BIOELECTRICITY GENERATION FROM A MIXTURE OF PALM OIL MILL EFFLUENT AND WET PALM OIL SLUDGE IN MICROBIAL FUEL CELL BY USING COPPER AS AN ELECTRODE

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ABSTRAK

Kajian ini menyiasat potensi tenaga elektrik yang dijana oleh dua ruang MFC menggunakan campuran efluen kilang kelapa sawit dan enap cemar minyak sawit basah. Matlamat penyelidikan ini adalah untuk membangunkan MFC dengan mempelbagaikan sistem operasi elektrod, seperti mempelbagaikan jenis elektrod, untuk menyiasat pengaruh litar pada voltan, arus, dan kuasa, dan untuk menentukan kesan pelbagai faktor penting pada prestasi MFC, seperti bahan elektrod, TSS, COD, pH, dan parameter operasi, seperti WPOS sebagai aditif dan masa operasi. Pertumbuhan pesat sektor perindustrian telah mengakibatkan peningkatan permintaan tenaga. Ia adalah keperluan moden untuk menyediakan tenaga elektrik yang mencukupi pada kos yang berpatutan dan dengan cara yang mesra alam. Teknologi MFC, yang boleh mencapai kecekapan penukaran sehingga 50%, ialah sistem bio-elektrokimia yang lebih baharu yang mempunyai kesan alam sekitar yang lebih sedikit daripada kaedah rawatan air sisa tradisional. POME dan WPOS, yang kedua-duanya berpotensi menjana elektrik, telah dipilih sebagai substrat MFC. Kedua-dua sampel diperoleh dari Kilang Sawit Lepar Hilir 3 dan disimpan di dalam bilik sejuk -4 °C. POME dan enap cemar minyak sawit basah telah disiasat untuk keupayaan mereka menjana elektrik dalam MFC. Kuasa yang dijana dalam kajian ini dikira menggunakan Hukum Ohm. Kesan parameter operasi telah dikaji, iaitu masa operasi dan dos WPOS. Akibatnya, arus maksimum yang dicapai ialah 0.48 mA, dan kuasa maksimum yang dicapai ialah 5.07 x 10-6 W. Dengan penambahan 4 mg/L dos, penjanaan kuasa telah dicapai. Kajian ini menunjukkan bahawa parameter boleh memberi kesan kepada prestasi MFC. Kepekatan TSS yang tinggi boleh menyebabkan penjanaan kuasa dalam MFC terganggu. Walaupun MFC mempunyai output kuasa yang rendah, elektrod tembaga masih boleh digunakan untuk menjana elektrik.

ABSTRACT

This study investigated the potential electricity generated by a dual chamber MFC using a mixture of palm oil mill effluent and wet palm oil sludge. The goals of this research are to develop the MFC by varying the electrode operational system, such as varying the electrode type, to investigate the influence of the circuit on the voltage, current, and power, and to determine the effect of various essential factors on the performance of the MFC, such as electrode materials, TSS, COD, pH, and operating parameters, such as WPOS as additive and operational time. The rapid growth of the industrial sector has resulted in an increase in energy demand. It is a modern necessity to provide enough electricity at a reasonable cost and in an environmentally friendly manner. MFC technology, which can achieve conversion efficiencies of up to 50%, is a newer bio-electrochemical system that has fewer environmental impacts than traditional wastewater treatment methods. POME and WPOS, both of which have the potential to generate electricity, have been chosen as MFC substrates. Both samples were obtained from Kilang Sawit Lepar Hilir 3 and were kept in a -4 °C cold room. POME and wet palm oil sludge were investigated for their ability to generate electricity in an MFC. The power generated in this study was calculated using Ohm's Law. The effect of the operating parameters was studied, which were operating time and dosage of WPOS. As a result, the maximum current achieved was 0.48 mA, and the maximum power achieved was 5.07 x 10-6 W. With 4 mg/L of dosage added, power generation was achieved. This study shows that the parameters can have an impact on the performance of MFC. The high concentration of TSS may cause power generation in MFC to be disrupted. Even though the MFC has a low power output, copper electrodes can still be used to generate electricity.

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LIST OF SYMBOLS

mg	Milligrams
cm	Centimetre
mm	Millimetre
L	Litre
%	Percentage
°C	Celsius
mg/L	Milligrams per Litre
V	Voltage
W	Watt
I	Current
R	Resistance
E	Cell potential
t	time
mA	Milli ampere
mV	Milli Voltage
mL/min	Millilitre per Minute
C/min	Celsius per Minute

LIST OF ABBREVIATIONS

POME	Palm Oil Mill Effluent
WPOS	Wet Palm Oil Sludge
POS	Palm Oil Sludge
MFC	Microbial Fuel Cell
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solid
TS	Total Solid
pH	Potential of hydrogen
FFB	Fresh Fruit Bunches
EFB	Empty Fruit Bunches
CPO	Crude Oil Palm
DO	Dissolved Oxygen

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Palm oil is a perpetual and useful crop that grows in tropical regions of the world such as Indonesia and Malaysia, which have hot and humid climates all year, and cultivation continues all year (S. P. Tan et al., 2017). In the early 1870s, the oil palm tree was first planted in Malaysia and commercial planting began on the property of Tennamaram in Kuala Selangor. Palm oil mill effluent (POME) is a liquid waste generated during the processing of crude palm oil. POME is a dark, non-toxic, viscous, acidic, and voluminous colloidal suspension with an irritating odor, made up of 95 to 96% water, 0.6 to 0.9% fat, and 2 to 12% suspended solids (Ng, F.L. et al., 2021). POME has a pH range of 3.4–5.2, total solids (TS) of 500–79000 mg L-1, total suspended solids (TSS) of 5 000–54 000 mg L-1, and total volatile solids (TVS) of 9 000–72 000 mg L-1 (S. P. Tan et al., 2017). POME has been commonly handled with anaerobic treatment and produces considerable sludge. Most firm residue remaining after the procedure is classified as palm oil sludge (POS). POS can create significant environmental issues when released into open waterways. Currently, most POS waste is disposed of in the palm plantation itself due to inadequate use of the wide waste produced. The sludge has a poor odour, leading to land waste that indirectly causes hygienic and environmental problems. As a consequence, turning POS into a value-added commodity may be a viable way to reduce environmental effects (Iberahim et al., 2019).

There is a direct relationship between the availability of fossil fuels and the growth of the country's economy in Malaysia. The industrial and transportation sectors of the country were still heavily reliant on oil and natural gas for their energy needs. Furthermore, the rapid expansion of the industrial sector has resulted in an increase in the demand for energy (Mushtaq et al., 2013). As a result, it is necessary to reduce our reliance on fossil fuels. Providing enough electricity at a reasonable cost and in an environmentally friendly manner is a modern necessity. A secure and dependable electrical supply is critical for an upper middle-income country like Malaysia in order to fuel economic growth, protect the environment, and maintain price competitiveness while also maintaining price competitiveness (Jaye et al., 2016). A significant amount of effort is being put forth to investigate alternative methods of generating electricity. New energy generation from renewable resources that does not result in net carbon dioxide emissions is a highly sought-after development. In recent years, academic researchers have expressed significant interest in a technology known as microbial fuel cells (MFCs), which converts the energy stored in chemical bonds in organic compounds to electrical energy through catalytic reactions carried out by microorganisms. MFCs are used to generate electricity by converting the energy stored in chemical bonds in organic compounds to electrical energy (Du et al., 2007). MFC technology, which has the potential to achieve conversion efficiencies of up to 50%, is a form of bio electrochemical system that has recently emerged due to its low cost and reduced environmental impacts related to greenhouse gas emissions and sludge generation as compared to traditional wastewater treatment methods (Ardakani & Badalians Gholikandi, 2020). The principle of microorganisms producing electric current has been around for over a century, and MFC instruments for electricity generation have been studied extensively for the past 50 years (Cao et al., 2019).

In these systems, microorganisms play a key role in producing electron-rich metabolites, maintaining the redox gradient, generating redox mediators, and delivering electrons to an electrode through direct electron transfer or a soluble electron transfer mediator, with the ultimate goal of producing electric current (Rasouli Sadabad & Badalians Gholikandi, 2017). The direct electricity generation in the MFC can be defined by voltage, current and power data. Several significant parameters influence the efficiency of MFCs, including (1) organic compound oxidation in the anodic chamber, (2) electron shuttle into the anode chamber to anode surface, (3) oxygen supply and reduction consumption rate in the cathode chamber, and (4) polymer membrane permeable to proton (Birjandi et al., 2016).

MFCs are made up of two chambers, the anode and the cathode, which both have an electrode and are divided by a cation permeable membrane (PEM). Respiratory bacteria in the anode chamber oxidize the organic substrate supplied to emit protons and electrons (Obileke et al., 2021). Several reactor designs have been proposed in the literature in recent years, each with its own set of advantages and disadvantages. One of the current problems is scaling up these systems in order to shift toward industrialization for the elimination of recalcitrant organic compounds from water. In order to promote scale-up and cope with industrial activity modes, several methods focused on flow cells have been introduced in the literature. To address the shortcomings of traditional batch reactors for the treatment of massive flows/volumes of effluents, continuous flow reactors must be developed in particular. There, few studies have studied the effect of operating parameters on the efficiency of such reactors (Monteil et al., 2021). Unlike other chemical fuel cells, MFC does not need complex convoluted structures or devices in its energy production phase because it uses microbes present in a mixture of POME and wet palm oil sludge as raw materials for the breakdown of organic matter into protons and electrons for the generation of renewable energy (James et al., 2020).

1.2 Problem Statement

In recent decades, Malaysia has risen to become one of the world's largest producers and exporters of palm oil products, surpassing even Brazil. Because of the rapid growth in the number of palm oil mills each year, the amount of fresh fruit bunch waste and effluent discharge has increased as a result. POME, on the other hand, is considered to be one of Malaysia's most significant environmental contaminants. The suspended solids and nutrient content of POME may be sufficient to support algae growth (Kamyab et al., 2018). POME discharges that do not undergo proper treatment have a negative impact on the environment. Following this decision, the Malaysian government passed the Environmental Quality Act 2009, which establishes the standard effluent discharge limit (SEDL). The use of biological treatment is the most common approach in Malaysia, but other approaches, such as physicochemical treatment and membrane filtering, are being researched. POME treatment procedures can be improved, and renewable energy can be generated in an environmentally friendly manner to aid in the cleaning of the environment (Sh & Elmi, 2014). A variety of technologies have been developed as a result to address the problems. The microbial fuel cell is one of the technologies being developed.

In addition to providing opportunities for environmental bioremediation, microbial fuel cell technology is a new field of alternative renewable energy production that has emerged in recent years (Javed et al., 2018). In recent years, the MFC has emerged as a technology capable of generating electricity by utilising electrons derived from biochemical reactions to do so. Catalysis will be used to break down the bacteria from the substrate. The bio electrochemical process, which is used in this technology, is capable of generating electricity. POME is one of the substrates that is frequently used in the production of MFC. It is regarded as polluted wastewater by the industry. The untreated discharge of POME will have a negative impact on the environment due to the high levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) they produce. Aside from that, POME contains phosphorus and has a significantly higher concentration of organic nitrogen than other foods (Kamyab et al., 2018). As a result, it is imperative that the performance of untreated POME and POS as substrate in a microbial fuel cell be investigated in order to generate electricity. Because of their high potential for use as a substrate for the production of electricity through the use of a microbial fuel cell.

The power generated by the MFC is still low, and it has not yet reached its maximum potential, according to previous studies (Moqsud et al., 2013). Consequently, it is critical to design and develop the electrochemical reactor by varying the electrode arrangement and the type of electrode material used in the cell. Cathode and anode electrodes can be made of a variety of materials, including graphite, graphite felt, carbon paper, carbon cloth, palladium (including palladium black), platinum (including palladium black), and reticulated vitreous carbon (RVC). In this demonstration, different activation polarizations will be demonstrated using different anode electrode materials. The performance of the MFC will improve as a result of the selection of appropriate materials, which may differ from one another. The cathode in a MFC, on the other hand, can be made of many different materials, including graphite (including graphite felt), carbon paper (including carbon-cloth), Pt (including Pt black), RVC (including RVC black), glass (including polycarbonate and Plexiglas), and metal (including platinum) (Du et al., 2007). All of these materials are suitable for use as electrodes in MFCs, with the goal of improving the overall performance of the microbial fuel cell system. This makes it possible to determine the amount of bioelectricity generated by the microbial fuel cell by varying its parameters.

In addition, the MFC generates a limited voltage and current, which differs from that of the unit cells, and thus their practical applicability is limited as a result (Kim et al., 2020). This problem has resulted in a decrease in the performance of the MFC and, consequently, a decrease in the amount of electricity generated. In addition, the design orientation of the electrode has an impact on its performance during the process. There are several different types of orientations that can be performed in the process, including vertical and horizontal orientations, each of which produces a different performance. The design is investigated and developed in order to identify the best performance in order to generate the greatest amount of electricity possible. Furthermore, there are numerous factors that can influence the performance of MFC, with the most important factors being the substrate, electron transfer, membrane material, and operating conditions, which include temperature, salinity, and pH, as well as the design of the MFC (Aghababaie et al., 2015). As a result, it is critical to investigate the effect of operating parameters such as operational time, inter-electrode distance, and pH on the electrochemical process in order to determine the effect of parameters on the MFC.

1.3 Objective of the Study

The main objective of this study is to generate bioelectricity from palm oil mill effluent in microbial fuel cell. Meanwhile the specific objectives are:

- To investigate influence of the circuit on the power, voltage and current output from by using copper as electrode.
- To determine effect of various essential factors on the performance of microbial fuel cell such as electrode materials, pH, chemical oxygen demand, total suspended solid, and operating parameter, which is WPOS as additive and operational time.

1.4 Scope of the Study

This research focuses on the generation of electricity from POME and wet palm oil sludge (WPOS) through the use of MFC in a series connection. POME and WPOS, both of which have the potential to generate electricity, have been selected as a substrate for MFC. Both samples were obtained from Kilang Sawit Lepar Hilir and stored in a cold room with a temperature of -4°C. The MFC type was a dual chamber design. Copper has been used as both the anode and cathode in the operation of MFCs.

Following that, the ability of POME and WPOS to generate electricity in an MFC was investigated. A multimeter was used to measure the voltage and current. Meanwhile, the power produced in this study was calculated using the Ohm's Law formula. The influence of the operating parameter was investigated. Operating time and dosage of WPOS were among the parameters measured. Using MFC, the operation was completed in 25 days, with 5 days spent on each different dosage level. In addition, the water quality of the POME added with dosage of WPOS on the MFC process was evaluated both before and after the MFC operation. pH, chemical oxygen demand (COD) and total suspended solids (TSS) are the parameters that have been measured to determine the water quality.

1.5 Significant of Study

Studies have shown that the waste from the POME, as well as WPOS, are both polluting factors in the environment. In the event that both types of waste are discharged into water, the aquatic life will be negatively affected by the high levels of pollution in the waste, such as BOD and COD. Consequently, it is critical to find an alternative solution to the problems. However, by using a mixture of POME and WPOS as the substrate in a MFC, the issues can be resolved in some cases. Pollution such as contaminated soil and surrounding lands, which can lead to acidification and eutrophication, can thus be reduced as a result.

Another issue is that there is an excessive reliance on fossil fuels for the generation of electricity. Renewable energy should therefore be preferred over other types of energy, such as non-renewable energy. Due to the fact that the use of non-renewable energy will have an adverse effect on the environment, in the case of fossil fuels, for example, excessive consumption will result in climate change and global warming. As a result, renewable energy sources such as bioelectricity generation through the use of a microbial fuel cell are being sought after more frequently. Furthermore, by using a mixture of POME and WPOS, it will be possible to reduce the pollution that would occur if the untreated POME and WPOS were discharged into the river in question.

The designation of the MFC is critical in order to achieve high performance through the process. As a result, it is critical to vary the operational system of the electrodes. Materials used in electrode construction produce a wide range of output characteristics. As a result, selecting the best materials will aid in the achievement of superior performance. Furthermore, it is critical to assess the performance and impact of operating parameters such as operational time and WPOS as a dosage on the results. According to their performance and operating parameters, the amount of electricity generated can be calculated by letting them run for a period of time. Thus, it will be easier to determine whether certain parameters cause a high or low level of electricity generation.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of Palm Oil

2.1.1 The Malaysian Palm Oil Industry

Oil palm (Elaeis guineensis) was first introduced to Malaysia as an ornamental plant in 1870, and it has since become a staple crop. Since 1960, the area under cultivation has increased dramatically. In 1985, 1.5 million hectares of land was dedicated to the cultivation of palm trees; by 2007, this figure had increased to 4.3 million hectares. It has grown to become Malaysia's most valuable commodity crop in recent years. The total gross planting area in 2011 was 4.917 million hectares (about 4.917 million acres).

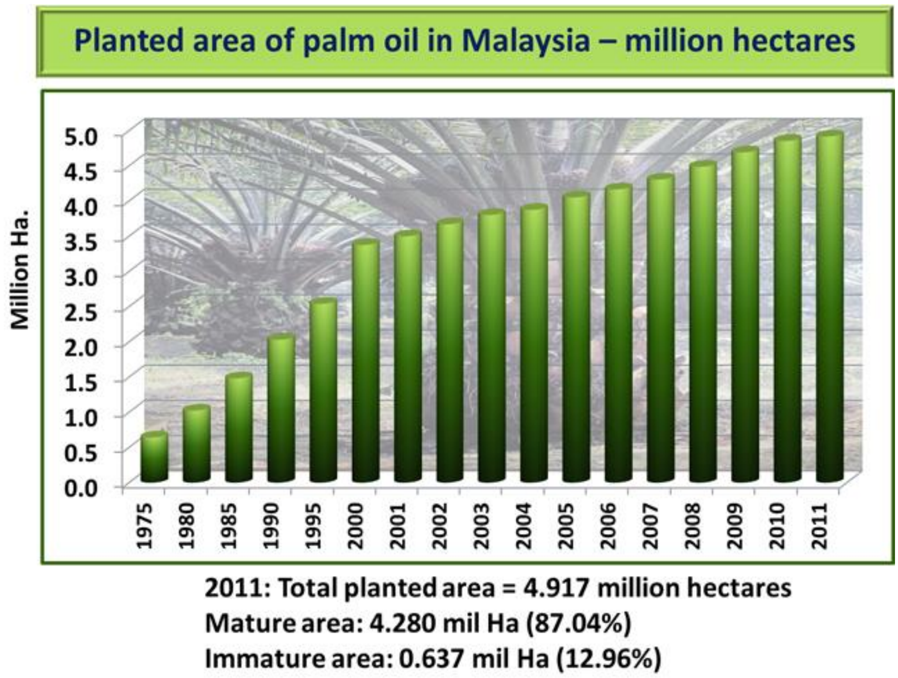

Figure 2.1 Planted area of palm oil in Malaysia

Source: Malaysian Palm Oil Industry (n.d.)

The oil palm variety currently being planted is the tenera hybrid, which produces approximately 4.0 tonnes of palm oil per hectare, as well as 0.5 tonnes palm kernel oil and 0.6 tonnes palm kernel cake, according to the International Palm Oil Council. Oil palm has a commercial life cycle of 25 years. 30 months after field planting, palm harvesting can begin (Malaysian Palm Oil Industry, n.d.)

According to the World Bank, Malaysia will account for 25.8 percent of global palm oil production and 34.3% of global palm oil exports by 2020. When other oils and fats manufactured in the country were taken into consideration, Malaysia accounted for 9.1 % and 19.7 %, respectively, of the world's overall output and exports of oils and fats in the same year. The processing of crude palm oil began in the early 1970s in response to the government's demand for increased industrialization in the country. In conjunction with the introduction of refineries came the introduction of a diverse range of refined palm oil products (Malaysian Palm Oil Industry, n.d.)

2.1.2 Generation of Waste in Palm Oil Mill Industry

The industry is critical to Malaysia's economy and has contributed to raising the living standards of the country's population, generating approximately USD 20 billion in annual revenue. Palm oil production, on the other hand, results in a significant amount of POME. Every tonne of fresh fruit bunches (FFB) that is processed results in a waste stream that includes the empty fruit bunches (EFB) (23%), mesocarp fibre (12%), shell (5%), and POME (60%). POME is the primary waste generated, and it is composed of wastewater from the sterilisation of fresh fruit bunches, palm oil clarification, and effluent from hydro cyclone activity. To produce one tonne of Crude Oil Palm (CPO), 5 to 7.5 tonnes of water are required, with half of this total amount constituting POME (polluted oceanic methane). Every year, Malaysia produces more than 55 million tonnes of POME (F. L. Ng et al., 2021).

Furthermore, POME contains a significant amount of organic matter, resulting in high levels of Chemical Oxygen Demand (COD, 15000e100000 parts per million) and Biochemical Oxygen Demand (BOD, 10250e43750 parts per million), both of which would result in significant environmental emissions if not properly treated. When the fibrous residue from the oil extraction procedure enters the POME, it becomes a part of the organic contaminants, which not only causes the waste to become cloudy, but also increases the difficulty of treating it. Furthermore, during the POME ponding treatment, an unpleasant odour would be released into the air. As a result, due to the brownish colour and odorous properties of POME discharge, the general public in neighbouring residential areas is frequently irritated by POME discharge (K. H. Ng et al., 2019).

However, while the primary goal of POME treatment has always been to 'treat and dispose,' there has recently been increased interest in cleaner production, which includes waste and pollution prevention, as well as sustainable recycling of wastes generated within the industry. It is anticipated that internal wastewater reuse will have the dual benefit of reducing fresh water consumption while also reducing the environmental consequences of wastewater disposal in the environment (Y. Y. Tan et al., 2021).

2.1.3 Properties of POME

POME is a dark, non-toxic, viscous, acidic, and voluminous colloidal suspension with an unpleasant odour. It is non-toxic, viscous, acidic, and voluminous. In terms of composition, it is composed of 95–96 % water, 0.6–0.9 % oil, and 2–12% suspended solids. Protein, fat, grease, starch, cellulose, and hemicellulose are all examples of diverse substrate components found in non-hydrolysed products that contain a high concentration of complex compounds, such as protein (F. L. Ng et al., 2021). The nutrients found in POME include nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), all of which are essential for plant growth and development. Other characteristics of POME include a high temperature, a pH of less than 7, and a high concentration of organic substances (Lokman et al., 2021). POME is also a wastewater mix from wet CPO milling that is composed of clarification wastewater (oil recovery from wet sludge cake), steriliser condensate (steam sterilisation of fruit bunch), and hydro cyclone wastewater (water-aided kernel-shell separation) in decreasing polluting strength and volumetric ratio (15:9:1) and increasing polluting strength and volumetric ratio (15:9:1) (Cheng et al., 2021).

Furthermore, POME contains a high concentration of BOD and COD, which is 100 times higher than that found in municipal sewage. POME is a non-toxic waste because no chemicals are used in the oil production process; however, because of its high oxygen depletion capacity in marine systems and the presence of organic and nutrient materials, it can cause environmental problems. A large amount of organic matter is derived from the presence of various sugars such as arabinose, xylose, glucose, galactose, and mannose. The suspended solids in POME are primarily composed of oil-bearing cellulosic materials derived from fruits, which are the majority of the suspended solids in POME. POME is a highly nutritious source of nutrients for microorganisms because of its non-toxic nature and the absence of chemicals used in the oil extraction process during the oil extraction phase (Kamyab et al., 2018).

POME is the only liquid oil palm waste with the highest yield (POME/CPO mass ratio 3.13), and its natural aerobic biodegradation in waterways may have an adverse effect on aquatic species by depleting the limited amount of dissolved oxygen (DO) available to the organisms (Cheng et al., 2021). A waste stabilisation technology called open ponding is frequently used to treat POME, with approximately 90 percent of millers employing it. Open ponding is capable of abating > 95 percent chemical oxygen demand (COD) and biochemical oxygen demand (BOD) over a lengthy treatment period (> 60 days). In addition to non-compliant wastewater discharge (in terms of COD and BOD), arable land loss (approximately 5 ha), depth-varying effluent quality (due to insufficient mixing), and odour annoyance (due to H2S-bearing biogas release), open ponding has other disadvantages (Cheng et al., 2021).

Figure 2.2 Palm oil mill effluent (POME)

Source: (*Properties and Uses of POME | BioEnergy Consult*, n.d.)

2.1.4 Properties of Wet Palm Oil Sludge (WPOS)

Palm oil sludge (POS) is a semi-solid residue produced by the acidification, anaerobic, and aerobic treatment of palm oil mill effluent (POME). Due to the large amount of POME (800 dm3 POME per tonne of FFB) produced by high water consumption in oil extraction and cleaning processes, POS is generated in significant quantities in mills located throughout Malaysia. The disposal of untreated POS, PKS, and EFB can have negative environmental consequences (Lee et al., 2017).

Due to insufficient utilisation of the large amount of waste generated, the palm plantation is currently responsible for disposing of the vast majority of POS waste. The sludge has an unpleasant odour and contributes to land pollution, which results in indirect hygienic and environmental issues. As a result, converting POS into a value-added material may be a viable option for mitigating environmental effects (Iberahim et al., 2019).

According to the research conducted by Thangalazhy-Gopakumar et al. for the pyrolysis method, the palm oil sludge was obtained from Seri Ulu Langat Palm Oil Mill Sdn Bhd, Dengkil, Selangor, Malaysia. The sludge in the effluent treatment section had previously been processed for total oil recovery and had travelled through acidification, anaerobic, and aerobic ponds before arriving there. The recovered sludge was dried in an oven at 65°C for 72 hours. Using a granulator, the dry sludge was crushed and sieved to remove any remaining particles. The moisture content (wet basis) of the sludge was calculated by estimating the weight loss of a sample after it was heated in an oven at 103°C for 16 hours. The ash content of the sludge was determined in accordance with the ASTM E 1755 standard. The higher heating value (HHV) of the sludge was determined by using an oxygen bomb calorimeter (IKA, model C2000). The temperature-gravimetric behaviour of sludge biomass under nitrogen conditions was investigated using a thermo gravimetric analyser (TA Instruments, TGA Q500). In a TGA study, a known quantity of sludge (approximately 5 mg) was heated from room temperature to 800°C at various heating rates of 10, 20, 30, and 40°C/min, and then held at the final temperature for 10 minutes. Throughout the study, a nitrogen flow rate of 100 mL/min was maintained. All tests were carried out in triplicate to ensure repeatability (Lee et al., 2017).

Figure 2.3 Wet Palm Oil Sludge (WPOS)

2.2 Current Energy Scenario in Malaysia

2.2.1 Progress in Renewable Energy

Climate change and energy scarcity are major concerns today, given that fossil fuels account for approximately 80% of total global energy consumption. The demand for energy is rapidly increasing, with a particular emphasis on renewable sources such as biomass, solar, and wind power. In terms of biomass, algae and photobiological methods are suitable for the production of energy from waste materials. Furthermore, nearly a quarter of the world's population does not have access to safe drinking water. Untreated wastewater, on the other hand, is discharged into water estuaries on a daily basis, resulting in water pollution and even less access to freshwater. As a result, there is an urgent need to treat wastewater so that it meets discharge standards before it enters receiving water bodies in order to avoid the negative effects of wastewater on water bodies and aquatic systems. It is estimated that the amount of recoverable energy in wastewater is ten times greater than the amount of energy required for the treatment procedure (Shabani et al., 2020). Using POME as a renewable energy resource has been recognised by the Malaysian government as an option (Choong et al., 2018).

In the context of energy, renewable energies are considered clean forms of energy because they have minimal environmental consequences, generate little secondary waste, and are long-term in terms of economic and social requirements. A paradigm shift in energy technology away from fossil-fuel technologies and toward renewable energy technologies is being predicted by recent research trends, investments, and government energy policies. Renewable energy is expected to have a long and prosperous era. There have been two major factors identified as having an impact on this change: (1) the depletion of global crude oil reserves, which is predicted to result in scarcity and an increase in fossil fuel prices in the future; and (2) the rising cost of fossil fuels in recent years. Secondly, the effect of fossil fuels on greenhouse gas emissions, which has resulted in significant global climate change. All of these elements have formed the basis for renewable energy research, investments, government regulations, and practical application of renewable energy technologies (Obi, 2015).

One of the most important sustainable and environmentally friendly methods of converting chemical energy into electricity is through bio electrochemical systems (BES). Fuel cells (MFCs) are a type of bio electrochemical system that can be used to generate low-cost energy in an environmentally friendly manner. BESs are classified into three types: microbial fuel cells (MFCs), microbial electrolysis cells (MECs), and microbial desalination cells (MDCs). There are numerous studies being carried out on the MFC in order to improve the conditions and increase the amount of power and energy produced. MFCs have the potential to be used in four different applications: (a) wastewater treatment, (b) onsite generation of electricity in remote areas for sensors, (c) utilising biomass to produce green energy, and (d) the potential use of reservoirs to remove petroleum contamination from the environment (Shabani et al., 2020).

Malaysian palm oil producers account for 38% of the world's total palm oil production, while the country is also the world's largest palm oil exporter, accounting for approximately 88% of the world's total palm oil exports. Despite the fact that Malaysia is one of the world's largest producers of palm oil, the country produces an estimated 50 million tonnes of dry oil palm wastes per year, with estimates predicting that this figure will rise to 100 million tonnes by 2020. Because of the government's shift away from conventional energy sources like coal, oil, and gas in order to increase energy security, oil palm biomass appears to have the potential to be a significant contributor to renewable energy. According to the researcher, it widely held beliefs, the use of fossil fuels as a source of energy for heat, electricity, and transportation contributes significantly to global warming. Because of its renewability and environmental friendliness, the world's transition away from traditional non-renewable energy sources toward renewable energy sources is critical for future generations (Aghamohammadi et al., 2016).

2.3 Microbial Fuel Cell

2.3.1 Basic Principle of Microbial Fuel Cell

A microbial fuel cell is a bio electrochemical device that is comprised of two chambers that produces electricity. The anode chamber in the first chamber is anaerobic, and the cathode chamber is aerobic in the second chamber. It will be separated physically from the other chambers by a proton exchange membrane (PEM), which will be placed between them in the MFC. In the anode chamber, there are microorganisms that act as catalysts, as well as an electrode that serves as anode. Microbes play a critical role in MFC, and as a result, microbe selection is critical in this process. The substrate will be oxidised in the anode chamber. Microbes in the anode chamber take advantage of these processes. Anode chamber microorganisms will release electrons that will be transported to the cathode via the external wire. The cathode is where the combination of the bacterial substrate with the water occurs in order to produce water during the catabolism process. Aside from that, the process results in the extraction of protons and electrons from the atmosphere (Javed et al., 2018).

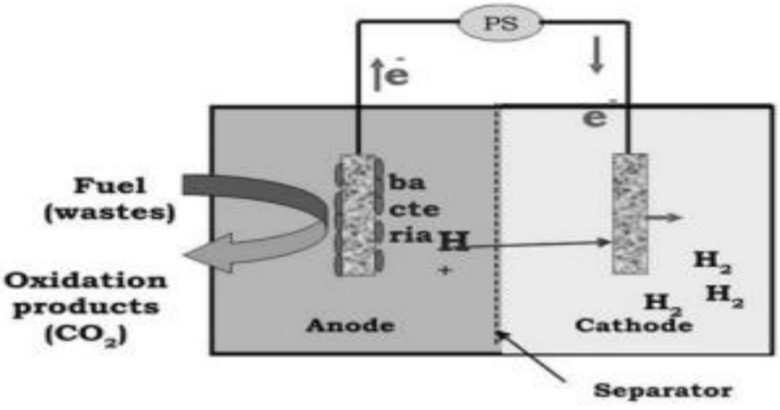

Figure 2.4 Basic principle of Microbial Fuel Cell

Source: Javed et al., (2018)

2.3.2 Double Chamber Microbial Fuel Cell

There are several different types of MFC. One of these is the MFC with two chambers. The anodic and cathodic chambers of this type of MFC are the two chambers that make up the device. In order for the proton transfer process to take place, a proton exchange membrane or salt bridge will be used to connect the two chambers together. As the anode moves closer to the cathode, the process will continue. Unless there is a significant amount of diffusion oxygen in the cathode, it will not pass through the proton exchange membrane or salt bridge and will instead be directed to the anode (*Benefits of Microbial Fuel Cell*, n.d.). During the anode chamber's operation, the microbe will cause the substrate to oxidise. In addition, the process results in the propagation of electrons and protons at the same time. The proton will then be able to pass through the proton exchange membrane and reach the cathode at that point. In the meantime, the external wire will allow the electrons to flow from the cathode to the anode, completing the process and cycle in the double-chamber MFC (Uddin et al., 2019).

Performance differences exist between double-chamber MFC and single-chamber MFC. This MFC uses a water-cathode mode of operation. In the meantime, the single-chamber MFC will be air-cathode. Improved cathode performance in double-chamber MFCs can be achieved by adjusting pH, reducing flow rate, removing pure oxygen, and adding electron mediators. One of the most common methods is pH control. As a result, the double-chamber MFC can perform better (Flimban et al., 2019).

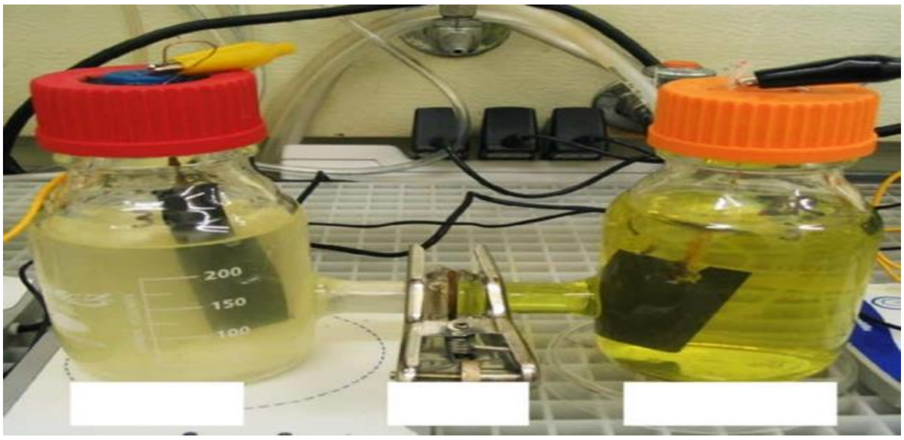

Figure 2.5 Simple Double Chamber Microbial Fuel Cell

Source: Ren et al., (2008)

2.3.3 Advantages of Microbial Fuel Cell Technology

Microbial fuel cell technology is a unique method of generating electricity that is being explored more and more. Because of the possibility of an energy crisis in the future, it is critical to find alternative sources of energy. As a result, it is necessary to develop alternative energy sources (Parkash, 2015). The microbial fuel cell is one of the technologies that has the potential to revolutionise the way we generate clean and renewable energy. It is one of the technologies that can contribute to the alleviation of the global energy shortage. Aside from being energy sources, this technology has the potential to provide and contribute to the development of sustainable power sources, which can be used to connect isolated communities, as well as the desalination of water (Benefits of Microbial Fuel Cell, 2017).

It will be beneficial to the environment, in particular, if this technology is implemented. This is due to the fact that the microbial fuel cell will aid in the reduction of pollution, particularly water pollution. In addition, the cost of water treatment can be reduced as a result of the reduction in pollutant levels in the water (Benefits of Microbial Fuel Cell, 2017). In the absence of this technology's ability to reduce pollution, water treatment, particularly wastewater treatment, was no longer necessary. Furthermore, microbial fuel cell technology is a straightforward system, as opposed to hydrogen fuel cell technology, which necessitates an extremely synchronised division system. Another advantage of the microbiological fuel cell is that it is more efficient in terms of harvesting electrons from the microbes' transport system when compared to enzymatic fuel cells (Parkash, 2015).

2.4 Components of Microbial Fuel Cell

2.4.1 Electrodes Materials

The improvement of microbial fuel cell performance is critical in order to increase the amount of electricity generated. The power output from the MFC is proportional to the performance of the component MFC. It is therefore necessary to develop materials that are more innovative in order to achieve the maximum amount of power generation in MFC. High power generation can be achieved by carefully selecting the components in terms of the material of the anode, the material of the cathode, the surface of the electrode, the spacing of the electrode, the configuration and concentration of the substrate (Mustakeem, 2015).

The cost of the electrodes and the performance of the electrodes are two critical factors in the efficient operation of MFCs. So, the investigation into the configuration as well as the electrode materials has been carried out in recent years. It is possible that energy losses are caused by the electrode material, which has a high internal resistance. In addition, the length of time spent in operation is critical. However, the cost of the electrode is more significant when compared to the operation time (Hamed et al., 2020).

Nowadays, various forms of carbon are used as anode and cathode materials in the construction of MFCs. Carbon-based materials with a defined surface area are known as well-defined surfaces. Because of their large surface area, brush anodes, for example, are capable of retaining electrochemically active microorganisms that are present on their surface. As a result, the amount of electricity produced could increase (Nam et al., 2017).

However, different materials have been investigated as anodes in MFCs, including graphite, carbon cloth, carbon fibre, activated carbon, stainless steel (SS), copper, and nanostructured materials, among others. It is generally accepted that noncorrosive, carbon-based materials are the most conducive to bacterial growth, especially when it comes to highly porous structures such as cloth, felt, and graphite fibre brushes, among other things. In bio electrochemical tests, it has been demonstrated that the use of corrosion-resistant, flat stainless steel for the anode results in current densities that are higher than those produced by graphite plates. The corrosion of a metal anode can have an impact on current generation in a variety of ways. In addition to abiotic current generation from metal corrosion, an increase in surface area may also result from an increase in current (Zhu & Logan, n.d.)

2.4.2 Separator

One of the most significant obstacles to the commercialization of MFC is the high cost of materials, particularly separators. Separators are used in MFCs to facilitate ion transport while also physically separating the anodes and cathodes. Separator-less systems have demonstrated higher power outputs in some cases as a result of lower internal resistance, making them an appealing option for lowering overall system costs. However, because of the occurrence of ionic species crossover and undesirable side reactions, they have limitations in terms of coulombic efficiency. Separators are also required for systems that require anolyte/catholyte separation (Li et al., 2011).

In addition, separator membranes are widely regarded as the most important component of MFCs. The primary function of separator membranes in two-chambered MFCs is to separate the anode and cathode chambers. Separator membranes also allow protons to transport from the anode to the cathode chambers, which is necessary for the maintenance of electrical current. In MFCs, the most serious issues associated with membrane separators are membrane biofouling, which reduces the proton transfer rate, and high membrane costs(S. Zhang et al., 2015).

In MFCs, a membrane separator serves a variety of critical functions. As previously stated, its purpose is to prevent short-circuiting between the electrodes and to separate the chemical reactions that occur between them (Figure 2.6). On the other hand, the membrane must function as a channel, transporting ions (protons, anions, or both) from the anode to the cathode or vice versa, and it must be capable of inhibiting organic compound crossover from the anode to the cathode as well as electron acceptor crossover, such as oxygen, from the cathode to the anode, i.e., the membrane must have a high species selectivity. In MFCs, a high ionic conductivity could be regarded as the second most important function performed by the membrane. To function as ion conduction channels, it is necessary for IEMs to have some hydrophilic properties. Porous membranes, on the other hand, do not require hydrophilic properties; in fact, they can be completely hydrophobic (Ramirez-Nava et al., 2021).

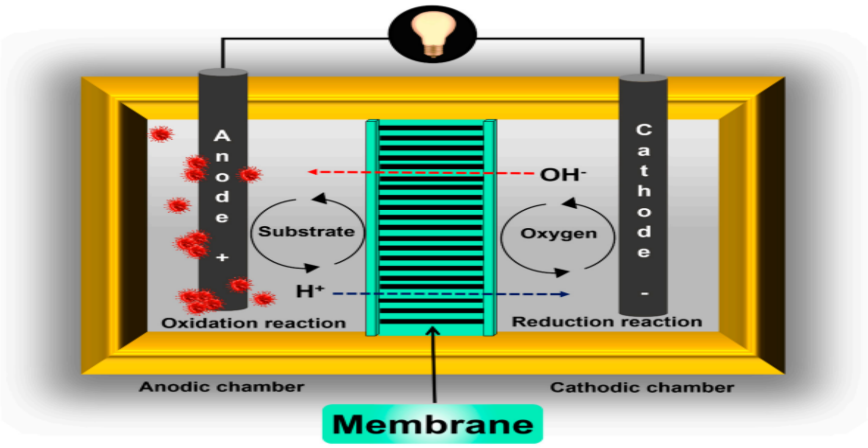

Figure 2.6	Membrane function

Source: Ramirez-Nava et al., (2021)

2.5 Electrochemical Cell Design

2.5.1 Effect of Electrode Arrangement

The voltage of the series and parallel arrangements are the same; however, the series arrangement resulted in a higher current initially. When using series and parallel in one arrangement, the values for voltage and current were lower than individual series and parallel arrangements. Therefore, operating the MFC in series arrangement would be a better option. The performance of serially and parallelly connected MFC was studied by Gurung and Oh, they found an increase in power generation when two individual microbial fuel cells were stacked together either in series or in parallel (Al-Asheh et al., 2020).

Parallel, series, and monopolar carbon electrode designs were used in this study to determine the optimal layout in the MFC process. Figure 4 (b) depicts the electrode arrangement design for monopolar parallel (MP-P) and monopolar series (MP-S). Anodes and cathodes are connected in parallel for MP-P connections, and all electrodes are connected to a power source. The current is distributed between electrodes in this manner with regard to specific cells (Khandegar and Saroha, 2013).

In comparison to a serial connection, a parallel connection requires a smaller potential difference. For the MP-S connection, the two outermost electrodes are connected to the power source, creating anode and cathode, while a pair of the inner electrodes are linked to each other but not to the power source. The inner electrodes are referred to as sacrificial electrodes (Moussa et al., 2016). The cell voltage is increased in this design, resulting in a greater potential difference. The BP connection depicts two sacrificial electrodes placed between two parallel electrodes that are not connected to a power source and are not connected to each other. In this structure, an electrical current is conducted through the sacrificial electrode, converting it into a charged electrode that undergoes opposite charge with the surrounding paralleled electrodes (Nasrullah et al., 2018).

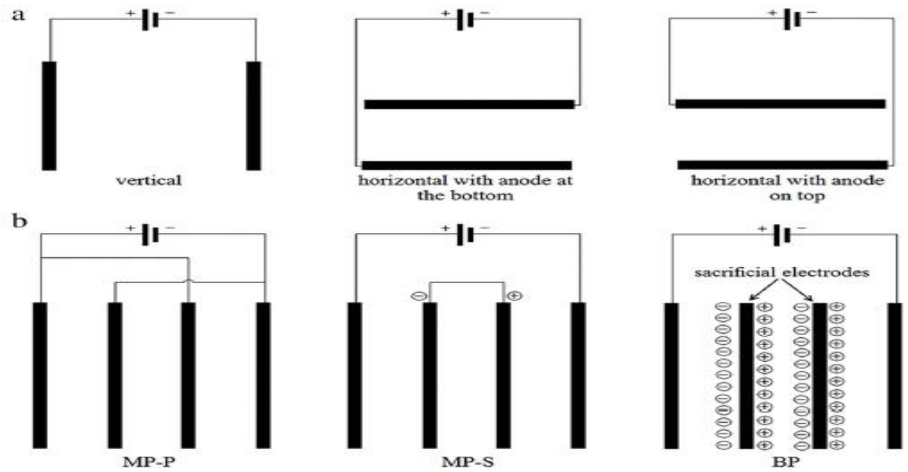

Figure 2.7 Electrodes design

Source: Nasrullah et al., (2018)

2.6 Effect of Operating Parameters in MFC Performance

When conducting an electrochemical process, it is critical to take into account the various operating parameters. As a result, it is possible to achieve high efficiency with MFC. A variety of factors can have an impact on the performance of the MFC as well as the amount of energy it produces. One of the factors that play a role in this process is the presence of microorganisms that have established themselves in the anodic chamber. Due to the function of metabolism in microorganisms, an electron will be transferred from the cathode to the anode in this case (Aghababaie et al., 2015).

In addition to pH and operational time, there are a number of other operating parameters that can have an impact on the electrochemical process and the performance of MFC. The pH level required for bacteria growth should be in the range of neutral to slightly alkaline. It is necessary to have a pH value of approximately 7.5 or higher in order to achieve a higher electricity generation (Aghababaie et al., 2015). Because the anode potential increases as the pH decreases, the voltage produced is low, and the current produced is also low, as is the current produced by the anode. If the pH is raised, the output voltage and current will be increased as a result of the production of negative anode potential at the electrode. As a result, when the current discharge is high, the pH will be low as well. As a result, the electrochemical performance of MFCs is declining, which will have an impact on the overall performance of MFCs (L. Zhang et al., 2011).

Along with this, the performance of the MFC will be affected by the COD. Increases in COD concentration result in a decrease in the power density recorded. Due to the fact that the anodic reaction is highly dependent on the characteristics of the substrate and the availability of carbon in the anode chamber of MFC, the power output of MFC is reduced. If there is a build-up of colloidal particles in the substrate, the factors will be restricted by these particles. Furthermore, the internal resistance will increase, resulting in a reduction in power density. Because of this, the power output decreases as the internal resistance rises. Because of the high COD, it is possible that the power density generated by MFC will decrease (López Velarde Santos et al., 2017).

Wastewater is frequently found to contain high concentrations of TSS. Among the operating parameters that will influence the performance of MFC is TSS. A high generation of power density and current density is expected to result from the use of TSS in MFC. Because of the presence of TSS, it is possible that the biodegradable function of MFC will be impaired. Bacterial degradation of organic matter is associated with the formation of films on the surface of suspended solid particles where the bacteria have grown and colonised over time. The increase in biodegradable function, on the other hand, will result in an increase in the system's internal resistance. The lower the internal resistance, the greater the amount of power that can be harvested. This will also have an effect on the performance of the MFC (Ismail & Radeef, 2019).

The presence of a diverse range of microorganisms in the anaerobic WPOS plays an important role in the development of a synergistic interaction within the community and the consumption of more organic compounds from the POME. Due to an overpotential at the anode, it is possible that the complex microbial community was able to keep the electricity generation to a bare minimum, despite the increased degradation of POME. Overall, the power density remained relatively stable throughout the MFC operation, with a gradual decrease in power density occurring towards the end of the operation. This is due to the fact that the anaerobic WPOS contains various groups of microorganisms that utilised the available organic waste from the POME, resulting in the continuous generation of electricity. A batch operation at the MFC would have resulted in a gradual depletion of the available organic compounds in the POME over time, effectively preventing any further electricity generation (Nor et al., 2015).

2.7 Characteristic of Microbial Fuel Cell Performance Evaluation

2.7.1 Voltage

Voltage is one of the key parameters that must be identified when evaluating the performance of MFCs. The power produced by the MFC under constant voltage has an impact on its overall performance. Specifically, power is dependent on two factors: voltage (V) and current (I). With the resistance of the fuel cell, Ohm's law can be used to demonstrate a relationship between voltage and current.

$$V = I \text{ x } R$$

V = the voltage (V)

I = the current (A)

R = the resistance (Ohm)

2.7.2 Current

The current also has an impact on the performance of the MFC. As a result, the determination of the current time is extremely important. Following the equation, current can be determined by using Ohm's law.

$$I = \frac{V}{R}$$

I = the electric current (A)

V = the voltage (V)

R = the resistance (Ohm)

2.7.3 Power Generation

In addition to voltage and current, power generation is an important factor in improving the performance of MFCs. This equation can be used to calculate the amount of energy present.

$$P = V \times I$$

P = power (Watts)

V = voltage (V)

I = current (A)

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is characterised as a systematic approach to solving a research problem by collecting data using different methods, interpreting the data, and drawing conclusions from the data. This chapter will describe the method, instrument, and material used in the recent study to develop the microbial fuel cell and to determine the performance and effect of operating parameters. This chapter presents the Palm Oil Mill Effluent (POME) and Wet Sludge Palm Oil (WPOS) as the substrates to generate electricity. The experiment began with samples collected from the first effluent pit at the Felda Lepar Hilir 3 Palm Oil Mill and preserved in a cold room with a -4°C temperature. A double chamber MFC was used in this study. A flowchart was used to outline the flow of the study in Figure 3.1.

3.2 Methodology Flowchart

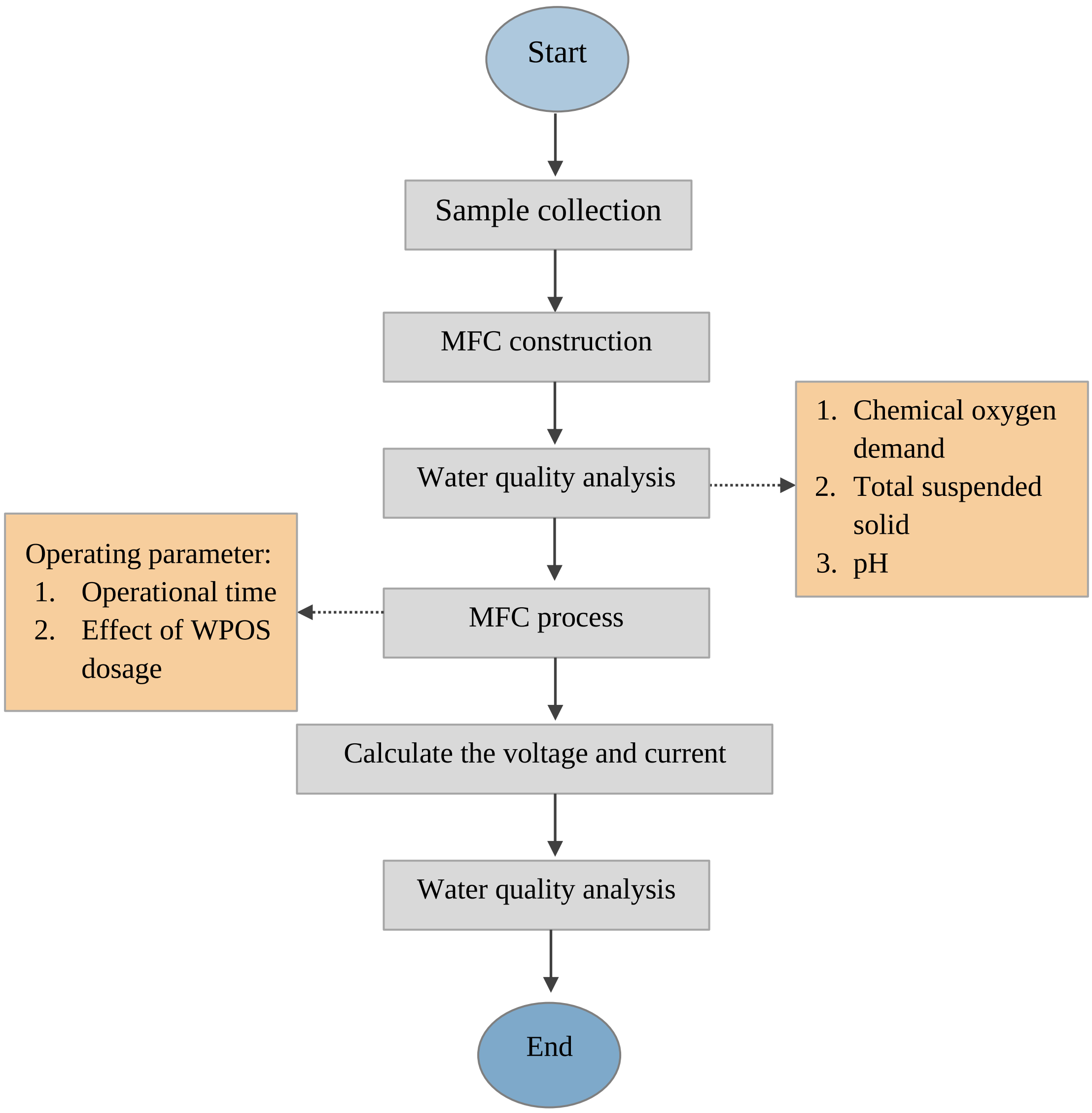

Figure 3.1 Methodology Flowchart

3.3 Sample Preparation

Palm oil mill effluent (POME) and wet palm oil sludge were the wastewaters that were chosen for use as substrates in this study. The samples were collected from the effluent at Kilang Sawit Lepar Hilir 3, Gambang, Kuantan, Pahang, and were analysed. POME was collected from the first pit of effluent, which is the first stage before the cooling pond and has not yet been treated, as shown in figure 3.2, to be used in the process. In the meantime, the sample for WPOS was collected at the end of the process as shown in figure 3.3. After that, both POME and WPOS were kept in a cold room with a temperature of -4 °C. The preparation of a 300ml sample of POME for MFC begins. Meanwhile, WPOS was used as an additive, with different dosages of 0 mg/L, 2 mg/L, 4 mg/L, and 6 mg/L of WPOS being added to MFC every 5 days.

Figure 3.2 Sample of palm oil mill effluent from Kilang Sawit

Figure 3.3 Sample of wet palm oil sludge from Kilang Sawit

3.4 MFC Construction

The dual chambered MFC was constructed with an octagon water tank made of Plexiglass material. The water tank has a capacity of 1.6 litres. The tank will be divided into two chambers, with the first chamber containing the anode electrode and the second chamber containing the cathode electrode. In this study, copper electrodes with a diameter of 1 cm and a length of 10 cm were used. Voltage and current readings were taken with digital multimeters, and the results were recorded. An illustration of the design and configuration of MFC is shown in Figure 3.4.

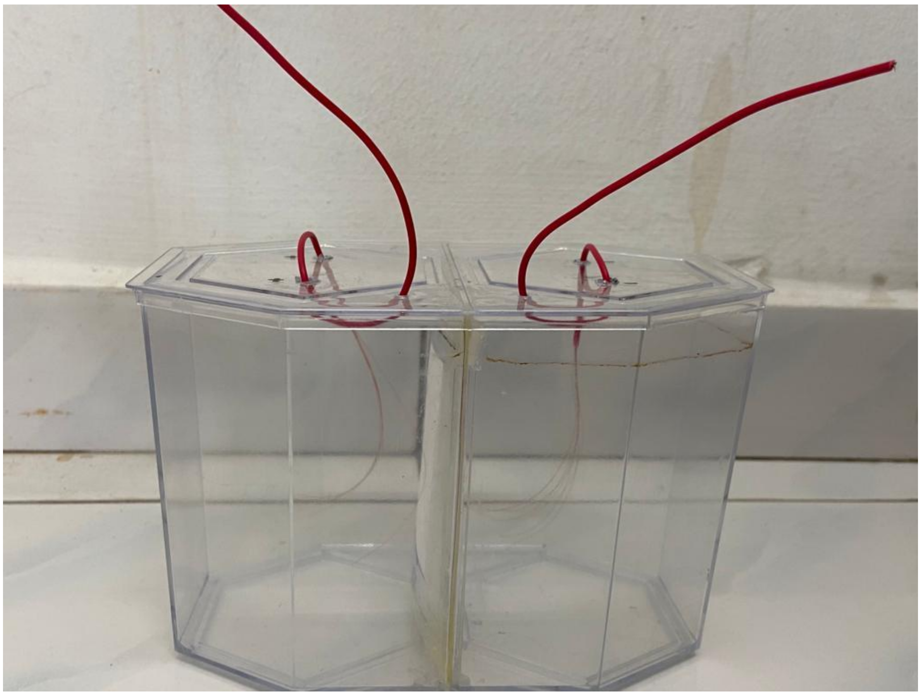

Figure 3.4 Dual chamber of MFC by using copper as electrode

A separator is used to separate the anode chamber from the cathode chamber. In order to prevent the sample and water from mixing in the chamber, five pieces of filter paper are used as a separator in the MFC. The dimensions of the filter are 8.5 cm in length and 11 cm in height. The filter papers are soaked in salt water for 24 hours before being placed in the centre of the MFC. Figure 3.5 illustrate the modification of filter paper as separator in MFC.

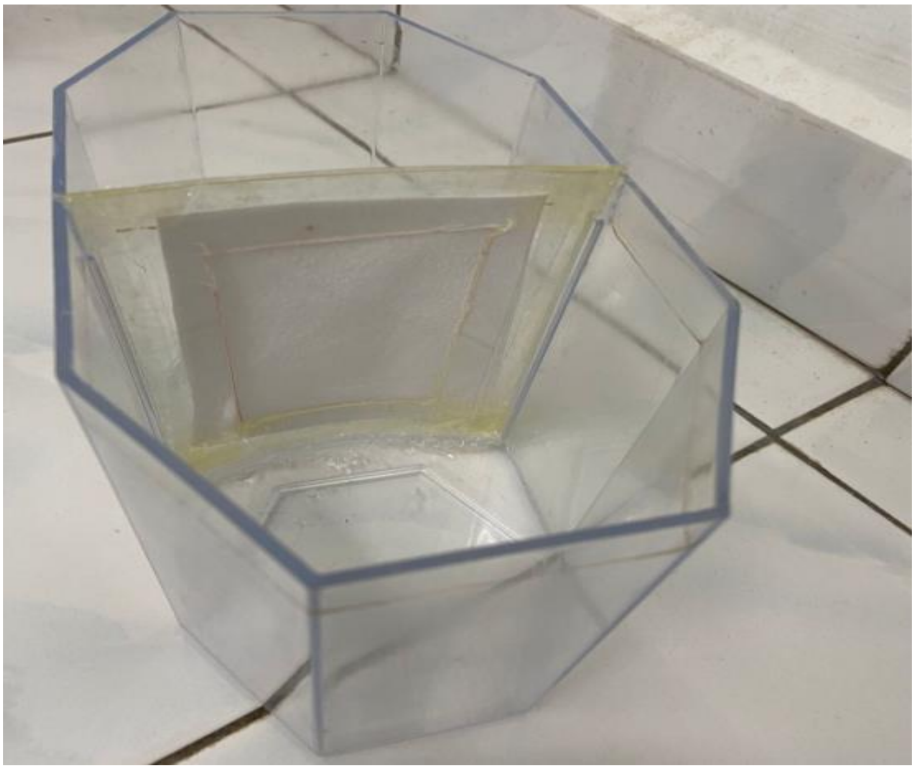

Figure 3.5 Modification of filter paper as separator

3.5 Water Quality Analysis for effect of Performance

There have been several parameters identified that have been shown to have an impact on the performance of MFC. The parameters that have been taken into consideration in this study are pH, COD and TSS. The parameter was evaluated by comparing the initial and final readings for different dosages of each parameter, which were 0 mg/L, 2 mg/L, 4 mg/L, and 6 mg/L, over a period of 20 days, for each parameter.

3.5.1 Measurement of pH

The activity of hydrogen ions in aqueous solutions is described by the pH value, which is typically measured on a scale ranging from 0 to 14. In addition to having a brownish colour and a discharged temperature of 80–90°C, the palm oil mill effluent (POME) also has an acidic property that ranges between pH 4.0–5.0. Between those two points in time, the POME sludge samples were predominantly blackish in colour, textured in texture and pungent in smell, with pH values ranging from 6 to 10. The procedure for determining pH by using the Hach method 8156. The electrode tip was rinsed with deionized water after being cleaned. Following that, the electrode tip was placed in a beaker containing the sample. The Read button was pressed, and the user should wait until the reading on the display has stopped. Finally, the pH and temperature results were recorded.

Figure 3.6 Apparatus used in pH analysis

3.5.2 Measurement of COD

The Chemical Oxygen Demand (COD) is the volume of oxygen absorbed by organic compounds and inorganic matter that has been oxidised in water. It is a quantitative index of the relative quality of organics and reflects the degree of contamination in the water. COD is critical in preventing overall emissions and managing the water environment. The COD Reactor was activated and preheated to 150°C. The reactor was protected by a safety shield that was placed in front of it. Two COD Digestion Reagent Vials had their caps removed.

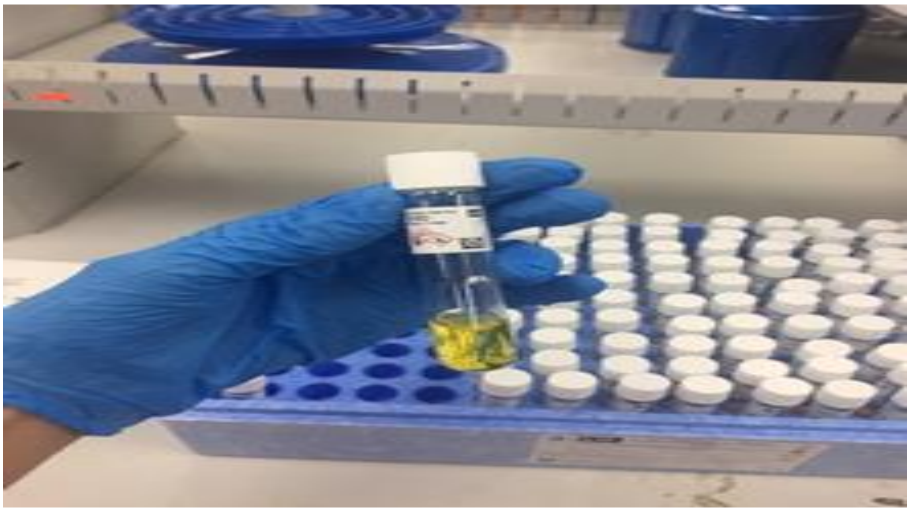

Figure 3.7 COD digestion reagent vials

One vial was held at a 45-degree angle to the other. Then, using a clean volumetric pipette, 2.00 mL of POME was added to the vial, and the vial was sealed. This is the sample that has been prepared. Then, using a clean volumetric pipette, 2.00 mL of distilled water was added to the vial to complete the reaction. This is where the blank will be filled in. The vials were tightly screwed shut. After that, a clean towel should be used to wipe the surface. To mix the contents, the vials were gently inverted several times. Then it was placed in the COD Reactor, which had been preheated, for 2 hours.

Figure 3.8 Several mixtures of samples with COD digestion reagent

On the other hand, the reactor has been shut down. Once the vials had cooled to 120°C or less, it took approximately 20 minutes. While the vials were still warm, they were inverted multiple times. The vials were placed on a rack and allowed to cool until they reached room temperature. When the button for Hach Programs was pressed, Then the 403 COD LR was tinkered with a little more. The start button was then pressed after that. To remove fingerprints or other marks from the outside of the vials, a towel was used to wipe the surface. After the adapter with a 16-mm hole had been installed, the blank was then inserted into the adapter and secured. Touched the zero button for the first time. There were no COD levels displayed on the display. Whenever the timer beeped, the sample vial was inserted into its adapter. An attempt was made to click on the Read button. Amount of COD in mg/L was then displayed as the result.

3.5.3 Measurement of TSS

There are two types of solids in wastewater: those with a small particle size and those with a diverse particle composition. In the TSS test, the amount of TS in a wastewater sample can be divided into TSS and TDS fractions depending on the amount of particulate present. As seen in the formula below, TS in a wastewater sample can be divided into TSS and TDS fractions depending on the amount of particle present. When a specific amount of wastewater needs to be separated, it is pulled through a filter disc using a laboratory bench-scale filtration device under pressure, which achieves the desired result. In contrast to TSS, TDS are solids that move through the disc and into the catch flask below. TSS are solids that sit on top of the disc, whereas TDS are solids that move through the disc and into the catch flask.

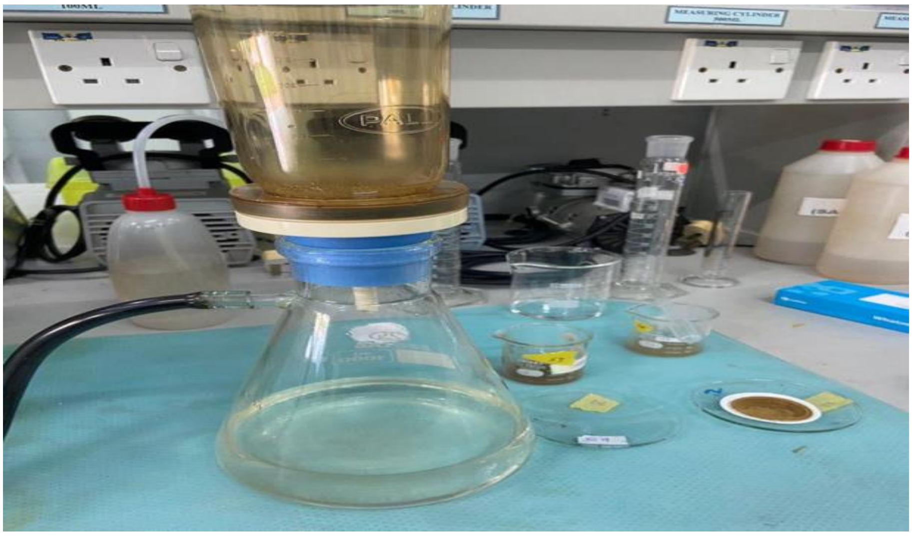

Figure 3.8 Apparatus used in TSS test

The preparation of a glass-fibre disc served as the starting point for the experiment. It was necessary to place the glass fibre wrinkled side up in the filtration apparatus. This was followed by three cleanings with 20 mL of reagent-grade water, each time vacuumed and cleaned three times. All signs of water were removed from the washings with the help of the vacuum, after which the vacuum was turned off and the washings were discarded. Once the filter had been removed from the filtration apparatus, it was placed in an inert aluminium dish before being placed in the oven for 1 hour at temperatures between 103 °C and 105 °C. With forceps, it was placed in the desiccator after 1 hour, allowing the temperature and weight to cool and stabilise while the dish was being cooled. As B (in milligrams), the analytical balance was activated and the filter and aluminium dish were weighed. The results were recorded. The suction method was implemented following the installation of the filtering equipment and filter. A small amount of distilled water was applied to the filter in order for it to seat properly.

A beaker containing a 10 ml POME was stirred with a magnetic stirrer at a rate that sheared larger particles in order to obtain the best results. It was necessary to wash the filter three times with purified water in order to allow for complete drainage between washes. Suction was maintained for approximately 3 minutes after filtration was completed. Following that, the filter was removed from the filtration apparatus and placed on an aluminium dish to serve as a support for the experiment. The filter was dried in an oven for at least 1 hour at 103°C to 105°C, then cooled in a desiccator to bring the temperature balance back into balance before being measured. The weight of the filter, dish, and residue labelled A was recorded as a unit in mg, and the drying, cooling, desiccating, and weighing procedures were repeated until a constant weight was obtained by repeating the process.

$$\text{mg TSS/L} = \frac{(\text{A} - \text{B}) \times 1000}{\text{Sample volume, mL}}$$

Where:

A = weight of filter + dried residue, mg

B = weight of filter, mg

3.6 Electrochemical Process in MFC

Basic components of microbial fuel cells include two electrodes, one anode and one cathode, a separator, and an external connection connecting the electrodes to the fuel cell. The sample will be placed in the anodic chamber. It is necessary to use microbes in order to oxidise the substrate, which is a mixture of POME and wet palm oil sludge. The microorganisms will then release an electron, which will then transfer from anode to cathode through the external wire, which is made of copper. For each electron that is conducted, a proton will be transported to the cathode across the separator in order to complete the reaction.

3.7 Acquisition of Power Generation Data

MFC are monitored for a total of 20 days, with 5 days spent monitoring each different dosage. The current and voltage generated by the MFC are measured with a digital multimeter for a total of seven hours per day. The Ohm's Law is used to calculate the power output (P) of the cells, which is explained in more detail below:

Power output (W) = Voltage (V) x Current (A)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This research aims to generate electricity from palm oil mill effluent by using copper as an electrode in a microbial fuel cell. The results of the analysis are discussed in this chapter. This study investigated the influence of the circuit on the power, voltage, and current output by using copper as an electrode. The relationships among palm oil sludge as a dosage, copper material, chemical oxygen demand, total suspended solid, and pH were examined during the process of MFC because these parameters can influence the performance of MFC.

4.2 Electricity Generation Analysis

4.2.1 Voltage, Current and Power Generation

A multimeter was used to record the voltage and current over a period of 5 days for each different dosage of WPOS. As shown in Figure 4.1, the voltage variation over time for different dosages of WPOS during the MFCs test is illustrated. The voltage where there is no additive added in POME shows a gradual decrease compared to other POME with additive added. Then, the voltage for the 2 mg/L and 4 mg/L dosages started climbing steadily on day 2, but then the voltage fell steadily on day 3. Next, the voltage for the 6 mg/L dosage fell considerably over the first and second days, reaching a low voltage of 19.8 mV. The highest voltage that was achieved was 149.3 mV for raw POME, while with 4 mg/L of WPOS added, it was 105.6 mV. In research by (Obileke et al., 2021), it was reported that the voltage generated by the bacteria did not last for a long period of time due to the bacteria's slowing down of their activities.

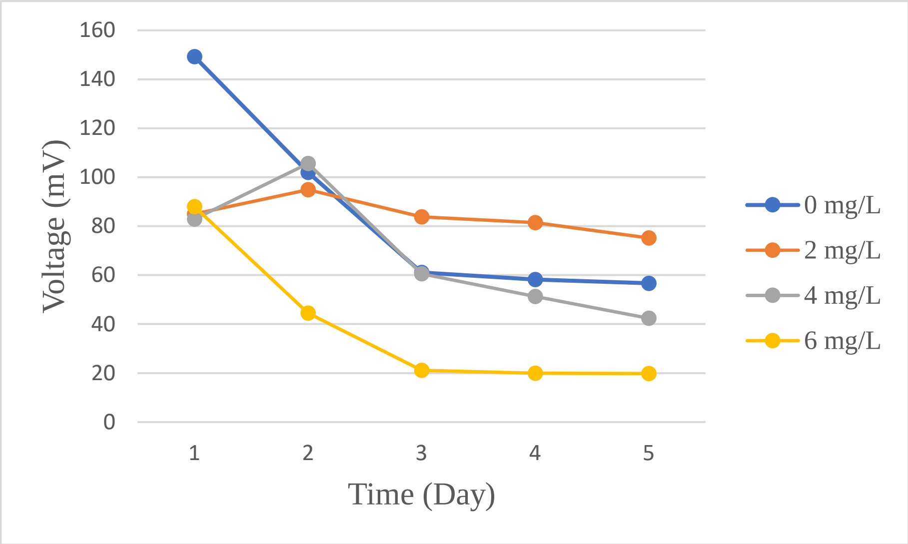

Figure 4.1 Voltage variation over time for different dosage of WPOS throughout the MFCs test.

The same goes for the current generated in MFC illustrated in Figure 4.2. Electricity production in each step includes three phases: increasing, constant and decreasing phase. It can be seen that the raw POME for day 1 produce some current, but then it does not generate much electricity or current until day 5, but when 2 mg/L and 4mg/L dosage is added, the result shows a tendency to gradually increase in day 2, which shows that the microorganisms were active when they were added to the water. The peak value for the current of MFCs is obtained for raw POME at 0.074 mA, while with 4 mg/L of WPOS added, it is 0.048 mA. Due to the biofilm that grows on the surface of electrode after 20 days of operation, this form may interrupt the electron transfer from microbes to the electrode surface, and it could be a reason for low power produced by MFC(Baranitharan et al., 2013).

Figure 4.3 illustrate the power variation over time throughout the MFCs test. The initial current generation, as well as the power generation, were significantly higher with raw POME, indicating that the microorganisms were already producing current and power. It was seen that the maximum power reached about 1.10 x 10-5 W at raw POME and at point 2 of 4 mg/L dosage, the value power was 5.07 x -10-6 W. In research from (Baranitharan et al., 2013), the power generation increased because of increased biological activity and the highly viscous nature of POME may clog the electrode surface, which reduces the mass transfer rate, thus it affects electricity generation.

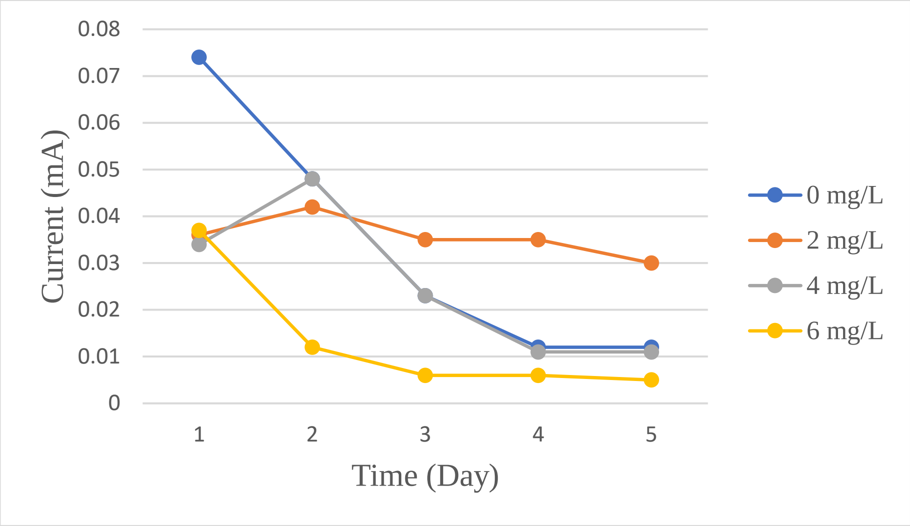

Figure 4.2 Current variation over time for different dosage of WPOS throughout the MFCs test.

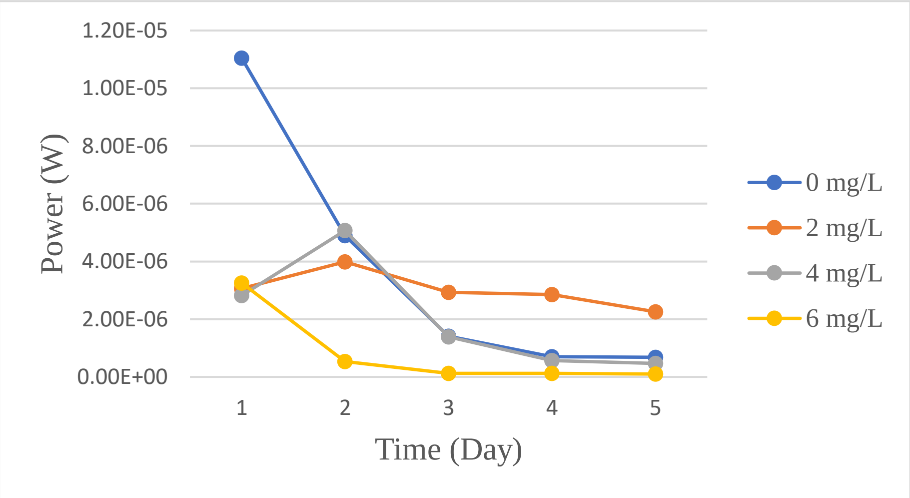

Figure 4.3 Power variation over time for different dosage of WPOS throughout the MFCs test.

4.3 Effect of Electrode Operational System

Copper was used as the electrode in this study in both chambers because copper is a good electrical conductor and low cost. The length of the copper used in this study was 6cm. Copper is a metal/metal oxides-based. This material is frequently used as electrodes in MFCs, but because of their corrosion, they are not compatible with microorganisms, limiting their scope and application in MFCs (Yaqoob et al., 2021). However, corrosion tends to increase the current through galvanic current production and the increased surface area or decrease the current through the generation of toxic product (Obileke et al., 2021). With the values of 105.6 mV for voltage and 0.048 mA for current, it still shows a good sign in this study. In research from(Idris et al., n.d.), the study results showed that the MFC achieved up to 202 mV and 153 mV in the presence and absence of air pump, respectively. Therefore, by adding the air pump in this study, it will improve the result.

4.4 Effect of pH, COD and TSS in MFC

4.4.1 pH

As shown in table 4.1, the pH of the POME and the additive of WPOS were analysed before and after the operation of the MFC.

Table 4.1 pH analysis evaluated based on different dosage of WPOS before and after MFC operation

Parameter	**Initial**	**0 mg/L**	**2 mg/L**	**4 mg/L**	**6 mg/L**
pH	4.71	4.37	4.56	4.11	4.25

Table 4.1 shows how the pH of each dosage of WPOS decreases from the initial reading. However, the reduction in pH is not too significant, as the pH is still in an acidic state of affairs. The acidic pH may have an effect on the performance of MFCs, resulting in a decrease in power production. The pH of a solution that is neutral is optimal for the growth of bacteria. The pH level in some wastewater, on the other hand, is extremely low. POME wastewater is one of the wastewaters that has a lower pH than the others, with an initial pH of 4.71 before MFC operation. The MFC will be unable to function properly as a result of this condition. When it comes to electricity generation, the slightly

alkaline anodic pH of around 7.5 is considered to be the most appropriate pH. (Aghababaie et al., 2015). The results show that the pH of each dosage is slightly lower than the previous one, with the lowest pH being 4.11. The decreasing pH has had an impact on the power generation in MFC, as illustrated in figure 4.3, where the power achieved at 9.90 x 10-8 W was low when compared to the power achieved at 4mg/L with 4.11 at the end of MFC operation, which was high. A low pH can make the anodic biofilm less active and thus slow down the growth of the organisms within. Meanwhile, a neutral environment should be considered in order for microbes to metabolise, grow, and attach to the anode. The diversity of microbes was restricted when the pH was between 4 and 5, which is under acidic conditions. The lower pH will have an effect on the abundance of anodic microbes. As a result, the amount of electricity produced by MFC decreased (L. Zhang et al., 2011).

4.4.2 Chemical Oxygen Demand

The initial COD reading and the final COD reading for each different dosage of WPOS have been determined. The COD analysis was performed by comparing the initial and final readings for each parameter at various dosages, as shown in table 4.2.

Table 4.2 COD analysis evaluated based on different dosage of WPOS before and after MFC operation

Parameter	Initial	0 mg/L	2 mg/L	4 mg/L	6 mg/L
COD (mg/L)	669	665	652	637	622

Table 4.2 shows that the final COD of each WPOS is lower than the initial reading when compared to the initial reading. The COD reading at the start of the experiment is the highest, at 669 mg/L. When compared to other dosages, the 6 mg/L dosage results in a slight decrease in COD. Even though there is a slight decrease in each dosage, the final readings for each dosage indicate that it is still high. As a result, as illustrated in figure 4.3, the production of electricity in MFC could be adversely affected. The power

production is not high and begins to decline after the second day. The decrease in power due to the toxicity of copper ions to microorganisms is caused by a number of factors. The corrosion of a metal anode can have an impact on current generation in a variety of ways. Microorganisms in these reactors were inhibited from producing current because of corrosion, which resulted in the production of soluble copper, which is known to be toxic to microorganisms. As a result, when the substrate is composed of colloidal particles, the amount of power produced is reduced. Ability to generate electricity in MFC based on the activity of bacteria or reduction oxidation reaction in which electrons and protons are generated as well as electron acceptor is referred to as electrochemical potential. The power generated will be affected by the anode potential and electrolyte used in conjunction with the substrate. According to (López Velarde Santos et al., 2017), if there are a large number of colloidal particles in the electrolyte solution, the electron and proton transfer may be inhibited. However, the MFC indicates that COD can be removed. Using different dosages of WPOS before and after MFC operation, the percentage of COD removed is shown in the tables 4.3.

Table 4.3 Percentage of COD removed for different dosage of WPOS before and after MFC operation

WPOS dosage (mg/L)	**Initial COD (mg/L)**	**Final COD (mg/L)**	**COD removal (%)**
0	669	665	0.6
2	669	652	2.5
4	669	637	4.9
6	669	622	7

The results of COD removal before and after MFC operation are shown in Table 4.3. The maximum COD removal rate in MFC is 7%. It indicates that the MFC is capable of removing COD, which can cause pollution if discharged without treatment. In MFC, the removal of COD demonstrates that the oxidation of the anodic chamber is accomplished through the process of direct anodic oxidisation. The consumption of organic matter contains microorganisms, according to (López Velarde Santos et al., 2017). As a result, the use of MFC has demonstrated that it can eliminate COD in POME and WPOS during the operation.

4.4.3 Total Suspended Solid

TSS is one of the factors that has an impact on the performance of the MFC. The initial TSS reading as well as the final TSS reading for each different dosage of WPOS have both been determined and recorded. Table 4.4 shows the results of the TSS analysis performed using different dosages of WPOS. In order to evaluate the parameter, it was necessary to compare the initial and final readings for various dosages of each parameter.

Table 4.4 TSS analysis evaluated based on different dosage of WPOS before and after MFC operation

Parameter	**Initial**	**0 mg/L**	**2 mg/L**	**4 mg/L**	**6 mg/L**
TSS (mg/L)	4800	1900	500	600	700

It can be seen that the TSS for each dosage of WPOS is decreasing from the initial value of 4800 mg/L. The high concentration of TSS in MFC has the potential to cause power generation to be disrupted. TSS may impair the bacteria's ability to break down organic matter, which could cause the process to be disrupted as a result of the increase in internal resistance to the bacteria. Bacteria that break down organic matter are typically found on the surface of suspended solids particles, where they can be found in large numbers (Ismail & Radeef, 2019). If the voltage source has a high internal resistance, it may have an impact on the ability of the current supply. As a result, the amount of TSS must be reduced in order to reduce the disruption in the generation of electricity in MFC.

4.5 Operating Parameter

4.5.1 Effect of WPOS as Additive

In the first day, the generation of electricity increased, reaching its maximum on the second day, after which it began to decline gradually. The power continued to be cut off for the next three days. The maximum current achieved was 0.48 mA, and the maximum power achieved was 5.07 x 10-6 W. The maximum current and power were both achieved. It was found that adding 4 mg/L of dosage resulted in the highest current. Due to the fact that WPOS contains a large number of different types of microorganisms and as a result, electricity was continuously supplied to them (Nor et al., 2015). It demonstrates the high-power generation capability of the POME when compared to the POME without WPOS. This demonstrates that the generation of electricity is improved by the presence of WPOS in the anodic chamber of the MFC. However, when compared to the WPOS with 4 mg/L, the WPOS with 6 mg/L generates significantly less electricity. This could occur as a result of the biofilm that forms on the electrode's surface after 15 days of operation. The formation of a thick biofilm may obstruct the movement of electrons, preventing electrons from travelling from microbes to the electrode surface, among other things. As a result, reduce the amount of electricity produced (Baranitharan et al., 2013).

4.5.2 Operational Time

Specifically, the operational time for MFC to generate electricity has been evaluated for a total of 20 days, with 5 days required for each different dosage of WPOS, including 0 mg/L, 2 mg/L, 4 mg/L, and 6 mg/L, and a total of 20 days required. In terms of electricity production, each different dosage exhibits the same trend, with the highest levels of power being achieved on the second and third days of MFC operations, respectively. It was the third day of operation when the power started to decline gradually. Even on the last day of operation, the current production for each dosage of WPOS can still be seen, albeit at a lower level than on the second and third days respectively. It indicates that the bacteria are still active at the start of the operation and that they begin to slow down on the third day of the procedure. Bacteria are essential in the oxidation of available organic matter, which results in the production of electrons and protons. During the transfer of electrons to the terminal electron acceptor, which is oxygen in the cathode chamber, energy will be generated (Song et al., 2019). Consequently, in MFC, electricity can be produced on a continuous basis.

CHAPTER 5

CONCLUSION

5.1 Introduction

The goal of this research is to generate bioelectricity from palm oil mill effluent in microbial fuel cell. The electricity generation was completed in this chapter. Some suggestion for improving the performance of MFCs.

5.2 Conclusion

In this study, by using copper as an electrode, a mixture of POME and WPOS was successful in producing electricity in a microbial fuel cell. Based on the results, it was found that with raw POME, both the initial current generation and the power generation were significantly higher, indicating that the microorganisms were already producing current and power. The maximum current reached about 0.074 mA and the power reached about 1.10 x 10-5 W at raw POME. Then, from a mixture of POME and WPOS with a 4 mg/L dosage, the current reached about 0.048 mA and the power reached 5.07 x 10-6 W. Power generation in MFC was found to be increasing until the second day, after which it began to decline gradually as time progressed. During the second day of operation, for each dosage of WPOS, the maximum power was reached. The results show that the biological activity of the microbes is active until the second day and then begins to slow down on the third day, continuing until the end of the operation. This may occur as a result of a variety of factors, including the fact that POME may clog on the surface of the electrode as a result of their highly viscous nature, which will slow the rate of mass transfer and cause the electrode to clog. Despite the fact that the power generated by MFC using copper as an electrode is significantly lower than that produced by graphite rod, it is still successful in producing some electricity. The lower the level of resistivity, the greater the amount of electrical conductivity a metal possesses. The low resistivity of copper makes it an excellent electrical conductor, and this is another advantage of using it. Furthermore, WPOS has proved its efficacy as an additive to increase power generation in MFC. TSS, COD, and pH are three parameters that can have an impact on the performance of MFC. The parameter was evaluated by comparing the initial and final reading for different dosages. This study shows that the parameters can have an impact on the performance of MFC. The high concentration of TSS may cause power generation in MFC to be disrupted. In conclusion, MFC by using copper as electrode is capable of generating electricity from a mixture of POME and WPOS, despite the fact that the amount of power produced is still limited. Various improvements can be implemented in order to improve the efficiency of MFC. As a result, the maximum amount of power can be obtained.

5.3 Recommendation

Although the power generated by MFC in this study was satisfactory, it could be improved. By increasing the efficiency of MFC, the potential as a source of renewable energy can be enhanced. As a result, it is possible to reduce our reliance on non-renewable energy. To increase the power generation in MFC, a number of recommendations should be considered for future studies. To begin, increasing the surface area of the electrodes can be used to improve the performance. As a side note, it is important to properly select operating conditions such as influent COD concentration, pH, and specific organic loading rate for operation in order to achieve maximum COD removal efficiency and power production. As a result, the amount of electricity produced in MFC can be increased. Finally, by achieving improved mass-transfer and electron-transfer rates, it is possible to run MFC that are free of extraneous mediators or biofilms while also achieving improved microbial consortium.

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APPENDICES

Appendix A: Voltage measurement in the MFCs process

Title: Dual chamber MFC