Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF MICROBIAL FUEL CELL USING FOOD-WASTE IN GENERATING ELECTRICITY

AHMAD AMIRUL FITRI BIN ABDUL RASHID

Bachelor of Electrical Engineering Technology with Honours

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AHMAD AMIRUL FITRI BIN ABDUL RASHID

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33 JALAN KE 3/1,
PERIDOT PRECINCT KOTA EMERALD,
48000, RAWANG,
SELANGOR.

MOHAMAD NA'IM BIN MOHD NASIR
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan Elektrik Dan Kejuruteraan Komputer
Fakulti Teknologi Kejuruteraan Elektrik Dan Elektronik
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ABSTRACT

In this modern time, electricity is an essential resource to power all sorts of devices from a lightbulb that shines the room, to powering an electric vehicle used for transportation. Various methods have appeared throughout the ages to generate electricity with minimum losses. Biomass is a renewable energy that produce large amount of electricity from organic materials, but has low efficiency. One of the underrated electricity generation in renewable energy is the microbial fuel cell (MFC) technology which also use organic materials and produce low amount of electricity, but much more efficient. This project aims to develop MFC for generation of electricity from food waste. In specific terms, food waste used in this project are leftover rice. A variety of materials for anode and cathode is available, but the materials used will be based on research. External circuit is included in the system as well to prove the MFC generates power. Upon completion in constructing the system, it is expected to generate power to fulfill its purpose as a microbial fuel cell. The project shows an eco-friendly renewable energy source that can be applied as a small fuel cell in a household or construct it in a large plant to power a town.

ABSTRAK

Pada zaman moden ini, elektrik adalah sumber penting untuk semua jenis peranti sama ada lampu yang menyinari bilik, ataupun enjin kenderaan elektrik yang digunakan untuk pengangkutan. Pelbagai kaedah telah muncul sejak dahulu lagi untuk menghasilkan elektrik dengan mengalami kerugian yang kurang. Biomass adalah tenaga yang boleh diperbaharui dan boleh menghasilkan tenaga elektrik besar daripada bahan organik, tetapi kurang cekap. Salah satu sumber tenaga yang boleh diperbaharui tetapi jarang guna adalah microbial fuel cell (MFC) yang mana ia menggunakan bahan organik untuk menghasilkan elektrik dalam kadar kecil, tetapi lebih cekap daripada Biomass. Tujuan projek ini adalah untuk membangunkan penggunaan MFC menjana elektrik daripada sisa makanan. Secara spesifik, sisa makanan yang digunakan dalam projek ini adalah sisa nasi. Pelbagai bahan dan bentuk untuk elektrod anod dan katod yang boleh guna untuk MFC, tetapi bahan yang dipilih adalah berdasarkan kajian. Litar elektrik bersambung dengan anod dan katod MFC untuk membuktikan bahawa teknologi ini menghasilkan tenaga. Setelah selesai pembinaan sistem, ia dianggarkan agar MFC menepati tujuannya untuk menghasilkan tenaga. Projek ini menunjukkan sumber tenaga yang boleh diperbaharui dan mesra terhadap alam sekitar boleh digunakan sebagai sel bahan api sama ada untuk kegunaan satu rumah sahaja, ataupun menjadi penjana elektrik untuk menghasilkan kuasa kepada sebuah pekan yang tiada sambungan dengan grid elektrik.

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CHAPTER 1

INTRODUCTION

1.1 Background

Organic wastes that are mismanaged have always been detrimental to the environment and harmful towards human's health. Therefore, modern societies would make use of such waste to produce electricity. The most popular process to convert organic substances to electricity is biomass. It generates large amount of power, but with low efficiency. However, there is another method of converting organic substance to electricity. This method is called microbial fuel cell and is rather underrated. Microbial fuel cell is considered to be as an alternative source for power generation that is clean, efficient process, reliable, and does not generate any toxic by-product [1].

It is a technology that makes use of microorganism's metabolism and converts it to electrical energy. The microbial fuel cell (MFC) consists of several main components which are the anode electrode, cathode electrode, separator, and substrate. MFC have the same design as batteries and can be describes as so. Both have two electrodes, a barrier or separator, and electrolytes [2]. For MFC's electrolytes, the substrate would be in the anode compartment, while the cathode compartment consists of only air or filled with water as long there is oxygen. Both compartments are separated by a barrier made of membrane which should be permeable to protons. Electrons can travel between compartments as well, but only through an external circuit where each end is connected to the electrode. There are several variables that affect the output generated by MFC.

The MFC for this project will focus on using leftover rice as substrate. Other variables that affect the power output will also be considered as long it is within reason and capability. This is to ensure maximum power output is generated as possible with limited resources.

1.2 Problem Statement

As stated before, if organic waste is not treated or handled properly, it will cause harm to people and environment. Such organic waste is food waste, where it is inevitable to stop it from being produced. Not to mention, a household also requires electricity to move on with their daily lives. Therefore, a renewable energy plant exists to solve the crisis of mismanagement of organic waste and generate a large amount of power for residential, commercial, or industrial usage. This renewable energy source is biomass. Although it can produce large amount of power, there is significant heat loss due to combustion and results to low efficiency. The cost of installation is high and can only be used as a plant that generates power for more than one house. However, another eco-friendly alternate energy source is available to compensate for such loss. This alternate energy source is MFC, where it has very high efficiency compared to biomass. It may generate very small power compared to biomass, but the cost is much cheaper and can be installed in each house independently. The materials needed to create MFC are mostly unavailable or very expensive. Nonetheless, there are various methods and materials that can be replaced to counter these problems. The MFC can use the organic waste such as leftover food as substrate or fuel and generate power.

1.3 Project Objectives

a) To develop a food waste-based, specifically leftover rice, for electricity generation in Microbial Fuel Cell.

b) To develop a Microbial Fuel Cell that is effective with limited materials for the components.

c) To investigate the performance of Microbial Fuel Cell daily when using leftover rice as substrate.

1.4 Scope of Project

The scope of work for the project includes conducting experiment and project runs, collect available data, and analyze it to study of nature of the microbial fuel cell. As mentioned the main components for MFC are electrodes, substrate, and separator. The anode and cathode compartments will be a medium sized container. There are two electrodes required, which are anode and cathode. In this project, both electrodes will be made of graphite with both surface areas equal. As for the substrate, the anode chamber will consist of leftover rice mixed with a substantial amount of contaminated water that consist bacteria. The cathode chamber will contain water mixed with potassium permanganate ($KMnO_4$). The $KMnO_4$ is used to oxidize the water at cathode chamber. The separator that connects both anode and cathode chamber will be a standard salt bridge which is made of water mixed with agar ($C_{14}H_{24}O_9$) and salt (NaCl). The results obtained are still low, but relatively higher than previously expected. The project can be seen as a homemade renewable energy source, or a prototype for a much larger scale useage.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Ever since human population has risen drastically since the last century, the demand for electricity is also at all-time high. Alongside that, waste produced is also high and can lead to harming the environment. To counter these two problems, MFC is one of many methods to the solution. Its key aspect is to handle the organic waste by human, specifically food waste, while at the same time generate electricity. Aside that, MFC can also filter the fuel or substrate and produce water. This chapter provides detailed research on MFC designs, food wastes as potential substrates, and electrodes material selection.

Several MFCs have been applied previously by various parties. However, MFCs were only applied for practical experiment instead of residential or commercial use. There were not many MFCs sold as a complete set in the market due to more research needed to be conduct. With detailed research on specific MFC designs, substrates, electrodes, and separator, an efficient eco-friendly renewable energy source can be installed in a residential premise if planned carefully as well.

2.2 Microbial Fuel Designs

In order to develop an efficient MFC, a thorough inspection on which design to use is important. As time passes on, MFC has been developed into several new designs. These newer designs have their own additional uses and flaws. Nonetheless, they stem from the original MFC design.

The MFC designs mentioned are standard MFC, Microbial Electrolysis Cell (MEC), Microbial Desalination Cell (MDC), and Microbial Electrosynthesis Cell [3]. By referring to **Figure 2.1**, the schematics of these designs can be seen.

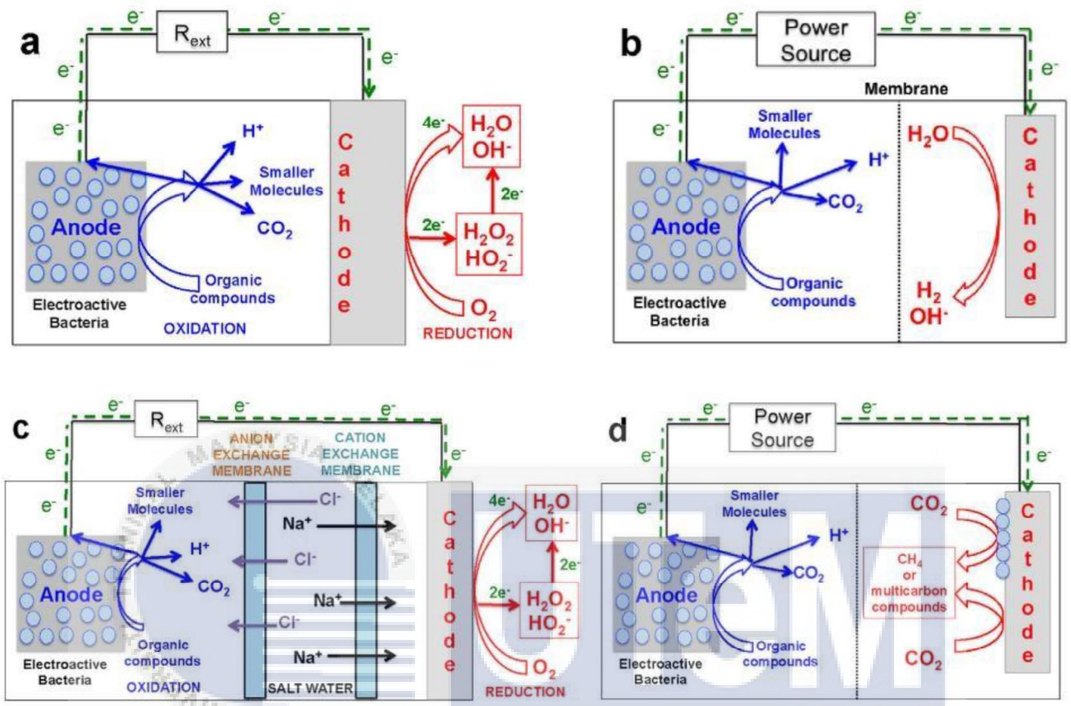

Figure 2.1. (a)Standard microbial fuel cell (b)Microbial electrolysis cell (c)Microbial desalinationcell (d)Microbial electrosynthesis cell [3]

According to the figure above, the standard MFC and MDC is connected to load to close the circuit. Thus, electrons will be able to flow and produce current. However, MEC and Microbial Electrosynthesis Cell require external source of electricity to activate them. The external sources power is only in small amount and will be reimbursed with electricity produced by the cell and can be seen as self-sustainable.

2.2.1 Standard Microbial Fuel Cell

MFC is a one of many renewable energy sources that can be further explored for suitable and efficient applications. It is mostly self-sustainable and friendly towards the environments. The process involves respiration of microbes in a chamber filled with substrates that will eventually produce electricity [4]. To simplify, it converts chemical energy to electrical energy. Normally, there would be two chambers in MFC, anode chamber and cathode chamber and commonly known as double chamber MFC. The schematic of MFC can be referred in **Figure 2.2**.

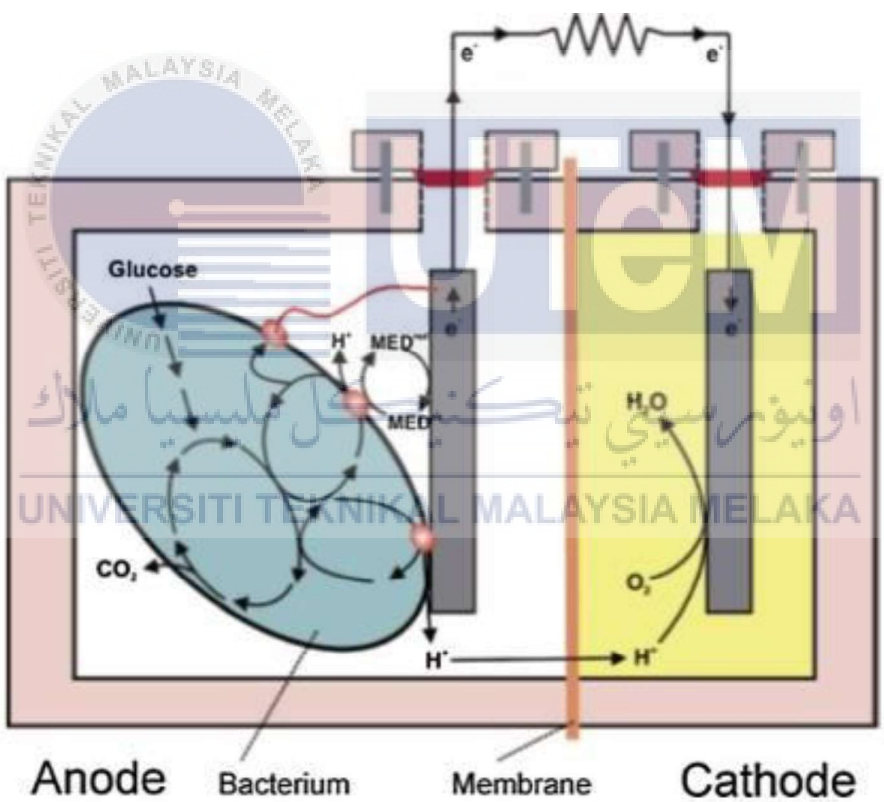

Figure 2.2. Double/dual chamber MFC [5]

The anode chamber is sealed air tight to prevent external oxygen from entering. Both chambers are separated by a membrane that is only permeable to protons. Electrons will travel through closed circuits connected externally. In anode chamber, microbes or bacteria will consume substrates and water to produce hydrogen ion and electrons. As for the cathode chamber, it will receive the hydrogen ions and electrons only to react with oxygen. The product in this chamber would be water [6]. Electrons travelled between both chambers and passing through load produced current. The chemical reactions involved in anode chamber, cathode chamber, or overall can be seen in equations below.

Anode reaction: $C_2H_4O_2 + 2H_2O \rightarrow 2CO_2 + 8H^+ + 8e^-$ [2]

Cathode reaction: $2O_2 + 8H^+ + 8e^- \rightarrow 4H_2O$ [2]

Overall cell reaction: $(CH_2O)_n + nH_2O \rightarrow nCO_2 + 4nH^+ + 4ne^-$ [2]

The MFC can generally be seen as a battery. It consists of two electrodes and electrolyte, which can be commonly be found in most batteries [2].

In some cases, MFC can also be designed with only one chamber, or commonly known as single chamber MFC. This MFC does not require the separator or a membrane. It does, however, still require two electrodes. This design is used because membranes in MFC may result in protons to gather in anode chamber. This will reduce the pH value of substrates and lead in deterioration of microbes' performances [7]. **Figure 2.3** shows the diagram of a single chamber MFC.

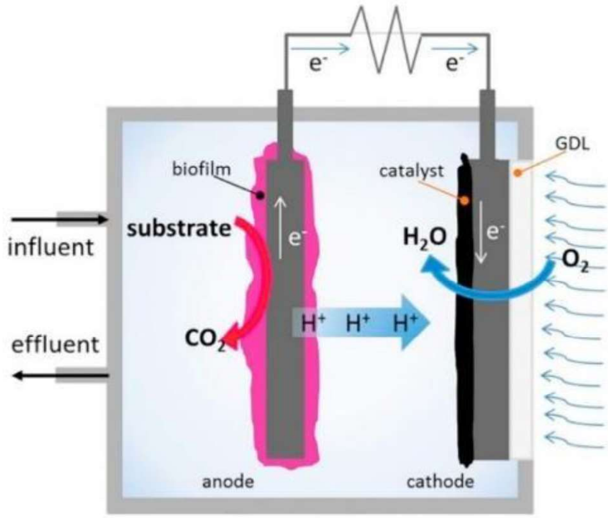

Figure 2.3. Air cathode single chamber membrane-less MFC [7]

2.2.2 Microbial Electrolysis Cell

In contrast to MFC, MEC require external energy to actually activate it and does not produce electrical energy. The power input is relatively small, around (>1.2V), but the product of MEC is high concentration of hydrogen gas. Installation of MEC is usually combined with other renewable energy sources to achieve self-sustainability. Such devices may be solar power, thermoelectric-power, or MFC itself [8]. The design of MEC is similar to that of MFC, only that instead of load at the external circuit, it is connected with external sources. **Figure 2.4** shows a simple diagram of MEC.

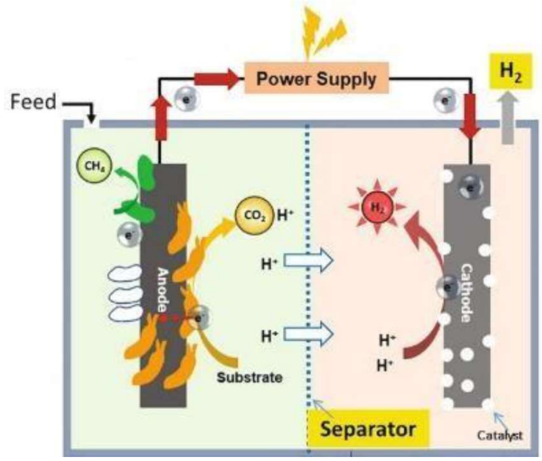

Figure 2.4. Microbial electrolysis cell [8]

The MEC is also separated into two designs, single-chambered MEC and two-chambered MEC. Both designs, however, end up with the same products and requirements. As with MFC, single-chambered MEC also does not have separator as to prevent accumulation of protons in anode chamber. Disturbances in pH value of both chambers may affect MEC performances.

Since the final product of MEC would be huge amount of hydrogen gas with small amount of power used, **Table 2.1** shows the chemical reaction that occurs in both chambers. The chemical reaction may vary depending on the type of substrates used [8].

Table 2.1. Table of chemical reactions in anode and cathode chambers [8]

Oxidant/reductant	Redox Reaction
Anodic reaction (oxidation)	
CO_2/Acetate	$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$
CO_2/Glucose	$C_6H_{12}O_6 + 12H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$
CO_2/ Formate	$HCOO^- + 2H_2O \rightarrow HCO_3^- + 3H^+ + 2e^-$
CO_2/ Glycerol	$C_3H_8O_3 + 3H_2O \rightarrow 3CO_2 + 14H^+ + 14e^-$
CO_2/ Lactate	$C_3H_6O_3 + 3H_2O \rightarrow 3CO_2 + 12H^+ + 12e^-$
CO_2/ Propionate	$C_3H_6O_2 + 4H_2O \rightarrow 3CO_2 + 14H^+ + 14e^-$
Cathodic reaction (reduction)	
H^+/H_2	$2H^+ + 2e^- \rightarrow H_2$

MEC may also contain methanogens in the anode chamber along with substrates. These are unwanted substances that is unavoidably present in the chamber. Methanogens will consume the substrates instead of exoelectrogens and produce methane. This will seriously hinder the production of hydrogen gas in MEC. Though in some cases, MEC is also used to only produce methane and hydrogen gas, or methane only [9].

2.2.3 Microbial Desalination Cell

MDC is another design that stemmed from MFC. The structure of MDC is also identical to that MFC, with slight difference on the separator part. It is a combination of two electrochemical energies, which are MFC and electrodialysis (ED) cell. Its purpose is to treat wastewater, desalinate water, and generate electricity [10]. In MFC, the separator consists of a single separator such as salt bridge, size-selective separators, and ion exchange membrane (IEM). The IEMs are separated into two parts, which are cation exchange membrane (CEM) and anion exchange membranes (AEM) [5].

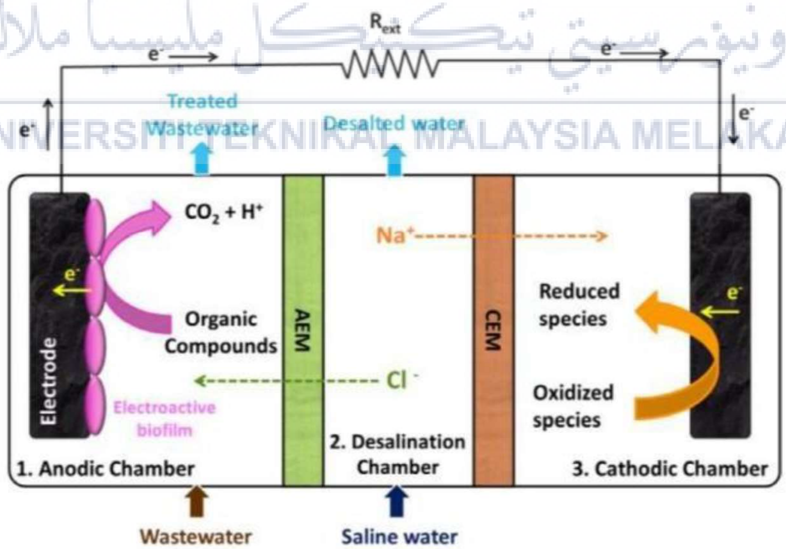

Figure 2.5. Diagram of MDC [10]

As for MDC, the separator is divided into three parts. They are AEM, desalination chamber, and CEM. **Figure 2.5** shows the diagram of basic MDC. The AEM is at the anode chamber, while the CEM is at the cathode chamber. The desalination chamber is where water is treated. Anode chamber is filled with organic substances, or substrates, while cathode chamber contains electron acceptors, such as oxygen at acid pH. Microbes consume substrates in anode chamber, thus leading flow of electrons from anode chamber to cathode chamber through external circuit. This leaves the anode positively charged and cathode negatively charged. In desalination chamber, chloride ion (Cl^-) will permeate to anode chamber through AEM, while sodium ion (Na^+) will permeate to cathode chamber through CEM. This process will result to water in desalination chamber being desalted [11].

2.2.4 Microbial Electrosynthesis Cell

Microbial electrosynthesis cell also originated from MFC. However, its purpose and function is the complete opposite to it. MFC produces electricity and water from microbes degrading substrates. The byproduct of this process is carbon dioxide in anode chamber. As for microbial electrosynthesis cell, it requires electricity, similar to MEC, and carbon dioxide to produce relevant substances such as methane [12].

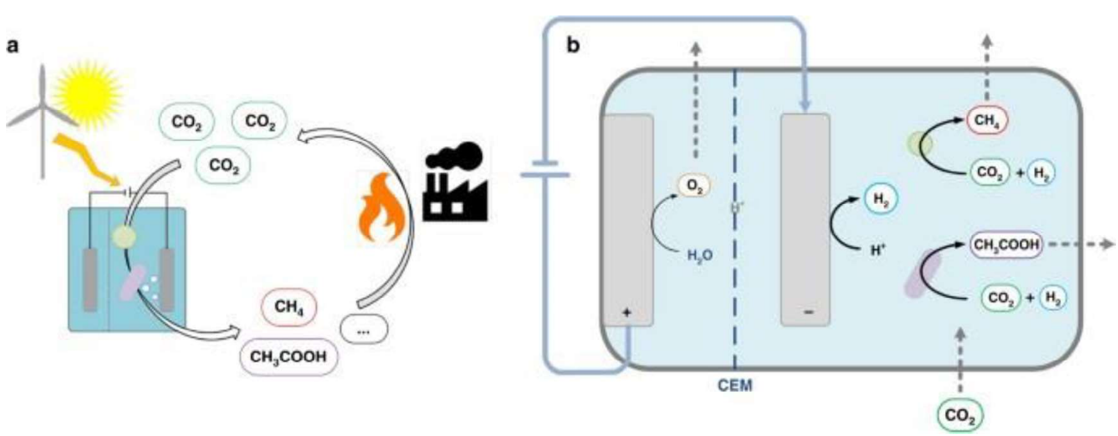

Figure 2.6. (a)Carbon cycle in industrial (b)Diagram of microbial electrosynthesis [13]

Other than methane, microbial electrosynthesis can also produce acetate or acetic acid [14]. **Figure 2.6.** (a) shows how factories produce carbon dioxides from combustion. These carbon dioxides will be used by microbial electrosynthesis cell to convert to acetic acid or methane from small external source input. The acetic acid and methane is then reused in factories for processing purposes.

The chemical reaction of microbial electrosynthesis in producing methane can be referred in equations below. Study shows only small amount of voltage (>0.2V) is needed to run the microbial electrosynthesis [12].

Anode reaction: $(CH_2O)n + nH_2O \rightarrow nCO_2 + 4ne^- + 4nH^+$ [12]

Cathode reaction: $CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$ [12]

2.3 Food waste

Food waste is the unwanted byproduct or leftover after humans consuming sustenance. These organic substances are an ethical issue and may endanger the social, economy, and environment if not managed properly. The mismanagement of food waste is one of the causes of food shortages. Although foods produced are sufficient in feed 7 billion people in the world, but 1.3 billion metric tons of food are lost waste or lost [15]. In a world filled with individualists and materialists, they neglect the need to counter food waste problems. These kind of people strive for self-happiness and ignore the needs of others.