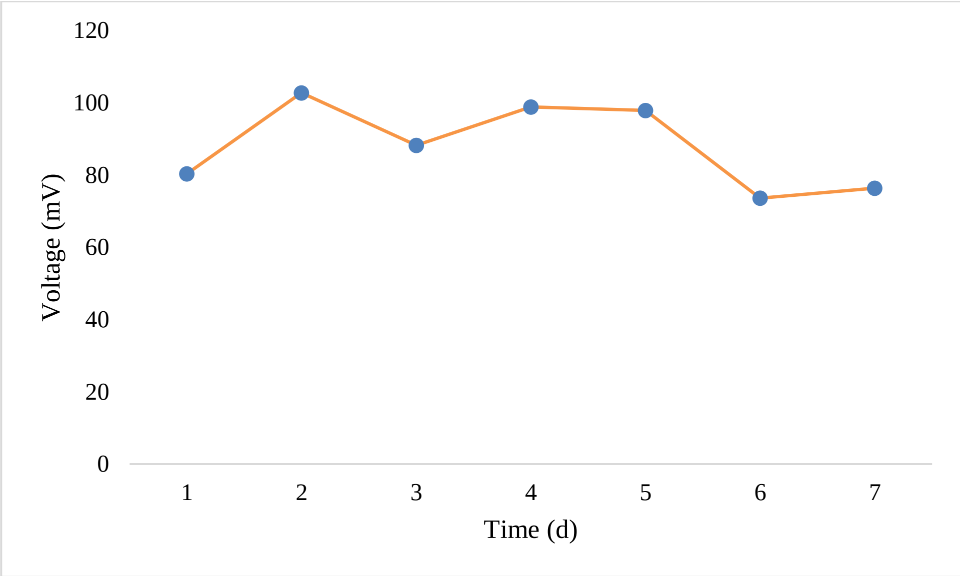

Figure 4.5 Average voltage generated for Raw FW 40%

Voltage generated by food waste using double chamber MFC was recorded at an interval of five hour per day for the entire period of 7 days as shown in Fig 4.2-4.5. The maximum generated voltage in each of the seven days is depicted in Table 4.1. Through the study, it is observed that there was a definitive increase in the generated voltage from day 1 to day 2 and then a decline in trend is observed on day 3 to 7 days but consist of slightly increase based on the different types of dilution and comparison the maximum voltage generated either with adding of wastewater in the food waste sample or by using the raw FW. The voltage generation fluctuated due to unstable microbial activity inside the chamber.

The maximum generated voltage for the Treated FW 70% of 180.22 mV at day 1 and minimum voltage of 125.380 mV at day 6. Moreover, the Treated FW 40%, the maximum voltage generated was 79.460 mV at day 5 and the minimum voltage generated 48.90 mV at day 3. Next, Raw FW 70% at day 2 was 161.20mV and the minimum generated voltage of 85.720 mV was observed on day 7. In addition, the maximum generated voltage for the Raw FW 40% at day 2 was 102.78 mV and the minimum generated voltage of 73.60 mV. The voltage measured was closed circuit voltage when the external resistance was completing setup.

Table 4.2 Voltage production (mV) versus time elapsed (d)

Time Elapsed (Days)	**Raw FW 70% (mV)**	**Raw FW 40% (mV)**	**Treated FW 70% (mV)**	**Treated FW 40%(mV)**
1.	140.475	80.325	180.225	72.000
2.	161.200	102.775	164.300	59.175
3.	137.500	88.220	142.480	48.900
4.	115.080	98.840	133.340	60.780
5.	98.720	97.860	127.240	79.460
6.	92.320	73.600	125.380	79.300
7.	85.720	76.420	129.200	77.860

4.5 Comparative analysis of Voltage (mV) and Current (mA) generated

Table 4.3 Maximum Electricity Production versus Sample Types

Types of Samples	**Voltage (mV)**	**Current (mA)**
Raw FW 70%	161.20	0.1612
Raw FW 40%	102.78	0.1028
Treated FW 70%	180.22	0.1802
Treated FW 40%	79.460	0.0795

Based on the comparative analysis of voltage and current generated from the MFCs. The current will produce by using the theoretical I=V/R (V represent the voltage generated and *R* represent the external resistor 1000Ω that used).

4.6 Power density generations

Power density obtained by FW using double chamber MFC was recorded as shown in Figure 4.6. The maximum generated power density in each of the seven days is depicted in Table 4.3. It is observed in overall samples that, there was a definitive increase in the generated power density from day 1 to day 2 and then a drop in trend is observed on day 3 to day 7. The maximum generated power density at day 1 of 1.163 mW/cm^2 for the Raw FW 70% and 1.915 mW/cm^2 for Treated FW 70% and the minimum generated power density were 0.344 mW/cm^2 for the Raw FW 40% observed on days 7 and 0.141 mW/cm^2 for Treated FW 40% on day 3. As a result, the power density measured was closed circuit voltage due to the usage of a 1k ohms external resistance.

Table 4.4 Electricity Production versus time elapsed (days)

	Power density, P (mW/cm^2)				**Current density, J (mA/cm^2)**			
Time Elapsed (Days)	**Raw FW 70%**	**Raw FW 40%**	**Treated FW 70%**	**Treated FW 40%**	**Raw FW 70%**	**Raw FW 40%**	**Treated FW 70%**	**Treated FW 40%**
1	1.163	0.380	1.915	0.306	0.008	0.005	0.011	0.004
2	1.532	0.623	1.591	0.206	0.010	0.006	0.010	0.003
3	1.114	0.459	1.197	0.141	0.008	0.005	0.008	0.003
4	0.781	0.576	1.048	0.218	0.007	0.006	0.008	0.004
5	0.574	0.565	0.954	0.372	0.006	0.006	0.008	0.005
6	0.502	0.319	0.927	0.371	0.005	0.004	0.007	0.005
7	0.433	0.344	0.984	0.357	0.005	0.005	0.008	0.005

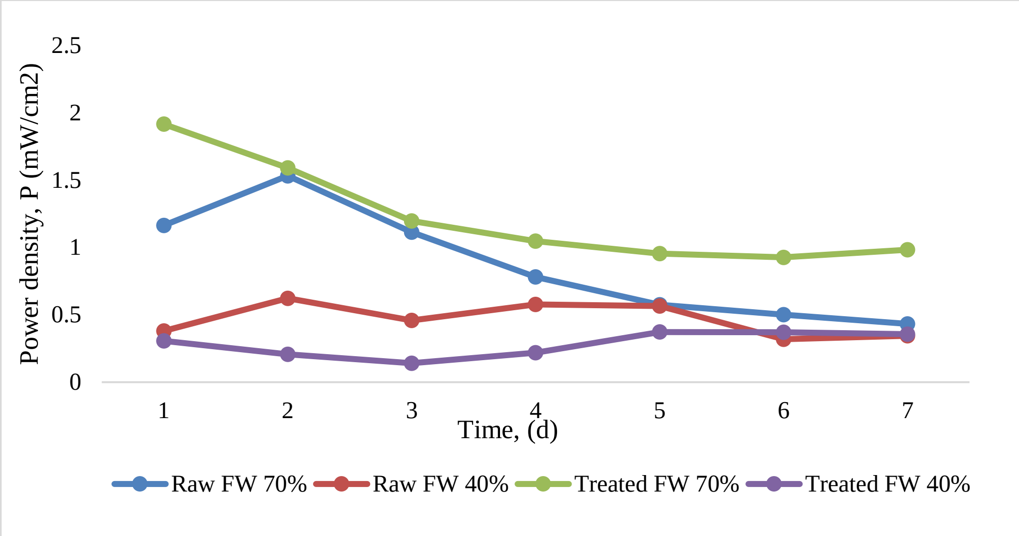

Figure 4.6 Power density vs. time in chamber-MFC and composed FW for Treated FW and Raw FW with different dilution recorded with same resistor.

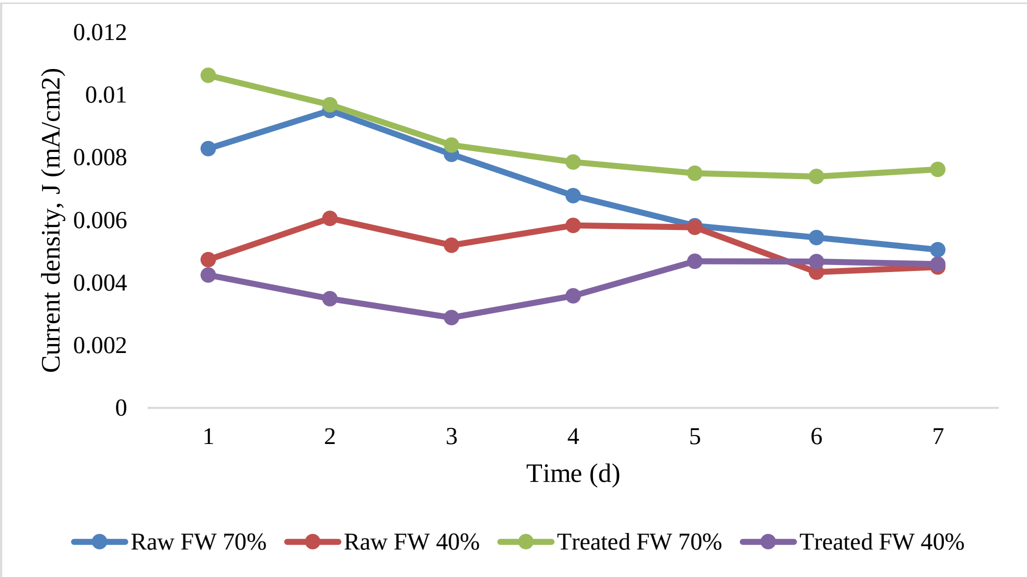

Figure 4.7 Current density vs. time in chamber-MFC and composed FW for Treated FW and Raw FW with different dilution. R= 1000Ω and A_g=16.96 cm^2.

Due to the high activity of the microbe inside the chamber, the trend graph showed an increase from day 1 to day 2. The microbes were considered in two phases: the lag phase, which refers to the phase of adaptability of the microbe to its new environment, and the exponential phase, which describes conditions that are optimal for growth and metabolic activity and contain high amounts of nutrients inside the chamber. From the 3 days until day 7 showed the decline in trend. Because of the microbes slowly less of nutrient and comes to the death phase causes of no addition nutrient inside the chamber. In addition, the growth of the microbes also was inhibited by its own waste product (Linda Bruslind, 2021).

4.7 Initial value of the pH and BOD

The initial pH of 70% and 40% diluted FW was 6.94 and 6.05, respectively. It shows that the pH optimum for microbes was about 5-7. The BOD_5 (mg/L) for 70% diluted FW was 24.43 and 40% diluted FW was 27.75. The Malaysia Effluent Regulation (Malaysia Act 1974) stated that BOD_5 at 20ºC was 20mg/L for Standard A and 50mg/L for Standard B. The result obtained confirms that the diluted FW follows Standard A compliance. The lower BOD value indicates cleaner water or less polluted and can be directly disposed.

4.8 Statistical Test in Evaluating the Performance of Differentiate Samples

A paired- samples t-Test was conducted to compare the Treated FW 70% and Treated FW 40% conditions. There was a significant difference in p value is 0.001053809. It observed that significant evidence of rejecting the null hypothesis. Because the $p< 0.05$, it concludes that, the means of both samples are not equal. Besides that, the performance of the Treated FW 70% produced bio-E more compared to the Treated FW 40% because of the conditions at diluted 70% consist of more FW compared to the 40% have more water.

Next, a paired- samples t-Test was conducted to compare the Raw FW 70% and Treated FW 70% conditions. There was a significant difference in p value is 0.114252184. It observed that significant evidence to accepting the null hypothesis. Because the $p> 0.05$, it concludes that the means of both samples are equal. Thus, its indicate that the raw and treated FW at 70% dilution generate voltage without too much of significant change. Its conclude that, at 70% dilution, no need to treat and can proceed directly into chamber.

After that, t-Test was conducted to compare the Raw FW 40% and Treated FW 40% conditions. There was a significant difference in p value is 0.002806288. It shows that significant evidence of rejection the null hypothesis. Because the $p<0.05$, it concludes that the means of both samples are not equal. In addition, it evaluated that the FW 40% is generate higher voltage compared with treated FW 40%. Because of the 10% of wastewater added in medium does not make any remarkable changes.

CHAPTER 5

CONCLUSION

5.1 Introduction

In conclusion, the food production in Malaysia is significant high. However, Malaysia lacks a proper FW management system, but some are under the planning and development. In addition, the reduction of petroleum resources motivated global experts to look for alternate energy sources. Using fossil fuels may also pollute the environment. Clean fuels, particularly fuel cells and biofuels, are acceptable substitutes for traditional fossil fuels.

MFCs are FCs (Fuel Cell) that generate energy from active biocatalysts like microorganisms or enzymes. MFCs are a newer technology for producing energy from various substrates. The community must understand the value of good food waste management in lowering environmental impact. This new technology and programme may not be effective if the community is still unaware of proper food waste management practises, especially in the home.

The main objective of this project which was to design and operational setup the MFCs was achieved. This design of MFCs was aiming for educational kit purpose and its dimension and sizing was not suitable for industrial usage. The operational setup also very easy and not complicated to used. In addition, the MFCs system also very functioning to represent the prototype in explaining the overall system working concept in generating the bioelectricity concept from FW by the activity microbes. The wiring system and devices such as multi meter has been tested and checked to ensure the system running properly and successfully.

Due to the result and discussion, the second objective to compare the performance of treated FW compared with the raw FW used in the MFC also successful. Through that, based on the statistical test of comparing the dilution 40% and 70% for the treated and raw FW has been observed and significant evident conclude that it indicates the raw and treated FW at 70% dilution generated the voltage without too much of significant change. Its conclude that, at 70% dilution, no need to treatment for 14 days, adding 10% of wastewater in the FW and can proceed directly into chamber.

On top of that, at the cathode side was chosen to apply the aquarium pump due its advantage in increased the surface contact to the surrounding and increasing the COD value. As a conclusion of the process, which might be related to the variety of bacteria that are working on pollutants. Additionally, the performance of the cell was improved (Hussein, 2014). Therefore, as higher exposer to the air at the cathode side, help in completing the cellular respiration of the microbe's cycle in the MFCs chamber.

5.2 Limitation

The amount of bioelectricity generated is insufficient, and the level of output is too low. This is due to the primary difficulty associated with the utilisation of microbial cells, which is dependent on their activity. This can be overcome by expanding the surface area of the electrodes and using several electrodes with closed ranges to improve the output production (Rahimnejad & Adhami, 2015). Finally, the other limitation that faced, lack of times to adding the any booster or cultured microbes inside the chamber. This is causing the microbial reactions death due to the losses of nutrient inside the chamber and resulting the growth of the microbes being restricted by their own waste.

5.3 Recommendation

The study of the development and designing of MFC is still in beginner phase. Modification in design components will provide to improve the result generated. The high-quality substrate should be used in the MFC will enhance the high-power production to run the electrical appliances, electronic device, or other industrial applications. The microorganisms which supply electrons can be modified genetically to provide more efficient electron transfer to electrodes (Thatoi, 2014). Next, submerged the electrode fully inside the chamber to increase the surface area for microbes attached and release the electrons.

Besides that, adding the dosage such as catalysed or essential nutrient for the microbe's growth and also help in increase the activities microbes inside the chamber to generate the bioelectricity. In addition, optimizing the process parameters that involved in production of electricity can be increased, such as increase the volume % of wastewater in the MFCs. Furthermore, extended the period from 14 days evaluation into more period time to observe the performance and trend of production bioelectricity in good trend. Moreover, the electrode spacing should be near to the PEM membrane to ensure the facilitation of proton transfer from anode to cathode will successfully generate the power.

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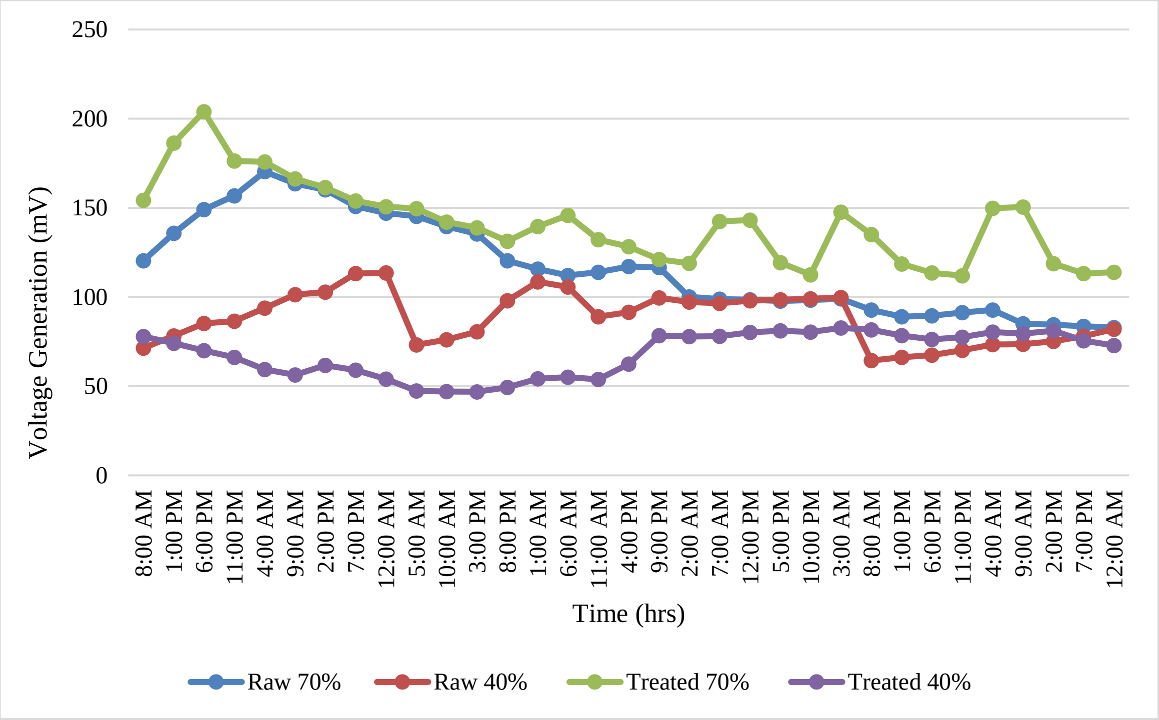
APPENDICES

Appendix A Electricity production for every 5 hours in 7 days observations.

Time (hrs)	**Raw 70% (mV)**	**Raw 40% (mV)**	**Treated 70% (mV)**	**Treated 40% (mV)**
8 am	120.4	71.4	154.2	77.9
1 pm	135.7	78.2	186.4	74
6 pm	149.0	85.2	204	69.9
11 pm	156.8	86.5	176.3	66.2
4 am	170.3	93.9	175.7	59.4
9 am	163.5	101.4	166.3	56.4
2 pm	160.1	102.7	161.4	61.8
7 pm	150.9	113.1	153.8	59.1
12 am	147.0	113.5	150.7	54
5 am	145.2	73.2	149.5	47.3
10 am	139.6	76.0	142.1	47
3 pm	135.4	80.5	138.8	46.9
8 pm	120.3	97.9	131.3	49.3
1 am	115.7	108.5	139.6	54.2
6 am	112.1	105.6	145.8	55
11 am	113.9	89.0	132.1	53.8
4 pm	117.2	91.5	128.2	62.5
9 pm	116.5	99.6	121	78.4
2 am	100.1	97.2	119	77.8
7 am	98.9	96.5	142.4	78.1
12 pm	98.5	98.0	143.2	80.1
5 pm	97.8	98.5	119.2	81
10 pm	98.3	99.1	112.4	80.3
3 am	99.0	99.7	147.6	82.7
8 am	92.8	64.4	135.1	81.7
1 pm	89.0	66.2	118.6	78.4

6 pm	89.5	67.5	113.6	76.2
11 pm	91.3	70.2	112	77.5
4 am	92.7	73.4	149.7	80.3
9 am	85.0	73.6	150.4	79.4
2 pm	84.4	75.1	118.8	81.1
7 pm	83.6	78.0	113.2	75.6
12 am	82.9	82.0	113.9	72.9



Appendix B Table of Statistical Test for comparing means between 2 conditions.

t- Test: Paired Two Samples Means of Treated FW 70% and Treated FW40%

	Treated FW 70% (mV)	*Treated FW 40% (mV)*
Mean	180.225	79.25
Variance	432.0291667	2.403333333
Observations	4	4
Pearson Correlation	0.454905361	
Hypothesized Mean Difference	0	
df	3	
t Stat	10.03354144	
P(T<=t) one-tail	0.001053809	

t- Test: Paired Two Samples Means of Raw FW 70% and Treated FW70%

	FW 70% (mV)	*Treated FW 70% (mV)*
Mean	161.2	180.225
Variance	65.13333333	432.0291667
Observations	4	4
Pearson Correlation	-0.41401308	
Hypothesized Mean Difference	0	
Df	3	
t Stat	-1.50870651	
P(T<=t) one-tail	0.114252184	

t- Test: Paired Two Samples Means of Raw FW 40% and Treated FW40%

	FW 40% (mV)	*Treated FW 40% (mV)*
Mean	102.775	79.25
Variance	62.4225	2.403333333
Observations	4	4
Pearson Correlation	0.883248228	
Hypothesized Mean Difference	0	
Df	3	
t Stat	7.159327271	
P(T<=t) one-tail	0.002806288	