

**RENEWABLE ENERGY FROM PALM OIL MILL EFFLUENT
(POME) USING MICROBIAL FUEL CELL**

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A thesis submitted

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Dedication

I wish to dedicate the success of writing this work especially to my beloved husband, Iswandy Bin Shafiee, for his encouragement and support. I am truly grateful for his sacrifice during the period of my studies. I would also like to dedicate this work to my beloved and respected father, Abdul Wahab Bin Aziz, and my loving mother, Fatimah Binti Zainuddin, for their endless support in making the completion of this work possible. My special dedication goes to my children, Nur Aini Farhanah bte. Iswandy, Nur Adriana Farzanah bte. Iswandy and Muhammad Arasy Firdhaus bin Iswandy, as they have been my source of motivation to complete this work.

I wish to dedicate this success also to both of my supervisors, Dr. Hj. Mohammad Omar bin Abdullah and Associate Professor Ir. Dr. Law Puong Ling for their words of advice and guidance throughout my studies in Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS).

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Abstract

(As fossil fuel becomes finite, the growing pressure is on finding and sustaining renewable energy). Renewable energy sources are from solar, wind, hydraulic, biomass and fuel cell (The Malaysian government has nominated renewable energy as its fifth fuel strategy, in addition to the current fuel strategy that is oil, natural gas, coal and hydropower, by 2020). With the development of Sarawak Corridor of Renewable Energy (SCORE) in the country, the sources of biomass and biogas from palm oil plantation has been made available) (These sources should be harnessed to produce renewable energy and to prevent harmful biogas released to the environment). (The purpose of this research was to examine the potential of palm oil mill effluent (POME) as a substrate to Microbial Fuel Cell (MFC). MFC is a system that converts organic matter into energy) (The research was carried out by studying the viability of POME to generate power density in batch mode and at varied feed rates of continuous flow in the MFC system.) (The result indicates that POME generates higher power density than other mixed culture reported previously. At a low feed rate (400 litre/hr), the MFC yielded power density of 160 mW/m^2 , with cell potential of 625 mV. At a high feed rate (420 litre/hr), the MFC demonstrated power density of 217 mW/m^2 , with cell potential of 727 mV. The result also indicates that MFC could produce higher power density when operated at continuous flow process (160 mW/m^2) than at batch process (54 mW/m^2). The MFC is likely to be a cleaner technology in converting the POME to useful energy as the by-products produced in the process is carbon dioxide and water. Based on the result obtained, it is very likely that the MFC could utilise the palm oil mill effluent on-site and generate energy back to the mill for some small power applications, such as lighting the light-emitting diode.

Abstrak

Tekanan untuk mencari dan mengekalkan tenaga diperbaharui semakin meningkat kebelakangan ini disebabkan oleh sumber bahan api yang semakin kehabisan. Sumber-sumber tenaga diperbaharui adalah seperti tenaga solar, angin, hidraulik, *biomass* dan *fuel cell*. Kerajaan Malaysia telah menamakan tenaga diperbaharui sebagai strategi bahan api yang kelima, penambahan kepada strategi bahan api yang sedia ada iaitu minyak, gas asli, arang batu dan tenaga hidro, menjelang tahun 2020. Dengan adanya pembangunan *Sarawak Corridor of Renewable Energy (SCORE)* di negara ini, sumber-sumber *biomass* dan *biogas* dari kilang kelapa sawit telah meningkat. Sumber-sumber ini hendaklah dijana untuk menghasilkan tenaga diperbaharui dan untuk mengelak *biogas* yang merbahaya dibebaskan ke alam sekitar. Tujuan kajian ini dijalankan adalah untuk mengkaji potensi efluen dari kilang kelapa sawit sebagai *substrate* untuk *Microbial Fuel Cell (MFC)*. *MFC* merupakan satu sistem yang menghasilkan tenaga daripada bahan organik. Kajian ini dijalankan dengan menguji kebolehpayaan efluen dari kilang kelapa sawit untuk menghasilkan tenaga dalam keadaan *batch process* dan juga pada keadaan *continuous flow process*. Hasil kajian menunjukkan efluen dari kilang kelapa sawit mampu menghasilkan ketumpatan kuasa yang lebih tinggi berbanding dengan *mixed culture* lain yang pernah dilaporkan sebelum ini. Pada kadar *feed* yang rendah (400 liter/jam), *MFC* menghasilkan ketumpatan kuasa sebanyak 160 mW/m² dan sel potensi sebanyak 625 mV. Pada kadar *feed* yang tinggi (420 liter/jam), *MFC* menghasilkan ketumpatan kuasa sebanyak 217 mW/m² dan sel potensi sebanyak 727 mV. *MFC* turut didapati menghasilkan ketumpatan kuasa yang lebih tinggi pada keadaan *continuous flow process* (160 mW/m²) berbanding dengan keadaan *batch process* (54 mW/m²). *MFC* dijangka menjadi teknologi yang lebih bersih dalam menjana tenaga

diperbaharui dari efluen kelapa sawit kerana produk sampingan yang dihasilkan adalah karbon dioksida dan air. Keputusan ini adalah amat memberangsangkan kerana *MFC* dijangka mampu menjana tenaga diperbaharui daripada efluen kelapa sawit untuk dikembalikan semula ke kilang seperti untuk menyalakan *light-emitting diode*.

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LIST OF ABBREVIATIONS AND SYMBOLS

A_{AN}	-	Anode Surface Area
AFC	-	Alkaline Fuel Cell
AN	-	Ammoniacal Nitrogen
b	-	Mol of Electrons produced per mol of Oxygen
BOD	-	Biochemical Oxygen Demand
BSA	-	Bovine Serum Albumin
CE	-	Carbon Electrode
C_{Ex}	-	Total Coulombs Calculated
C_{Th}	-	Theoretical Amount of Coulombs
COD	-	Chemical Oxygen Demand
DMFC	-	Direct Methanol Fuel Cell
E_{CELL}	-	Cell Voltage
EFB	-	Empty Fruit Bunches
F	-	Faraday's Constant
FFB	-	Fresh Fruit Bunches
HRT	-	Hydraulic Retention Time
I	-	Current
K_S	-	Half-saturation constant
M	-	Substrate Concentration
MCFC	-	Molten Carbonate Fuel Cell
MFC	-	Microbial Fuel Cell
NAC	-	Net Anodic Compartment

NAD	-	Nicotinamide Adenine Dinucleotide
P	-	Power Density
P_{AN}	-	Power Density (normalised to projected anode surface area)
P_{max}	-	Maximum Power Density
PAFC	-	Phosphoric Acid Fuel Cell
PEM	-	Proton Exchange Membrane
PEMFC	-	Proton Exchange Membrane Fuel Cell
POME	-	Palm Oil Mill Effluent
R_{EXT}	-	External Resistance
RVC	-	Reticulated Vitreous Carbon
S	-	Substrate Concentration
SALCRA	-	Sarawak Land Consolidation and Rehabilitation Authority
SCMFC	-	Single Chamber Microbial Fuel Cell
SEM	-	Scanning Electron Microscope
SOFC	-	Solid Oxide Fuel Cell
TKN	-	Total Kjeldahl Nitrogen
t_i	-	Time Interval
V_{AN}	-	Anode Compartment Volume
V_i	-	Voltage at Time Interval
ϵ_C	-	Coulombic Efficiency

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The growing pressure on our environment and the increase in the oil price had lead to the development of renewable energy resources. There is a growing demand in the development of sustainable and renewable energy portfolio recently. Renewable energy is the energy from resources that will not be depleted, such as wind, mini-hydro, solar and biomass (Randhawa, 2004). Traditionally, Malaysian energy policy (Floyd, 2003) always revolved around four fuel strategy that is oil, natural gas, coal and hydropower. However, the fossil fuel source in Malaysia and elsewhere in the world is finite. The oil reserves are anticipated to last at least for the next fifteen years or so while the gas reserves can last for the next forty-two years (Floyd, 2003). This forces the Malaysian government to introduce the fifth fuel strategy in our Vision 2020, which is known as the Renewable Energy (8th Malaysian Plan 2001-2005).

Under Vision 2020 (8th Malaysian Plan 2001-2005) the government strongly endorses the usage of renewable energy. The government target is 20% of the energy requirements in the year 2020 shall be met by renewable energy. Some renewable energy includes solar, wind, hydraulic, biomass and fuel cell. In the 8th Malaysian Plan, the renewable energy resources

that will be prioritised are biomass, such as palm oil, wood residues, rice husks, biogas, municipal waste, solar and mini-hydro (Floyd, 2003). It is targeted that palm oil sectors will be the greatest potential producer for biomass and biogas.

Malaysia is the world's largest producer and exporter of palm oil contributing about 50% of world production and 65% of the world export market (Floyd, 2003). Each year, the country produces 14 millions tonnes of waste from the processing of fresh fruit bunches (Randhawa, 2004). These wastes are in the form of empty fruit bunches, fibre, shells and palm oil mill effluent. These wastes can be utilised as a source of renewable energy. The biomass is from the empty fruit bunches, fibre and shells. Meanwhile, the biogas is from the palm oil mill effluent.

The palm oil mill effluent is very high in content of degradable organic matter (Table 1.1). The effluent can be a significant polluting source to the environment if left untreated and channel to the water course. Therefore, the effluent is treated in retention ponds to reduce its polluting effects. However, this leads to an anaerobic condition that produces methane gas, or also known as biogas. When this biogas is emitted to the environment, it will cause global warming. Hence, this biogas should be harnessed than released to the environment.

1.2 Sarawak Corridor of Renewable Energy (SCORE)

The Prime Minister of Malaysia, Datuk Seri Abdullah Ahmad Badawi had launched Sarawak Corridor of Renewable Energy (SCORE) in February 2008. The Sarawak Corridor of

Renewable Energy is one of the five regional development corridors being developed throughout the country. There are five major areas of development namely industries, power sector, human capital, physical infrastructure and institutional infrastructure at present. SCORE focuses on hydropower, coal and natural gas in the power industry. Palm oil sector is also included as one of the ten top priority industries that are expected to give significant impact to the state development specifically to provide sustainable sources for biomass and biogas in the region (www.sarawak.gov.my).

Table 1.1: Palm Oil Mill Effluent Characteristics (Source: <http://www.mpob.gov.my>)

Characteristic	Value
Ph	4.2
Oil and Grease	4, 000 mg/l
Biochemical Oxygen Demand (BOD)	25, 000 mg/l
Chemical Oxygen Demand (COD)	51, 000 mg/l
Total Solid	40, 000 mg/l
Suspended Solid	18, 000 mg/l
Total Volatile Solid	34, 000 mg/l
Ammoniacal Nitrogen	35 mg/l
Total Nitrogen	750 mg/l

1.3 Fuel Cell

Fuel cell is one of the potential renewable energy sources around the globe. It is a system that oxidises or reduces chemicals to produce electricity. It contains two electrodes called the anode and cathode. These electrodes are separated by electrolyte or membrane. Chemically, a fuel cell takes in hydrogen and air, creates electricity, and produces by-products of water

and heat. The anode separates hydrogen into protons and electrons. The electrons flow along the path, producing electrical current for a circuit, while protons move through the electrolyte to the cathode. The cathode combines the oxygen with protons, as well as collecting some of the electrons in the circuit, to produce water (Larminie & Dicks, 2003).

There will be half reactions take place at the surface of each electrodes and the overall reaction is the sum of the two half reactions. Chemical reactions on the anode and the cathode are shown below:

Anode:



Cathode:



Overall reaction:



There are few types of fuel cells namely Alkaline Fuel Cell (AFC), Proton Exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC) and also Microbial Fuel Cell (MFC). Table 1.2 shows different types of fuel cells and its state of nature.

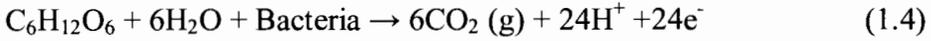
Table 1.2: Different Types of Fuel Cells (Source: Bahnemann *et al.*, 2003)

Name	Electrolyte	Anode Gas	Cathode Gas	Temperature	State
Alkaline Fuel Cell (AFC)	Potash	Hydrogen	Oxygen	Below 80 °C	Commercial
Proton Exchange Membrane Fuel Cell (PEMFC)	Polymer Membrane	Hydrogen (direct or from reformation of methane or methanol)	Oxygen or Atmospheric Oxygen	To 120 °C	Being Developed
Direct Methanol Fuel Cell (DMFC)	Polymer Membrane	Methanol	Atmospheric Oxygen	90 ~ 120 °C	Being Developed
Phosphoric Acid Fuel Cell (PAFC)	Phosphorus	Hydrogen (direct or from reformation of methane or methanol)	Atmospheric Oxygen	200 °C	Commercial
Molten Carbonate Fuel Cell (MCFC)	Alkali-Carbonates	Hydrogen Methane	Atmospheric Oxygen	650 °C	Being Developed
Solid Oxide Fuel Cell (SOFC)	Ceramic-Oxide	Hydrogen Methane	Atmospheric Oxygen	900 ~ 1000 °C	Being Developed

Microbial fuel cell (MFC) is considered as a promising new technology for an efficient production of electrical energy from wastewater treatment. It is a device that uses bacteria as the catalysts to oxidise organic and inorganic matter to generate electric current. In the system, the bacteria oxidises the substrates and produces electron. Electron (e^-) is transferred to the anode by electron mediators or shuttles. Protons (H^+) flow from the anode to the cathode chamber through proton exchange membrane (PEM). The electron flows from the anode to the cathode linked by a conductive material containing a resistor. This results in the

current flows in an opposite direction of the electron flow that is from the cathode to the anode. Figure 1.1 shows the configuration of a typical microbial fuel cell.

At the anode:



At the cathode:



Unlike other fuel cell types, Microbial Fuel Cell is capable of converting chemical energy into electrical energy. It utilises the microorganisms that are readily available in the substrate to oxidise the organic substrate to create electrical power. The microorganisms use the substrates to maintain their metabolisms and reproduction. Hence, MFC could generate useful electrical energy from the wastewater.

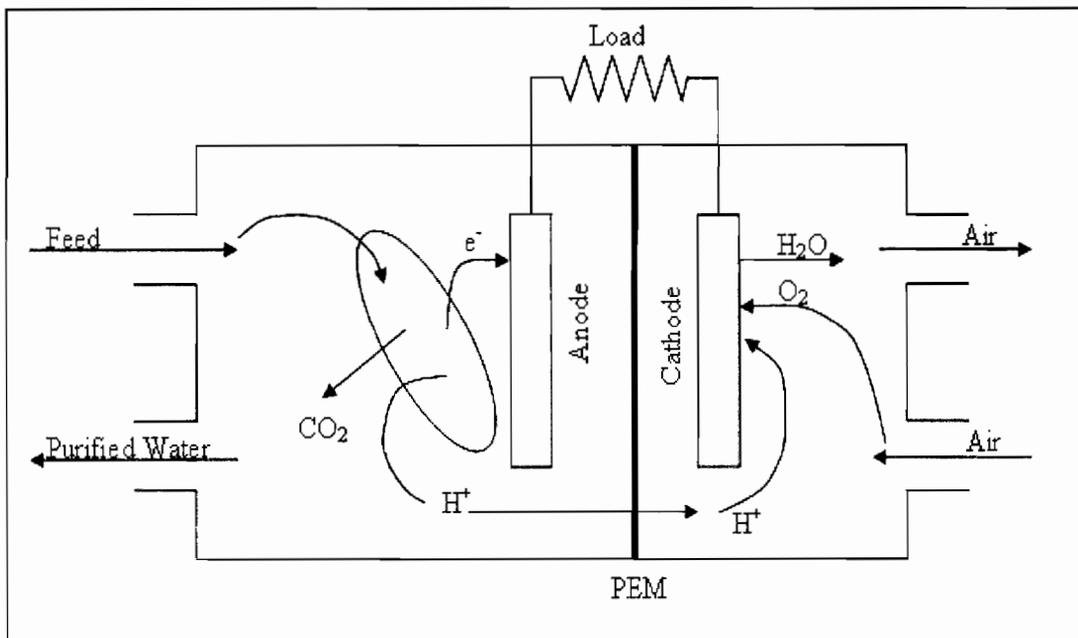


Figure 1.1: Configuration of Microbial Fuel Cell (Logan *et al.*, 2006)

In the Microbial Fuel Cell, the bacteria in the substrates depend on the anode for their metabolism. The bacteria strategically positioning themselves onto the anode surface and form a bacterial community called the biofilm (Figure 1.2). Here, the bacteria produce a matrix of material so that they stick to the anode. The sticky biofilm is made up of complex extracellular proteins, sugars and bacterial cells that enable the bacteria to transport electrons to the anode (Science Daily, 2008).

MFC requires high quality and reliable influent as its substrate. Some of the wastewaters that had been used in the previous studies as MFC substrates are domestic wastewater (Liu *et al.*, 2005; Logan *et al.*, 2005; Min *et al.*, 2005 & Logan *et al.*, 2006), anaerobic sediments (Liu *et al.*, 2004), swine wastewater (Min *et al.*, 2004), meat packing wastewater (Heilmann *et al.*, 2006) and animal wastewater (Logan *et al.*, 2006). In the present study, the experiment is conducted using wastewater from the palm oil mill as the MFC substrate. Palm oil mill effluent (POME) is investigated as a potential substrate because of its high content in biodegradable organic matter (Ahmad *et al.*, 2003). Microbial Fuel Cell (MFC) may provide an alternative energy sources and become a novel wastewater treatment process for POME in the future.

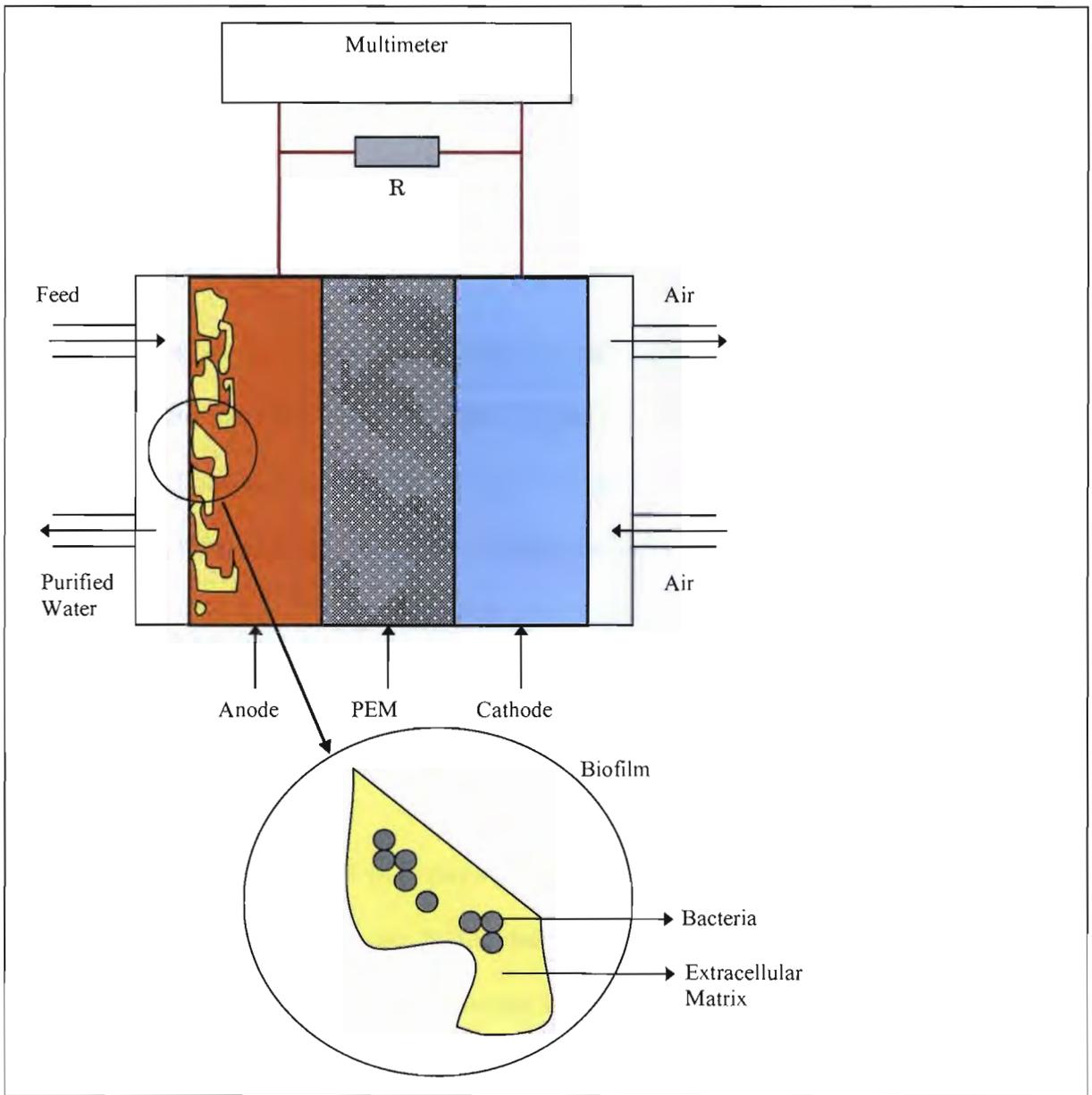


Figure 1.2: Schematic Diagram of Biofilm Developed on the Anode Surface Area
 (Source: Science Daily, 2008)

1.4 Palm Oil

Palm oil industry is one of the biggest biomass producers in Malaysia. Based on the Industrial Processes & the Environment Handbook No. 3 (1999), 1.5 m³ of water is used to process

every tonne of fresh fruit bunches of palm, and from this amount of water used, 50% of it is released as the palm oil mill effluent (POME). For every 1 m³ of POME released, when treating using the conventional biological treatment system, about 14.15 m³ of methane gas is released. In Malaysia, the palm oil mills are estimated to produce 31, 500 million m³ of POME every year (Floyd, 2003), hence, about 4.46 x 10⁵ million m³ of methane gas is released. The state government of Sarawak, in particular, is continuously promoting large scale agriculture activities in the country. In the 9th Malaysian Plan Sarawak Perspective 2006, the Chief Minister of Sarawak, Yang Amat Berhormat Pehin Sri Datuk Abdul Taib bin Mahmud stated that there is a target of a million hectares for large scale oil palm plantations in the state by the year 2010. About 543, 304 hectares have been planted at an estimated investment sum of over RM 6.5 billion. There will be further investment in more palm oil mills and downstream activities in near future.

Since there is a large amount of wastewater produced in the process of palm oil and this amount will continue to increase in the future as the palm oil processing activities are increasing. The common practice for treating POME in Malaysia involves a combination of aerobic and anaerobic methods. The process requires proper maintenance and monitoring as the process solely rely on microorganisms to break down the pollutants. It generates vast amount of biogas containing methane, carbon dioxide and trace amounts of hydrogen sulphide. These gases are very corrosive and odorous (Ahmad *et al.*, 2003). The methane gas is a powerful greenhouse gas that contributes to global warming. It is about 21 times as much as carbon dioxide (Randhawa, 2004). On the other hand, by the application of Microbial Fuel Cell (MFC), the palm oil mill effluent could be converted into a useful and clean energy power. Here, the primary interest is to utilise the palm oil mill effluent on-site and to turn it