Simultaneous Wastewater Treatment and Power Generation with Single Chambered Up-flow Membrane-less Microbial Fuel Cell

by

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LIST OF ABBREVIATIONS

ABRX3	Active Brilliant Red X-3B
AFM	Atomic Force Microscopy
AO7	Acid Orange 7
BOD	Biological Oxygen Demand
CEM	Cation Exchange Membrane
CE	Coulombic Efficiency
CNF	Carbon Nanofiber
CNT	Carbon Nanotube
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
DO	Dissolved Oxygen
EPS	Extracellular Polymeric Substances
FTIR	Fourier-Transform Infrared Spectroscopy
GC-MS	Gas Chromatography Mass Spectroscopy
HCl	Hydrochloride
HPLC	High-Performance Liquid Chromatography
HRT	Hydraulic Retention Time
KCl	Potassium Chloride
MFC	Microbial Fuel Cell
MWCNT	Multi-wall Carbon Nanotube
NaCl	Sodium Chloride
OCV	Open Circuit Voltage
OMC-AU CNT	Ordered Mesoporous Carbon-Au Carbon Nanotube
PEM	Proton Exchange Membrane
PPy-CNT	Polypyrrole Carbon Nanotube
Pt	Platinum
SEM	Scanning Electron Microscope
SUFML	Scaled-up Up-flow Membrane-Less
UASB	Up-flow Anaerobic Sludge Blanket
UFML	Up-flow Membrane-Less
UV-Vis	Ultraviolet-Visible Spectrophotometry

Rawatan Air Sisa Dan Penjanaan Kuasa Serentak Dengan Ruang Tunggal Sel Bahan Api Mikrob Yang Tidak Bermembran

ABSTRAK

Sel bahan api mikrob (MFC) adalah teknologi yang membolehkan penukaran tenaga kimia kepada tenaga elektrik daripada biomas. MFC adalah salah satu teknologi yang menjanjikan penjanaan tenaga bio hijau yang mampan. Perkembangan teknologi MFC telah diperluas kepada pelbagai aplikasi, seperti rawatan air sisa, rawatan pencemar bukan organik yang tertentu, bioremediasi sedimen dan biosensor. Tesis ini membincangkan potensi aliran atas MFC tidak bermembran (UFML MFC) untuk rawatan air sisa dengan pelbagai parameter konfigurasi dan pembolehubah. Objektif pertama dalam kajian ini adalah untuk mengkaji potensi dan mekanisma tentang inovasi terbaru UFML MFC dengan mengguna pelbagai jenis bahan karbon sebagai biokatod cecair. Penyiasatan lanjut dijalankan untuk menilai kesan pembentukan biofilm pada morfologi permukaan bahan karbon yang berbeza berdasarkan prestasi output kuasa dan pengurangan *chemical oxygen demand* (COD) dalam UFML MFC. Serpihan karbon, kertas karbon yang dimuatkan platinum, piring karbon dan *felt* karbon digunakan sebagai biokatod cecair. Output voltan untuk serpihan karbon (384 ±16 mV) tidak dijangka boleh dibandingkan dengan kertas karbon yang dimuatkan platinum (399 ± 9 mV). Peratusan pengurangan COD di rantau anod dan efluen untuk semua bahan katod masing-masing adalah sebanyak 75% dan 85%. Kawasan permukaan dan morfologi bahan katod boleh menjejaskan keupayaan perlekatan mikrob dan pemindahan elektron. Hasilnya menunjukkan bahawa penjanaan kuasa dan pengurangan COD telah dipengaruhi oleh bahan katod. Selain itu, UFML MFC digunakan untuk meneroka potensi dan mekanisma antara biodegradasi Acid Orange 7 (AO7) dan penjaan bioelektrik. Kecekapan penyahwarna AO7 adalah sebanyak 96%. Output voltan keseluruhan telah dipengaruhi oleh peningkatan dos Acid AO7. Walau bagaimanapun, peningkatan dos AO7 dan aliran 24-jam berterusan dapat membantu menurunkan aktiviti mikrob anaerob yang lain dan seterusnya menyebabkan lebih banyak elektron yang sedia ada boleh digunakan oleh penyahwarna AO7 dan penjanaan elektrik. Tambahan lagi, penyahwarna lanjut AO7 di rantau katod menunjukkan bahawa oksigen dan pewarna azo bersaing sebagai penerima elektron. Berdasarkan analisis UV spektrofotometer, pecahan ikatan azo AO7 dalam keadaan anaerobik telah mengakibatkan banyak sebatian aromatik yang lebih bertoksik. Kemudian sebatian aromatik ini boleh dipecahkan lagi ke dalam rantai pendek asid alifatik dan akhirnya terurai menjadi karbon dioksida dan air. Tambahan pula, sebahagian zat antara yang munasabah telah dikenal pasti dalam senarai laluan biodegradasi. Keputusan ini membuktikan bahawa gabungan anaerobik-aerobik dalam UFML MFC dapat mendegradasikan AO7 sepenuhnya. Akhir sekali, UFML MFC (SUFML MFC) baru yang dipertingkatkan telah direka dengan konfigurasi anod yang inovatif (kiub karbon felt dan pautan karbon felt). Reaktor ini digunakan untuk memeriksa prestasi keseluruhan output kuasa dengan masa pengekalan hidraulik yang berbeza (HRT) dan jarak elektrod. Hasilnya membuktikan bahawa anod pautan karbon felt mempunyai corak aliran dan pemindahan jisim yang lebih baik, juga memberikan output voltan keseluruhan yang lebih baik pada semua HRT dalam sepanjang fasa pegun.

Simultaneous Waste Water Treatment and Power Generation with Single Chambered Up-flow Membrane-less Microbial Fuel Cell

ABSTRACT

Microbial fuel cell (MFC) is a technology that can convert chemical energy into electrical energy from biomass. MFC is also one of the promising technology to generate sustainable green bioenergy. The development of MFC technologies have been expanded to various application, such as wastewater treatment, specific inorganic pollutant treatment, sediment bioremediation and biosensor. This thesis addressed the potential of an up-flow membrane-less (UFML) MFC that used for wastewater treatment with an enormous variety of configurations and working parameters. The primary objective of this study is to examine the potential and the mechanism of the novel UFML MFC by using various carbon material as aqueous biocathode. Further investigation was conducted to evaluate the effect of the biofilm formation on different carbon material surface morphology based on performance of power output and chemical oxygen demand (COD) reduction in UFML MFC. Carbon flake, Pt-loaded carbon paper, carbon plate and carbon felt were used as aqueous biocathode. The voltage output for the carbon flake cathode (384 $\pm$ 16 mV) was comparable to the Pt-loaded carbon paper cathode (399 $\pm$ 9 mV), which is unexpected. The COD reduction efficiency for all cathode materials at the anode region and effluent were achieved as high as 75% and 85%, respectively. The surface area and surface morphology of the cathode material may influence the ability of microbial attachment and electron transfer. The results suggested that the power generation and the COD reduction were influenced by the cathode material. Besides, UFML MFC was also used to further explore the potential and the mechanism between biodegradation of Acid Orange 7 (AO7) and generation of bioelectricity. The decolorization efficiency of AO7 was up to 96%. Overall voltage output was affected by the increased dosage of AO7. However, the increased dosage of AO7 and continuous 24-h flow could help to lower down the other anaerobic microbial activities and consequently caused more available electrons which can be used by AO7 decolorization and electricity generation. Furthermore, the decolorization of AO7 at cathode region indicated that the oxygen and azo dye were both competed for electron acceptor. Based on the UV–visible spectra analysis, the breakdown of the AO7 azo bond into more toxicity aromatic compounds in anaerobic condition were confirmed. Nonetheless, these aromatic compounds can be further degraded into short chain aliphatic acids and lastly decomposed into carbon dioxide and water. In additional, the intermediates listed in the proposed plausible biodegradation pathway were partially identified. These results proved that the combination of anaerobic-aerobic in UFML MFC was able to completely mineralize the AO7. Lastly, the new enhanced up-scaled UFML MFC (SUFML MFC) was fabricated with innovative anode configuration (cube carbon felt and linked carbon felt). This reactor was used to examine the overall performance of power output with different hydraulic retention time (HRT) and electrode spacing distance. The results proved that the linked anode was better in flow pattern and mass transfer, providing overall better voltage output during stationary phase at all different HRT setup.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Energy is essential for everyday life and also economic growth of a country; it provides heat and light for all human activities. Most of the energy nowadays comes from fossil fuels. The use of fossil fuels, especially petroleum has accelerated in recent years. It is one of the main contributors of releasing carbon dioxide into the atmosphere which illustrates a phenomena of global energy crisis. Energy crisis will gradually affect the sustainable development of a country. Besides, global warming and climate change are mainly caused by an imbalance of natural cycle of greenhouse effect. Carbon dioxide (CO_2) is known as one of the greenhouse gases. The emission of CO_2 is generally due to anthropogenic activities and it contributes to an increase in average global temperatures. Therefore, the clean alternative energy is important to replace the use of fossil fuels.

Considerable attention had been paid to renewable energy as an alternative energy source to alleviate the global energy crisis and global warming. There are several alternative source of energy such as solar, wind, biomass and nuclear energy. Solar and wind energy are sustainable and clean energy that are available today. However, it is still difficult to replace fossil fuels as the amount of energy in those renewable resources are nowhere comparable to fossil fuels. Consequently, fuel cells are considered as a preferable energy source because it can directly convert chemical energy to electrical energy easily. Hydrogen is used as fuel for electricity generation in the fuel cell. Anode region will generate protons and electrons from hydrogen, then pass through the electrolyte and external circuit to form water in cathode region, respectively. However, these fuel cell have some disadvantages, such as high cost of operation and materials used. Therefore, a combination of biomass with electrochemistry is a futuristic alternative, environment friendly, sustainable energy resource. Microbial fuel cell (MFC) is one of the latest emerging sustainable energy technology that could convert chemical energy by using microorganism to oxidize the organic carbon sources. MFC has similar function and construction as a hydrogen fuel cell. The difference is MFC use microorganism as catalyst rather than high cost precious platinum. Besides, the MFC can work in room temperature where it is easier to operate. Moreover, MFC reuse waste resources as fuel to generate bioenergy, which can reduce the consumption of fossil fuel and environmental pollution.

Most of the present wastewater treatment plants are using conventional aerobic treatment system with oxygen supply (Adav, Lee, & Lai, 2010; Kushwaha, Srivastava, & Mall, 2011; Vázquez, Rodríguez, Marañón, Castrillón, & Fernández, 2006). The energy consumption in the wastewater treatment plant generally contributed by aeration. Anaerobic treatment system is getting more popular for wastewater treatment due to no energy requirement for aeration. Hence, anaerobic treatment system is more cost effective for high strength wastewater. An alternative with simultaneous electricity generation has gained more attentions from many researchers (Clauwaert et al., 2007; G. D.Saratale et al., 2017; Yoshizawa, Miyahara, Kouzuma, & Watanabe, 2014). MFC is one of the anaerobic treatment system to produce green sustainable bioenergy. The conventional design of MFCs usually consists of either a single chamber or double chambers with a proton exchange membrane (PEM) acting as a separator (Mansoorian et al., 2013; Venkata Mohan, Veer Raghavulu, & Sarma, 2008). The mechanism of MFC is the breakdown of organic matter by the anaerobic microbes surrounding the anode electrode to generate electrons and protons. The microbes attached on the surface of the anode will act as biocatalyst to improve the electron transfer efficiency. The electrons will be transferred from anode electrode to cathode electrode through an external circuit while protons pass through PEM to cathode region. The electrons will then react with the protons transferred from anode region and oxygen from air to form water. Therefore, the complete transfer of electrons could generate current in a closed circuit. Various anaerobic microorganisms can assist the electron transfer via catabolism. These microorganisms can be easily found in wastewater, activated sludge and marine sediment. Besides, these microorganisms are capable to degrade various organic substances for power generation (Du, Li, & Gu, 2007). Higher concentration of organic substances has higher chemical energy per unit volume. Therefore, higher concentration of organic substances in wastewater is required in order to achieve higher electricity production (Huang, Yang, Guo, & Zhang, 2011). Many researchers have proved that MFC can remove high concentration of COD (Liao et al., 2014; Sangeetha et al., 2016).

The development of MFC technologies have been expanded to various application rather than power generation. Several researchers have widely studied the potential of MFC in specific inorganic pollutant treatment, sediment bioremediation, biosensor and hydrogen production (Aelterman, Rabaey, Clauwaert, & Verstraete, 2006; Clauwaert et al., 2008; Hu, Fan, & Liu, 2008; Kaur et al., 2014; Kumlanghan, Liu, Thavarungkul, Kanatharana, & Mattiasson, 2007; Z.Liu, Liu, Zhang, Xing, & Su, 2011; Rozendal, Jeremiasse, Hamelers, & Buisman, 2008). For example, MFC as biosensor can work as indicator to monitor the Biological Oxygen Demand (BOD), microbial activity and toxicity in any environment (Z.Liu et al., 2011). The success of MFC technology when applied in these application suggests that MFC technology has a promising future.

MFC is an ideal fuel cell designed for wastewater treatment to degrade the organic matter by using microorganisms as biocatalyst and simultaneously generate electricity (Y.Cui, Rashid, Hu, Rehman, & Han, 2014). MFC have been used for various types of organic wastewater treatment to produce renewable energy (Fornero, Rosenbaum, & Angenent, 2010; N.Lu et al., 2009; Min, Kim, Oh, Regan, & Logan, 2005). Treatment of dye containing wastewater is very important nowadays due to excessive effluent from many industries such as paper, textiles, paint, printing, etc. Discharge of this dye containing wastewater without treatment will cause a serious pollution to the environment as it contains synthetic colorant which is toxic and carcinogenic that could cause serious public health problems (Selvam, Swaminathan, & Chae, 2003). Therefore, treatment of the dye containing wastewater is the major concern nowadays.

Azo dye wastewater can be treated by many methods which includes physico-chemical processes and biological processes. Physico-chemical processes for azo dye treatment includes coagulation-flocculation, membrane filtration, adsorption, advanced oxidation process, photocatalytic process, adsorption process and ozone treatment (Brillas & Martínez-Huitle, 2015). These type of treatments have more disadvantages than advantages such as the cost for huge amount of chemical used; generate secondary pollutants and it is difficult to remove recalcitrant azo dye (R. G.Saratale, Saratale, Chang, & Govindwar, 2011). Nonetheless, biological processes use less amount of chemicals due to the metabolic versatility of microorganism to convert hazardous compounds into less harmful environmental friendly co-products (Méndez-Paz, Omil, & Lema, 2005; Solís, Solís, Pérez, Manjarrez, & Flores, 2012). Degradation of azo dye is difficult under aerobic conditions but the azo bond can be broken down effectively enzymatic mechanisms under anaerobic conditions (van derZee, Lettinga, & Field, 2001).

The co-product aromatic amines after breakage of azo bond are recalcitrant to further metabolize in anaerobic condition yet it can be completely mineralized under aerobic condition. Therefore, a combination of sequential anaerobic-aerobic treatment of azo dye has been gradually studied in recent years.

1.2 Problem Statement

Recent years, the performance of MFCs has been improved gradually by various bioreactor design and material used for fabrication (X.Li et al., 2013; Rahimnejad, Adhami, Darvari, Zirepour, & Oh, 2015). The membrane functions to minimize the crossover of oxygen from the cathode to anode region (Du et al., 2007). However, the commonly used Nafion 117 membrane in MFC; the oxygen diffusion is still occurred due to Nafion membrane is quite permeable to oxygen (K. J.Chae et al., 2008). MFCs designed without using PEM were less complex, less maintenance and low construction cost (Cristiani et al., 2013; Ghasemi, Daud, et al., 2013; G.Zhu, Onodera, Tandukar, & Pavlostathis, 2013). Besides, the membrane-less MFC is a more feasible configuration for large scale application in the future (Abourached, Catal, & Liu, 2014; W.Liu et al., 2015; Pennsylvania, 2004). The performance of MFC consist of membrane will deteriorate as the build-up of biofilm on the surface of membrane may cause biofouling, and this could hamper the transfer of protons from anode to cathode region (Daniel, DasMankidy, Ambarish, & Manogari, 2009; Heidrich, Edwards, Dolfing, Cotterill, & Curtis, 2014; Osman, Shah, & Walsh, 2010). Moreover, the anode configuration in up-flow membrane-less MFC may also cause the effectiveness of the mass transfer from anode to cathode region, and this was not many researchers reported.

The studies on the comparison among different types of carbon material as electrode are still limited (Zhou, Chi, Luo, He, & Jin, 2011). Moreover, they are focused on the electricity output from the MFC rather than the performance of MFC in wastewater treatment (JingLiu et al., 2012). Carbon based electrodes for anode are commonly utilized because of low cost and the high effectiveness of microbial attachment (Crittenden, Sund, & Sumner, 2006). The most common material used as cathode by other researchers was carbon containing platinum which could enhance the oxygen reduction rate especially in a reactor with a single-chamber membrane-less MFC. Recently, the use of biomass as catalyst has been investigated as low cost alternative to platinum (Bajracharya et al., 2016; Gajda et al., 2014). The growth of biofilm on the carbon cathode may act as biocatalyst to enhance the oxygen reduction rate and subsequently improve the voltage output (He & Angenent, 2006). Besides membrane and electrode material, others factors, such as volumetric flow rate, organic loading rate, directional flow pattern, ohmic resistance, type of substrate, concentration of substrate, internal resistance of the reactor, operation pH and temperature, could also influence the performance of power generation (Gil et al., 2003; Jana, Behera, & Ghangrekar, 2010; Nasharudin, Kamarudin, Hasran, & Masdar, 2014).

Some researchers have used single chamber anaerobic MFC for azo dye degradation (Cao, Hu, Sun, & Hou, 2010; Sun, Hu, & Hou, 2011). In order to completely mineralize azo dye by using MFC, a combination sequential anaerobic-aerobic treatment could be tricky. Lately, many researchers have used anaerobic-aerobic separated bioreactors sequential treatment system for decolorization of azo dye (D.Cui et al., 2014; Fernando, Keshavarz, & Kyazze, 2014a; García-Martínez et al., 2015; YangLi, Yang, Shen, Mu, & Yu, 2016). However, several researchers have used a combined of anaerobic-aerobic single chamber MFC for azo dye treatment, where it was less complex and low fabrication cost. Despite reports by several researchers on the capability and performance of the usage of MFC to decolourize azo dye and generate electricity simultaneously, but the mechanisms and correlation between azo dye biodegradation and MFC operation remained vague. Besides, identification and toxicity of the final biodegraded products from the azo dye remained unexplored. Lastly, the capability and mechanism of azo dye as an electron acceptor at cathode region in a single chamber was not investigated.

1.3 Objective

The overall aim of this research is to develop a single chamber membrane-less MFC for wastewater treatment. A distinctive design of MFC is necessary to overcome the typical limitations before for real application. The distinctive designed MFC is expected not only to improve the performance of wastewater treatment, but also to enhance the electricity generation at low fabrication and operation costs. Therefore, the major focus of this project is to develop and investigate the mechanism of the low cost distinctive MFC for simultaneous dye wastewater treatment and electricity generation. The main objectives of this research are to:

a. Design and develop single chambered up-flow membrane-less MFCs under batch and continuous mode for simultaneous wastewater treatment and electricity generation.

b. Evaluate and enhance the performance of MFC with various parameters: Cathode material, electrode spacing, organic loading rate, ionic strength, dye concentration, and etc

c. Explore the mechanisms and degradation pathway during AO7 decolorization in single chambered up-flow membrane-less MFC

d. Inspect the performance of enhanced scaled-up up-flow membrane-less MFC by various anode configuration

1.4 Scope of Study

This project focuses on designing and developing a cost effective up-flow membrane-less (UFML) MFC for simultaneous wastewater treatment and electricity generation. The scope of study includes constructing an UFML MFC without using the costly proton exchange membrane. The study was started with a batch operation mode during the initial stage and subsequently established in a continuous operation mode. Carbon felt, carbon plate, carbon flake and Pt-loaded carbon paper were used as the cathode materials in this research to investigate the effects on the performance of MFC. Besides, this project will further investigate other operating parameters which could affect the performance of wastewater treatment and electricity generation such as concentration of organic substrate, types of cathode material, electrode spacing, potassium chloride (KCl) dosage and etc. Moreover, this study also further investigates the interrelation between surface morphology of cathode material and biofilm formation that could affect the performance of power output and chemical oxygen demand (COD) reduction.

Azo dye was applied as one of the organic pollutants in this UFML MFC to explore the mechanism of the biodegradation ability and the potential as an electron acceptor in cathode region. The performance of power output, COD reduction and decolorization were investigated with different initial dye concentration and operating conditions. The plausible mechanism for the degradation pathway of azo dye will be proposed with various identification analysis such as gas chromatography - mass spectroscopy (GC-MS), ultraviolet-visible spectrophotometry (UV-Vis), high-performance liquid chromatography (HPLC) and Fourier-transform infrared spectroscopy (FTIR). Lastly, a new up-scaled UFML MFC with innovative anode structure design (cube carbon felt and linked carbon felt) was developed to investigate efficiency of electrons and protons transfer from anode region to cathode region. Mass transfer efficiency was examined by using different hydraulic retention time (HRT) and electron spacing.

CHAPTER 2 : LITERATURE REVIEW

2.1 Background and History

Microbial fuel cell was featured as a bio-electrochemical technology that can convert chemical energy from organic waste or biomass into green electricity. MFC mainly use microbes as a biocatalyst to oxidize the substrate and transfer electrons to anode electrode. This mechanism was slightly different to traditional abiotic electrochemical fuel cell. Potter was the founder of MFC and he cultured *Escherichia coli* and *Saccharomyces* to generate low electricity with a setup of MFC using platinum electrode (Potter, 1911). He explained that the electricity generated by electron transfer released from organic carbon to an extra cellular electrode through an intercellular electron shuttling compound. However, the power output was low until 1980s and thus electron mediators were used to improve the power output.

Most of the microbial species could not transfer electrons directly to anode because of the non-conductive lipid membrane. Therefore, electron mediators function as a medium to enhance the transfer of electrons from microbes to the anode. The mediators can go through the cell membrane easily as an oxidized form to transfer the electron to the anode (Davis & Higson, 2007). Methylene blue, thionine, and 2-hydroxy-1,4-naphthoquinone were commonly used as mediators to improve the electricity output (Bennetto et al., 1985). However, there are several researchers who setup MFCs without using mediators as some of the mediators may be harmful to the microbes and expensive in terms of cost, which could affect the general performance of mediator MFC. B. H.Kim, Kim, Hyun, and Park (1999) are the first researchers to discover that the growth of microbes surrounding the electrode can directly transfer the electrons without using a mediator. Several researchers have proved that some microbe species have the ability to directly transfer electrons to anode naturally, such as *Shewanella oneidensis, Geobacter sulfurreducens, Pseudomonas aeruginosa* and *Clostridium butyricum* (Karube, Matsunaga, Tsuru, & Suzuki, 1977). These findings have greatly gained the interest of MFC studies in past decade. Rabaey, Lissens, Siciliano, and Verstraete (2003) reported a MFC containing mixed bacterial culture by utilizing glucose dosage to enhance the power output. Hence, the use of these types of microbes without mediator is more practical for MFC application. Logan et. al (2006) has done a lot of fundamental studies about microbial fuel cell. Their team have constructed and analysed based on different scientific and engineering principles, including microbiology, electrochemistry, material and environmental engineering. Besides, H.Liu, Ramnarayanan, and Logan (2004) introduced the usage of domestic wastewater as fuel to generate electricity with MFC. The use of this technology in wastewater treatment can convert organic contaminants into less toxic compounds and simultaneously produce clean energy. The MFC uses microorganisms to degrade the organic contaminants in wastewater to generate protons and electrons. Electrons will be transferred from anode region to cathode region through an external circuit. Protons will be transferred to cathode through a PEM and reduced to water molecules with the existence of oxygen.

MFC technology has several advantages compared to traditional biotechnology. MFC has vast availability of fuel that can be used to generate electricity, such as wastewater, sludge, sea clay and biomass. Besides, MFC produces environmental friendly end product and green bioenergy. MFC usually can fully function at mild operating condition, such as low temperature and low pressure. MFC also uses non precious metal as catalyst with development of biotic anode and cathode. Lastly, MFC can be applied in various industries through special designs and fabrication for optimum performance. However, MFC is still considered as an immature biotechnology with various limitations. The electricity generation is still low compared to traditional fuel cell and has high fabrication cost. In recent years, the power generation has been improved by innovative designs and materials used. It is proving that MFC technology has the potential to be more a promising bio-renewable energy source in the future. Therefore, a better understanding based on development of engineering and science is essential in order to achieve optimum performance of MFC.

2.2 Challenges in microbial fuel cell

Despite the improvement of MFC performance in recent years, the power output still considered low, and therefore a large scale MFC is still a great challenge in order to generate higher power output. The major challenges of MFC technology are low current and voltage output. The main factors to cause low current and voltage output were related closely to the structure design and material used to construct MFC. The conventional MFC would have high cost PEM, high internal resistance which may be caused by electrode distance, size of electrode, size of the anode and cathode chamber, biofilm thickness, mass transport of nutrient and conductivity of working medium. Moreover, the use of commercial PEM in MFC may hamper the transfer of protons from anode region to cathode region after using for a certain period. The growth of biofilm on the PEM surface can cause instability of the MFC system and low voltage output performance. Therefore, researchers have concentrated on the design of MFC structure and material used to improve the performance of bioelectricity generation in recent years. Challenges in fabrications and anode materials for MFC were well reviewed in other literature (Choi, 2015; Doherty et al., 2015; Rahimnejad et al., 2015).

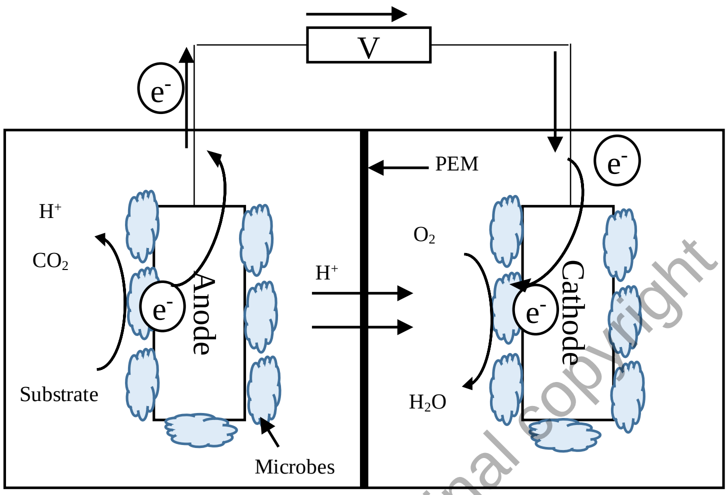

Figure 2.1: Schematic diagram of general MFC mechanism.

The challenges of MFC technology are highly related to its mechanism. The general mechanism could be explained with typical double chambered MFC with anode and cathode chamber, separated by PEM (Fig. 2.1). Attached growth microbes on anode surface can degrade the organic carbon sources in anode chamber and generate electrons and protons (Equation 2.1). The protons at anode region will flow through the PEM to cathode region, while electrons will go through the external circuit to cathode directly reacting with oxygen and protons to form water. (Equation 2.2)

$$CH_3COO^- + 2H_2O \xrightarrow{\text{oxidation}} 2CO_2 + 7H^+ + 8e^- \tag{2.1}$$

$$4H^+ + O_2 + 4e^- \xrightarrow{\text{reduction}} 2H_2O \tag{2.2}$$

2.3 MFCs' Configuration and Performance

The performance of a MFC mainly depends on the reactors design and materials selected. There are several components related to the design of MFC, such as material of electrode, spacing distance of electrode, availability of separator, size and specific surface area of the electrode, and availability of the catalyst at cathode region. Different designs of MFC will have different operation methods and cost of construction. Besides, the operating parameter plays an important role to achieve the ideal performance. Moreover, the type and source of inoculum (microbial) used in anode chamber could be a potential factor which affects the performance output of a MFC. Different species of the microbial community would have different growth rate, electron transfer ability and substrate uptake rate. Moreover, the thickness of biofilm could affect the activity of the electricity generation.

2.3.1 Types of MFC Design

The design of reactor architecture could affect the performance of MFC in terms of wastewater treatment and electricity generation (Table 2.1). Studies have been done to improve the performance of MFC by overcoming the limitations of the reactor designs (Choi, 2015). In recent years, researchers have introduced MFC design ranging from 2 μL to 10 L. The design of MFC could be classified into membrane MFC and without membrane MFC.