EFFECTS OF PROCESS PARAMETERS ON GEOBACTER SULFURREDUCENS AND BACILLUS SUBTILIS FROM DEWATERED SLUDGE FOR ELECTRICITY GENERATION IN MEMBRANE – LESS MICROBIAL FUEL CELL

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by

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LIST OF SYMBOLS

$	Dollar
Ω	Ohm
%	Percentage
Tcf	Trillion cubic feet
ktoe	Kilogram of oil equivalent
ºC	Degree Celsius
g	Gram
h	Hour
β	Beta
μ	Specific growth rate
wt%	Weight percentage
R^2	Correlation coefficient
R_{ext}	External resistance
V_{max}	Voltage maximum
R_{int}	Internal resistance
e^-	Electrons
USD	United Stated Dollar
USD/kWh	United Stated Dollar/ kilowatt hour
V	Voltage
mV	Millivoltage
A	Ampere
mA	Milliampere
mA/cm^2	Milliampere/ centimetre square
W	Watt
mW/m^3	Milliwatt/ meter cubic
mW/m^2	Milliwatt/ meter square
kW/m^2	Kilowatt/ meter square
kW/day	Kilowatt/ day
kWh/day	Kilowatt hour/ day
kWh/m^3	Kilowatt hour/ meter cubic
MW/day	Megawatt/ day
w/w	Weight for weight
μg/L	Microgram/ litre

mg/L	Milligram/ litre
mgh^{-1}	Milligram/ hour
mb/d	Million of barrel/ day
nm	Nanometer
μm	Micrometer
cm	Centimetre
mL	Millilitre
mg(Lh^{-1})	Milligram litre/ hour
g/l/day	Gram/ litre/ day
cell/mL	cell/ millilitre

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AD	Anaerobic Digestion
ADP	Adenosine Diphosphate
ATP	Adenosine Triphosphate
ANOVA	Analysis of Variance
ARB	Anode Respiring Bacteria
CCD	Central Composite Design
CFD	Computational Fluid Dynamics
COD	Chemical Oxygen Demand
DC	Direct Current
DoE	Design of Experiment
DMFC	Direct Methanol Fuel Cell
EAB	Electrochemically Active Bacteria
EB	Electrogenic Bacteria
EET	Extracellular Electron Transport
EU	European Union
ETC	Electron Transport Chain
FELDA	Federal Land Development Authority
FiT	Feed – in – Tariff
GDP	Gross Domestic Product
GHG	Green House Gases
ICP – OES	Inductively Coupled Plasma Optical Emission Spectrometry
IWK	Indah Water Konsortium
MEA	Membrane Electrode Assembly
MFC	Microbial Fuel Cell
ML – MFC	Membrane-less Microbial Fuel Cell
MP	Malaysia Plan
MSW	Municipal Solid Waste
MtCO_2	Million tonne Carbon Dioxide
NBS 2020	National Biomass Strategy 2020
NEEAP	National Energy Efficiency Action Plan
NPS	New Policy Scenario

OCV	Open Circuit Voltage
OFAT	One Factor At A Time
ORR	Oxygen Reduction Reaction
PBR	Photobioreactor
PV	Photovoltaic
PEM	Proton Exchange Membrane
RE	Renewable Energy
redox	Reduction and oxidation
RSM	Response Surface Methodology
SBCP	Sahabat Biomass Cogeneration Plant
SDE	Substrate Degradation Efficiency
SDG	Sustainable Development Goal
SPF	Sludge Production Factor
SREP	Small Renewable Energy Power
TGE	Tawau Green Energy
TSCF	Trillion Standard Cubio Feet
US	United State
USM	Universiti Sains Malaysia
UV - Vis	Ultraviolet – Visible
WTG	Wind Turbine Generator

LIST OF APPENDICES

KESAN PARAMETER PROSES TERHADAP GEOBACTER SULFURREDUCENS DAN BACILLUS SUBTILIS DARIPADA ENAPCEMAR TERNYAH AIR BAGI PENJANAAN TENAGA ELEKTRIK DI DALAM SEL BAHAN BAKAR MIKROB TANPA MEMBRAN

ABSTRAK

Sel bahan bakar mikrob tanpa membran (ML-MFC) ialah teknologi yang boleh diperbaharui termaju yang dapat membantu menyelesaikan dilemma tenaga dunia.Bakteriaelektrogenik (EB) iaitu *Geobacter sulfurreducens* (GS) and *Bacillus subtilis* (BS) bertindak sebagai biomangkin dalam ML-MFC, ia membolehkan sistem dalaman mencipta tenagaelektriksecara elektrokimia. ML-MFC menggunakan enapcemarternyah air daripada dua loji rawatan air yang berasingan (A – IWK Juru and B – IWK Butterworth). Dari analisis unsur, enapcemar A menunjukkan tinggi bilangan magnesium dan kalsium berbanding enapcemar B justeru memudahkan pemindahan elektron dalam ML – MFC. Prestasi ML-MFC menggunakan enapcemar A dan B sebagai substrat kemudiannya dinilai menggunakan pendekatan satu faktor pada satu masa (OFAT), diikuti dengan kaedah Kaedah Permukaan Sambutan (RSM) menggunakan mod kuadratik melalui reka bentuk komposit pusat (CCD).Nilai terbaik bagi jarak elektrod 4 cm (ED), pH 9, kandungan lembapan 40 % (v/w) dan suhu 40 ℃ telah memperoleh tindakbalas yang optimum; biojisim (1.88 mg/L), penyingkiran COD 46.52% (202 mg/L) dan ketumpatan kuasa (7.848 mW/m^2) dalam penyiasatan awalan OFAT. Voltan telah dipertingkatkan keberkesanan dengan keadaan optimum yang disyorkan oleh RSM. Seperti yang dinyatakan melalui pertumbuhan kinetic EB bahawa parameter RSM mampu

menghasilkan signifikan bagi kadar pertumbuhan spesifik (μ) (21.005 mg(Lh^{-1})) dan masa penggandaan (*Td)* (0.033mgh^{-1}). Kemudian peringkat akhir ML-MFC telah disahkan dari sudut prestasi biojisim 1.9 mg/L, penyingkiran COD 75.4 % dan ketumpatan kuasa 20.329mW/m^2 menurut keadaan terbaik RSM. Bagi menggalakkan penjanaan elektrik, ML-MFC telah juga dijalankan dalam litar bersiri yang terdiri dari 3 hingga 5 MFC disusun dalam litar bersiri. Litar siri dari keadaan RSM dilihat sebagai prestasi yang baik dengan penjanaan tenaga sehingga 37.125mW/m^2.

EFFECTS OF PROCESS PARAMETERS ON GEOBACTER SULFURREDUCENS AND BACILLUS SUBTILIS FROM DEWATERED SLUDGE FOR ELECTRICITY GENERATION IN MEMBRANE – LESS MICROBIAL FUEL CELL

ABSTRACT

The membrane-less microbial fuel cell (ML-MFC) is a cutting-edge renewable energy technology that might help to solve the world's energy dilemma. Electrogenic bacteria (EB) which are *Geobacter sulfurreducens* (GS) and *Bacillus subtilis* (BS) served as a biocatalyst in the ML-MFC, allowing it to create power electrochemically. The ML-MFC employed dewatered sludge from two separate wastewater treatment plants (A – IWK Juru and B – IWK Butterworth). From the analysis of elements, sludge A showed a large amount of magnesium and calcium elements than sludge B which facilitate electron transfer in ML - MFC. The performance of the ML-MFC utilising sludge A and B as substrate were then assessed using the one-factor-at-a-time (OFAT) approach, followed by response surface methodology (RSM) using a quadratic model through Central Composite Design. The best pH 9, electrode distance (ED) 4 cm, the moisture content (MC) 40 % (v/w) and the temperature 40 ℃ obtained the optimum responses; biomass (1.88 mg/L), COD removal 46.52 % (202 mg/L) and power density (7.406 mW/m^2) in the preliminary OFAT research. The voltage was effectively enhanced by utilising the optimal conditions recommended by the RSM. As stated by the kinetics growth of *EB* shows that in RSM parameter conveys a significant specific growth rate (μ) (21.005 $mg(Lh^{-1})$)and doubling time (*Td*) (0.033mgh^{-1}). Then the final stage the ML

– MFCs were validated in term of performance of EB biomass 1.9 mg/L, COD removal 75.4 % and power density 23.906 mW/m^2appropriately according to RSM best condition. To boost the electricity generation, the ML-MFC has been setup with a series circuit, there were MFCs with 3 and 5 MFCs setups were arranged in a series circuit. RSM series circuit view as a good performance through power generation up to 37.125 mW/m^2.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Non-renewable energy sources such as oil, natural gas, and coal account for 85 percent of global energy. Oil provides over 40% of the world's energy(Calderone, 2019). Linearly from 2012, rising transportation fuel consumption and robust industrial demand have resulted in an increase in non-renewable energy usage (Calderone, 2019). About 1.3 billion people in the globe do not have access to electricity, and another three billion rely on traditional fuels, which can have negative consequences for their health, ecosystems, and development. According to what is known about global energy demand, it is expected to grow at a pace of 1.6 percent per year on average from 2008 to 2030 (Kumar, Ashwani., Ogita, Shinjiro., Yau, 2018).

Non-renewable energy is the most frequently stated problems with constantly increment of prices and CO_2emission which both coal and natural gas is the major impact. Along with this statement is evidence that oil prices are expected to remain between US$ 50.0 and US$ 80.0/barrel until 2030 as stated. Moreover T. Ahmad & Zhang (2020)claims that the increase in the market is due to structural changes and energy efficiency gains on the market. Besides European oil consumption will be reduced by 3.0% over the next 15 years. In addition oil supply globally is increasing by 14.0 mb/d to 104.0 mb/d by 2040 even though the drift timely expenditure specifically (IEA: Directorate of Global Energy Economics, 2013).

There is a large volume of published studies describing on greenhouse gases (GHG) which cause by reradiated infrared radiations by CO_2, CH_4, O_3, NO_2 and NO slightly by water vapours thus significantly to maintain Earth's temperature by 33℃(Kumar et al., 2018). Between 2000 and 2010 annual anthropogenic GHG emissions have increased directly coming from energy supply (47%), industry (30%), building (3%) and transport (11%) (IPCC, 2014a, 2014b). Emission of greenhouse gases continuously will cause further warming called as global warming which is irreversible and gives pervasive impacts for people and ecosystems. It has been reported that major drivers of increment in CO_2 emissions are from both fossil fuel combustion and coal impacted by economic and population growth globally (IPCC, 2014a, 2014b). Furthermore, according to Ahmad (2011), Malaysia's petroleum resources are very limited compared to other international areas, at roughly 5.5 billion barrels, with petroleum output peaking in 2004 at roughly 861.8 thousand barrels per day. Nevertheless, these resources will be consumed and become more expensive in the long run (S. Ahmad et al.,2011)

Effect of oil and natural gas usage can be shown in **Figure 1.1** , CO_2 emission has doubled since early 1970s, accelerating environmental change and climate degradation (IPCC, 2014b, 2014a). Most countries occur a sustained increase due to global economic shift perpendicularly with power consumption clearly world economy is booming which gross domestic product (GDP) growing 2.5 times over the past three decades (Kan et al., 2019).

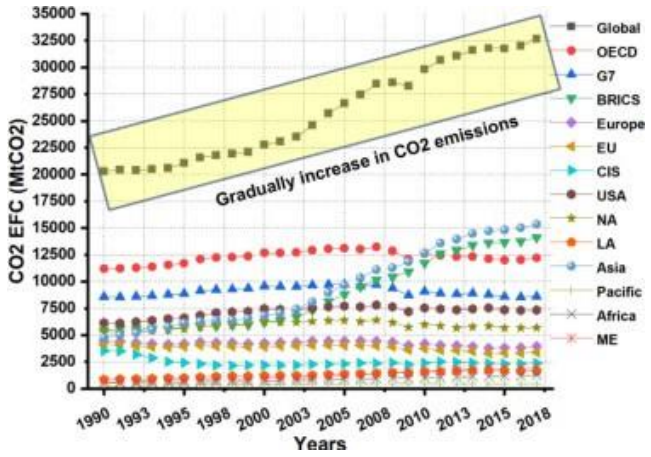

Figure 1.1 CO_2 emissions from fuel combustion ($MtCO_2$)(T. Ahmad & Zhang, 2020)

Figure1.2 and **Figure 1.3** explained about statistic of world's total electricity generation since 1990 and overview of the percentage increase/decrease in world energy, oil, gas, coal, CO_2 emissions and the share of renewable energy in electricity generation respectively. Recently based on **Figure 1.3** below shown that natural gas, oil and coal cover up to 84 % of world's primary energy consumption in 2019 (Robert, 2020). The increment came from both from public and private utilities hence China; Asia significantly contributing almost half of the increase in 2017 due to high demand for electricity combined to accelerate development of production capacity (Ahmad & Zhang, 2020). According to the New Policy Scenario (NPS), global primary energy requirements increased by 37 % between 2012 and 2040 which considers existing government initiatives. As a result, by 2040, oil, coal, and natural gas were expected to account for around a third of total demand. Various states declared new initiatives to decrease CO_2 emissions at a long-term climate summit named the Paris Agreement in 2015; nonetheless, emissions continue to rise by 20 % (Ahmad & Zhang, 2020). Meanwhile, Climate Change Conference 2021 (COP 26) that had been conducted by United Nation

(UN) also highlighted on several circumstances that better that Paris Agreement in which almost 90 % had been covered by a net – zero target (Lord, et al., 2021).

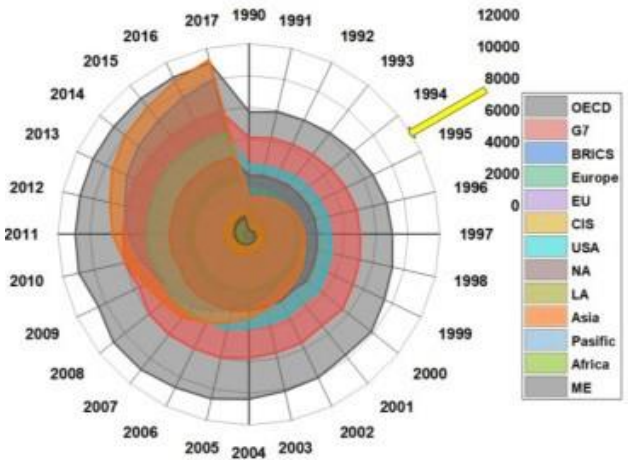

Figure 1.2 World's total electricity generation (TWh)(Ahmad & Zhang, 2020)

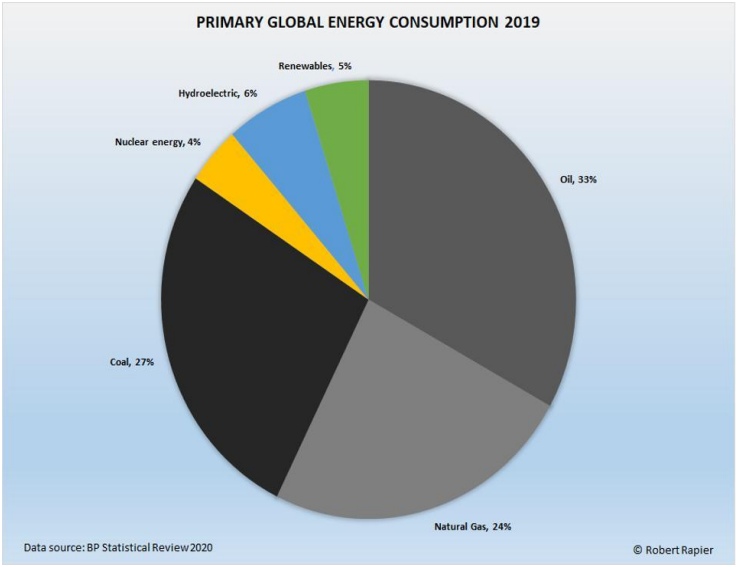

Figure 1.3 World's primary energy consumption in 2019 (Robert, 2020).

Figure 1.4 shows that the total percentage of renewable energy generation has been steadily increasing since the end of the 2000s, reaching over 25% in 2017. In the EU, the United States, India, Japan, and China, stringent environmental policies have a significant impact on solar and wind energy development**.** Without a doubt, the share of renewable energy in the entire generation of electricity is gradually increasing daily (Ahmad & Zhang, 2020). As well as that bulk of employment sources are increasing perpendicularly with large number of renewable energy sources.

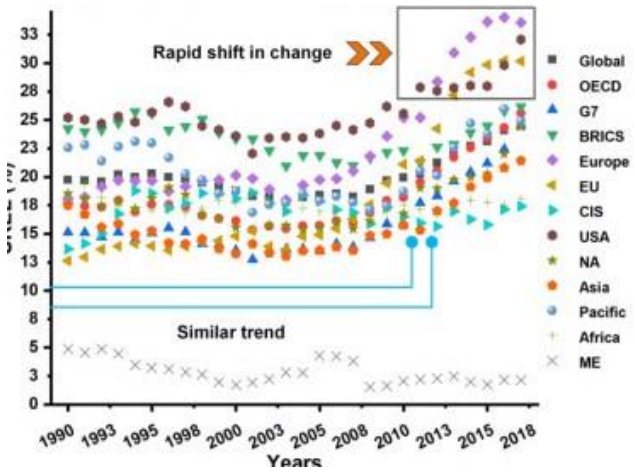

Figure 1.4 Share of renewable in electricity production (%)(Ahmad & Zhang, 2020).

In recent years, there has been renewed interest in renewable energy whereas Malaysia also been on the right track. Malaysia's 11th Malaysia Plan emphasized the importance of pursuing green growth for long-term sustainability and resilience. Renewable energy is a major driver of increased total installed capacity, and green building construction is promoted under Malaysia's Carbon Reduction and Environmental Sustainability Tool (Ministry of Economic Affairs, 2018). It has been implemented by Malaysia government on 2016 through National Energy Efficiency Action Plan (NEEAP) to audit, retrofit and energy management projects for 13 government, 103 industrial and 84 commercial buildings. To date, there has been a utilization of renewable energy such as biomass, micro- and pico – hydro and solar will be used particularly on remote areas based upon Pillar Three of 11th Malaysia Plan (Ministry of Economic Affairs, 2018). Moreover, the Pillar Five in 11th Malaysia Plan highlight on reducing dependency on fossil fuels onward to explore new renewable energy, namely biomass, biogas, mini hydro and solar photovoltaic (PV).

Significantly by 2030, national commitment to reduce GHG emissions intensity to GDP by 45% will be success through development of skilled personnel in the field of renewable energy. As conclusion, Malaysia is one step moving toward application of Sustainable Development Goal (SDG) as shown in **Figure 1.5**.

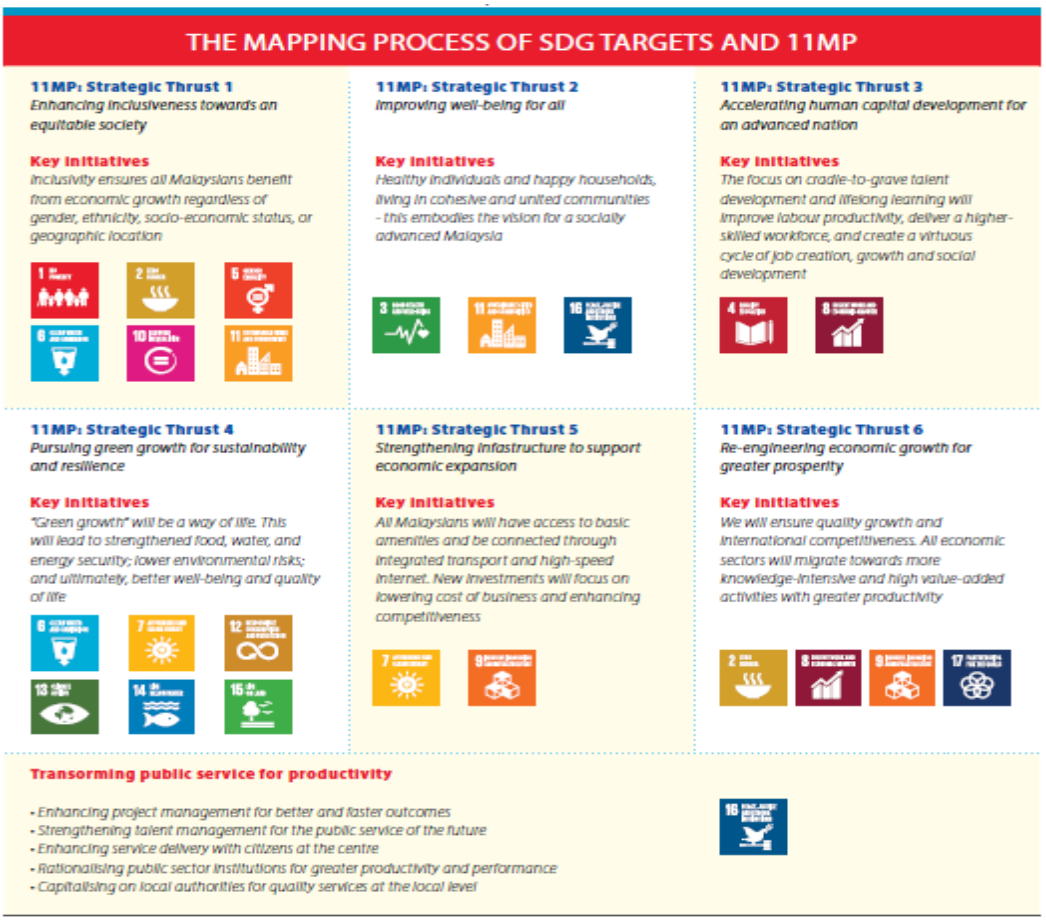

Figure 1.5 Mapping process of SDG targets and Eleventh Malaysia Plan(Economic Planning Unit, 2017).

The major issue arises when non-renewable energy becomes completely reliable, causing prices to skyrocket and as previously stated, negatively impacting the environment. As a result, a new solution with a better conclusion from green energy is required. Microbial fuel cells (MFCs) which convert biochemical energy consisted in the substrate to electrical energy can be a part of it. This green energy technology capable of utilized any type of carbon waste that seen to be impactful on community, government, and environment. However, there is an immediate need to investigate low-cost materials and resources for usage in MFCs to generate power.

1.2 Problem Statement

The dewatered sludge contains an enormous energy reserve that has gone unnoticed. They have made of biodegradable organic matter, and the energy they contain might be recovered (Becker & Fischer, 2012; Nimje et al., 2012). It was reported that sludge had been developed and applied onto soil hence usually as fertilizer It's a promising energy source, and if the energy can be recovered, the treatment facility can run on its own power (J. R. Kim et al., 2007). Dewatered sludges generated daily from the wastewater treatment plant were analyzed for it capabilities to support growth of the electrogenic bacteria (EB) for the electricity generation (Huang et al., 2014). Instead of harming the environment, dewatered sludge can be used as a value-added substrate.The efficiency and economic viability of converting sludge to bioenergy are determined by its features and components (You-Zhao Wang et al., 2013).Waste companies can become more efficient both financially and environmentally by harvesting the energy from sludge.

Furthermore, implementation of mediator such as potassium ferricyanide that facilitates electron transfer to the immersed electrode must eliminate due to major side reaction at low pH generating toxic and hazardous HCN. This research converts usage of mediator and chemical membrane into mediator – less which more environment and low in price. Despite the numerous studies that have been carried out on electricity generation, there was less reported on research of MFC basis on mediator-less, membrane-less and air – cathode which can give advantage as mentioned above. Plus, there was lack of optimisation information about the influence of operational conditions on the performance of the MFC. Electricity generation and stabilization of dewatered sludge (COD removal) in ML – MFC can be influence by both physical and chemical parameter (pH, moisture content, electrode distance and temperature). In this regard, these

parameters need to be examined to get optimize operating condition for ML – MFC. Instantly this research was carried out to investigate the optimum operating condition for ML – MFC that can contribute for electricity generation and COD removal.

1.3 Objectives

The main goal of this research is to investigate the performance of ML-MFC using dewatered sludge as the substrate. In view of such potential, this study was carried out based on following the objectives:

i. To determine the proximate composition of dewatered sludge from different wastewater treatment plant (IWK Juru and IWK Butterworth).

ii. To optimize the operating condition (pH, electrodes distance, moisture content and temperature) in a batch ML – MFC for generation of electricity and COD removal using OFAT and RSM methods.

iii. To assess the electricity generation by ML – MFC in series circuit using the optimized condition.

1.4 Significance of Study

In this present study, dewatered sludge was tested for micronutrients, macronutrients, and trace components that affect toward performance of ML – MFC significantly on electricity generation. This research used two optimisation approaches, One-Factor-At-A-Time (OFAT) and RSM:CCD, to identify the best power generating performance by altering different operating parameters (pH, moisture content, electrode distance and temperature). This research will also provide an added value of electricity basically by implementation of series of MFC whereas the voltage of the MFC is the sum of the individual MFC voltage.

1.5 Thesis Organization

Chapter 1 comprises of description on lack of access to clean electricity. The chapter also highlighted on problem statement, research objective, significance of study and thesis organization.

Chapter 2 initiates with the elaboration on different types of power generation based for both non-renewable and renewable energy sources. The chapter also briefly reviews on related factors that may affect the performance, theories, method, and analyses on mechanism of MFC and types of MFC architecture. Perhaps this chapter also describes on history of MFC, advantage of MFC compared to anaerobic digester and types of microorganism that previously used.

Chapter 3 starts with the elaboration on general materials and methods used in this work on growth of the bacteria, COD removal and electricity generation from ML – MFC will be presented in detail. Some of the specific method engaged such as analytical methods in specific parts of the work, will be explained separately in the following chapters.

Chapter 4 presents results and discussions on the experimental data regarding composition of dewatered sludge from different wastewater treatment plant (IWK Juru and IWK Butterworth), parameters using condition One-Factor-At-A-Time (OFAT) and RSM Response Surface Methodology (RSM) CCD with the elaboration on materials and designs of ML – MFC depending on substrate used which is dewatered sludge. This chapter focuses on optimization of biomass, power density and COD degradation using both methods in ML – MFC.

Chapter 5 concludes the electrogenic bacteria reaction in ML – MFC involved in electricity generation and COD degradation. End of this chapter will be

summarized on the series circuit electricity generation and effect of trace elements, for both RSM CCD and OFAT condition; pH, electrode distance, moisture content and temperature. Lastly recommendation for future ML – MFC research also will be comprise in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Desolation impact of global warming had realized many world authorities where countries and people work together to reach the Paris agreement target well (IEA, 2017). In addition, one hundred ninety – three countries signed the Sustainable Development Goals (SDGs) in September 2015.Malaysia is known as a developing country that is influenced by strong demand from industrial and residential sectors thus demand electricity will be increased up to 274 TWh by 2030. Moreover, the government also realized that both global warming and climate change would directly hit Malaysia's economic survival as a developing nation (Ali et al., 2012). Malaysia has also got involved with the transition to the implementation of renewable energy since 2000 whereas there are several policies and actions such as the eighth Malaysia Plan (MP), Small Renewable Energy Program, National Green Policy, and National RE Plan 2010. These all to contribute reducing dependency on fossil fuels and towards environmental integrity and energy security (Phun et al., 2017).

2.2 Non - Renewable Energy

Non–renewable energy or also called brown energy obtained from static stores of energy that lay hidden unless released by human interaction for example are fossil fuels of crude oil, coal, natural gas, and nuclear fuels. All these sources of energy must initially have an isolated energy potential and external action then can initiate the supply of energy for practical purposes.

2.2.1 Crude Oil

Fundamentally crude oil is a natural product that is extracted from mineral deposits and consists essentially of many different non–aromatic hydrocarbons. Historically the origin of crude oil stated in Baku (Azerbaijan) in 1837 when the first commercial oil refinery was established to distill oil into paraffin that was used as heating oil and lamp. About 10 years later, Baku accounted to reach over 90% of the world's oil production, mostly going to Iran (Persia). The price quick rise tremendously from roughly about $0.49 a barrel in 1861 to $6.59 a barrel in 1865. This oil is mainly found in reservoirs under the ground with dark in color hardly a mixture of hydrocarbons that exists as a liquid when brought to the surface when compared to petroleum which broad category of product. Electricity is generated wisely by process steam that rotates the turbine, assisted of shell and tube exchangers as the heat recovery units. The heat exchangers in the crude preheat train in refineries are prone to fouling (Deshannavar et al., 2010) hence there are a lot of lost and may lead to shutdown of plant. In order to achieve those definitive on legal authorities, electricity that been produced from crude oil is expensive compared to other fossil fuels such as gas or coal. Either carcinogenesis or mutagenesis, crude oil can rattle physiological

and biochemical activities to some organs and genetic material (Onwurah et al., 2007). Various studies report that the spillage and leakage of crude oil may lead to pollution especially soil pollution as high as 10% w/w (Guwahati et al., 2003) due to complex mixtures of several thousands of hydrocarbons (Onwurah et al., 2007).

As January 2010, Malaysia held proven oil reserves of 4 billion barrels which 56% of the reserves in Peninsula and others 19% exist in East Malaysia. The share of oil in the generation mix was seen to drastically declined about 0.2% in 2010 (Ali et al., 2012). Several investigations on Malaysia reserves crude oil reported a deficit from 2015 to 2017 about 1181 billion Barrel which are Peninsular (536 billion Barrel), Sarawak (403 Billion Barrel) and Sabah (242 Billion Barrel). In 2017, 0.343 TWh (30%) of crude oil been supplied as primary energy from total primary energy supply 1.143 TWh (Statistics, 2019).

2.2.2 Coal

Malaysia had found three geographical provinces of coal which stated in Sarawak, Sabah and Peninsular Malaysia. Average of 9.5% Malaysia's electricity was contributed by coal in 1992 (Pei, 1993). Pollution had arisen from the usage of coal to generate electricity thus there are a lot of environmental audits that emphasized ambient air, thermal effects of cooling discharge, marine life and surface water. For example, fly ash that was collected from electrostatic precipitator later stored in silos use as raw material in cement manufacture. Indeed, the cost for generation of coal-based to compete with gas because of the inaccessibility of the coal deposits, inadequate infrastructure, and the projected small-scale operation of mines if planned dedicatedly to supply coal only to local power stations.

Statistically electricity production by ASEAN region coal as sourced initialed on 1990 up to 20 000 GWh while on 2015 the usage linearly increased up to 1 million GWh thus one – third of all emission of CO_2 due to increment of coal usage in South – East Asia (UN ESCAP, 2019). Lastly within the energy mix, ASEAN's primary energy supply had recorded coal as raised tripled since 1990 (UN ESCAP, 2019). It has noted that in 2017 0.241 TWh (21.1%) from total primary energy supply 1.143 TWh are sourced by coal due to that increment of electricity generation mix about 13 233 GWh from 2015 to 2018 from total 26 905 GWh (Statistics, 2019).

2.2.3 Natural Gas

Remains of decayed plants and animals had built thick layers called organic material that sometimes refers as a compound consist mainly carbon. Addition of pressure and heat changed some of this organic material into coal, while some to oil (petroleum) and some into natural gas. Natural gas contained smaller amount of natural gas liquids which are hydrocarbon gas, a largely of methane (CH_4), ethane (C_2H_6) also with propane (C_3H_8) and butane (C_4H_{10}) and also consisted non – hydrocarbon gases such as carbon dioxide and water vapor. Usage of natural gas widely as industrial and domestic fuel, generate energy to heat up meal and electricity.

In 2010, Malaysia was the world's tenth-largest holder of natural gas with proven reserves of 83 trillion cubic feet (Tcf), which found off the east coast of Peninsula Malaysia 38%, 48% offshore Sarawak and the enduring offshore Sabah 14%. Comprehensively 57% from 26 265 MW of total estimated plant generating capacity came from natural gas until end of 2010 (Ali et al., 2012).

Statistically, the production power which natural gas as a source in Malaysia started in 1995 below 100000 GWh. Later in 2015, Malaysia's power generation by natural gas was peak up to 300000 GWh (UN ESCAP, 2019). As well as that both Peninsular and Sabah used 51% and 72% of natural gas to generate electricity respectively (Lumpur, 2018). Thus the production of natural gas in 2015 was about 62,119 kilogram of oil equivalent (ktoe) which is approximately 722 444 MWh (Lumpur, 2018). Lastly within the energy mix, ASEAN's primary energy supply had recorded natural gas raised tripled since 1990 (UN ESCAP, 2019). Previous studies of natural gas demonstrated a deficit of 17 515 trillion Standard Cubic Feet (TSCF) which Peninsular Malaysia 6834 TSCF, Sabah 2485 TSCF, Sarawak 8196 TSCF from 2015 to 2017. In 2017, the primary energy supply by fuel type for natural gas showed 41.9 % (0.479 TWh) contradicting the amount in 2015 which is 0.487 TWh proportionally with an electricity generation mix deficit of about 1910 GWh (Statistics, 2019).

The main obstacle in the use of non-renewable energy is adverse for the environment and upsets Earth's "carbon budget" through burning fossil fuels later they released carbon dioxide into atmosphere that keeps heat in Earth's atmosphere, a process called the "greenhouse effect". Similarly burning of coal, toxic gases and pollutants into atmosphere and environmental problems also occur catastrophic during extracting natural gas cause of mini – earthquakes, can become contaminated and risky.

Uncontrolled usage of these non – renewable energy resources may contribute to global crisis owing to liberation of CO_2 and various toxic gases to the environment. Since few decades ago, various research and finding from scientists are look up and focusing on renewable energy from solar radiation (sunlight), wind power, hydropower (river or damn), geothermal heat,

biomass and other to alleviate and carter the environmentally related issues which mainly from non – renewable energy.

2.3 Renewable Energy

Widely renewable energy perceived with term of standard of living, sustainability, and security thus this energy obtained from endless flows and naturally repetitive of energy occurring in the local environment. Interestingly renewable energy or green energy may developed sustainable, defined as living, consuming and producing in a manner that meets the needs of the present without negotiating the ability of future generations (Sataloff et al, 2015). Report by (Martha Ekkert, 2018) highlighted that in order to achieve 2℃ climate goal, increment in the share of renewable energy in the final energy consumption from 19% in 2017 to 65% by 2050. Renewable energy can be categorized as solar radiation (sunlight), wind power, hydropower (river or damn), geothermal heat, biomass and other such continuing resources.

2.3.1 Solar

The energy basically obtained from solar radiation which linked by the Earth and the Sun. Solar radiation reaches the Earth's surface at a maximum flux density (irradiance) of about 1.0 kW/m^2 in a wavelength band between 0.3 and 2.5 μm. The special distribution called shortwave radiation is determined by the -6000 K surface temperature of the Sun. The greatest contribution of technology in 2017 was nominated to solar photovoltaic (PV) which have new installed capacity (at least 98 GW) (Hales, 2018). It has been reported that China, the United States, Japan, Italy and Germany are the countries with the most installed capacity of solar PV.

Solar considering as national energy supply in United Kingdom about 30% is used for heating within building besides Australia also used about 20% for heating fluids. Again evolvement of solar PV can initiate the climate goal of 2℃ from around 1% of total electricity generation in 2015 to 22% in 2050 (Martha Ekkert, 2018). The extent to which solar PV generation and concentrated solar power give an investment of roughly 7 trillion USD (Solaun & Cerdá, 2019). Likewise, Kabir (2018) holds the view that high investment costs constitute an important barrier for the upscaling of solar generation. From 2015 to 2017, solar has recorded an increment for primary energy supply in fuel type by 0.0002 TWh. Moreover by the end of 2017 total solar installed about 357.6 MW which allocated to Peninsular Malaysia for 318.1 MW, Sabah 39 MW and Sarawak 0.5 MW had installed (Statistics, 2019).

2.3.2 Wind

Electricity can be generated by wind energy via wind turbines, again this is highly dependent on location thus Malaysia faces greater challenges in developing wind energy because situated in a low wind speed region. Besides usage of Wind Turbine Generator (WTG) with suitable condition may affected existing wind speeds at offshore but it is the most expensive ways of generating electricity due to the logistics of construction, maintenance and connection (Ho, 2016).

In 2017, generation of energy from wind accounted for 559 GW for installed capacity and offshore capacity worldwide which majority comes from China, the US, India and Germany (Hales, 2018). Expenses for levelised cost are reduction slightly from 0.08 USD/kWh in 2010 to 0.06 USD/kWh (IRENA, 2018). Previous study by (Hdidouan & Staffell, 2017) have found that high capital expenditure and low operational costs are two major problems usually faced by wind farms.

2.3.3 Hydro

Hydro or water energy is the most established, long-lasting, and widely used renewable energy source for electricity generation. Global leaders in annual installed capacity are Brazil, China, the US and Canada (Hales, 2018). Moreover Asia, Central Africa and America are the greatest gross potential areas for hydroelectric (Hoes et al., 2017). The installation for this energy usually came up with combination with flood control, the supply of water and with pumped storage of water for subsequent hydropower. The opportunities depend crucially on rainfall and topography to provide sufficient water fall and flow. It has been reported by Martha Ekkert, (2018) that total generation of hydro is expected to decline by 2050, owing to spike in energy demand and in other renewable technologies.

The scales are from (~kW) for hydro-turbines the earliest electricity in 1881 to (~GW) for hydropower capacity in 2008.Total worldwide installations continues rise at about 2% per year. Increment Malaysia's hydropower contribution up to 31.4% generation mix in 2010. Development of hydropower had been very slow and delayed because of great distance between the principal watersheds and the load centers, high initial costs, and low consumption (Ooi, 1986). In addition from 2015 to 2018, escalated of energy mix generation for hydro energy about 10 771 GWh (Statistics, 2019).

2.3.4 Geothermal

The heat that came from Earth's interior is called geothermal energy. This energy escaped as steam which is clean and sustainable. Resources of geothermal energy are located down deeper to the extremely high temperature of molten rock. Generally, this energy is used to cool off buildings, steam from reservoir to power a turbine thus electricity generated. The efficiency of electricity generated from geothermal steam ranges from 10 to 17% which is three times lower than nuclear or fossil–fuel plant efficiency. This comparison showed that geothermal plants had the lowest efficiency values due to the low temperature of the steam, generally below 250℃ (Barbier, 1997). Moreover, it also comes with costs significantly higher because the plant is plotted as an individual, therefore the quality of their resources and management needs to study. Additionally, the cost involves when the existing wells decline in productivity and thus need to replace (IRENA, 2018).

By the end of 2016, the deployment of geothermal reached about 12.7 GW through installed capacity globally. Increment up to 26% from installed geothermal plant energy in 2010 which can reach the capacity of 780 MW in 2016 (IRENA, 2018). The first geothermal power plant in Malaysia was discovered in Tawau in 2008. The geothermal energy by the implementation of flash steam technology came from a deep underlying neutral chloride fluid and a deep temperature of about 200 ℃(Ching Sien & Aini Osman, 2015). In 2016, Tawau Green Energy (TGE) was in the preparation stage to supply up to 37 MW of renewable energy to the state grid (Ching Sien & Aini Osman, 2015). Due to no major development progress on the project, the geothermal plant has been revoked by Malaysia's government (Aziz, 2018).

2.3.5 Biomass

Biomass is defined as originating from indigenous plants, animals and microorganisms also non – fossilized but not limited to products biodegradable organic material by – products residues and waste from municipal waste and agriculture industrial originating from Malaysia.

In Malaysia, Federal Land Development Authority (FELDA) had managed the Sahabat Biomass – EFB Power Plant in FELDA Sahabat. This plant also called as Sahabat Biomass Cogeneration Plant (SBCP) has generates up to 7.2 megawatts (MW) of electricity, which has the potential to provide power up to 4000 houses. Biomass has chronicled an escalated for primary energy supply in fuel type by 0.0002 TWh from 2015 to 2017. In addition biomass that been installed by the end of 2017 about 748.2 MW which allocated to Peninsular Malaysia for 403.2 MW, Sabah 29.5 MW and Sarawak 49.5 MW (Statistics, 2019).

As indicated by Ali (2012) which the increment amount of solid municipal solid waste (MSW) shown the growth of population whereas about 9 million tons per year. Daily generation estimated around 24,650 tons of MSW averagely. Abundant of biomass had initiated Malaysia's government a National Biomass Strategy 2020 (NBS2020) as stated in **Table 2.1** which shown a concrete pathway on biomass utilization. This NBS2020 projected an opportunities in the biomass value chain for utmost RM 30 billion (USD 6.98 billion), creation of 66,000 new high – value jobs and 12% plus on potential reduction in carbon emissions (Oh et al., 2018).

Table 2.1 Thrust of energy policies and initiatives in Malaysia.

Year	Policy	Thrust/Objective
1975	National Petroleum Policy	Ensure optimal use of petroleum resources via regulation of ownership and management of the industry including related economic, environment safeguards and social.
1979	National Energy Policy	Achieve supply and utilization of energy resources with environmental considerations.
1980	National Depletion Policy	Guard against over – exploitation and hence dependency on crude oil and natural gas.
1981	Four – Fuel Diversification Policy	Strategize generation mix as based on oil, gas, hydro and coal.
1998	National Mineral Policy	Utilize locally sourced coal.
2001	Five – Fuel Diversification Policy	Recognize renewable as fifth fuel in generation mix.
2001	Small Renewable Energy Power (SREP) programme	Encourage small private power generation projects using renewables.
2009	National Green Technology Policy	Use green technologies and promote cogeneration and renewable in power generation.
2010	New Energy Policy	Enhance energy security to include economic, environment and social considerations.
2011	Renewable Energy Act	Enhance feed – in – tariff (FiT) scheme for RE.
2011	National Biomass Strategy 2020	Recognize use of biomass waste for biofuels.