Microbial Fuel Cell: Transformation of Wastewater to Green Energy

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INTRODUCTION

Malaysia has been depending on oil, coal and natural gas as sources of energy for the country's economic progress and the nation's development. However, there are rising concerns on the scarcity of these resources as well as the detrimental effects they can have on the environment. Realising this, Malaysia is looking into other sources of energy to meet the nation's energy needs and moving towards renewable energy for a more sustainable source. Several policies on energy, as shown in Figure 1, were developed to ensure sustainable development of the nation.

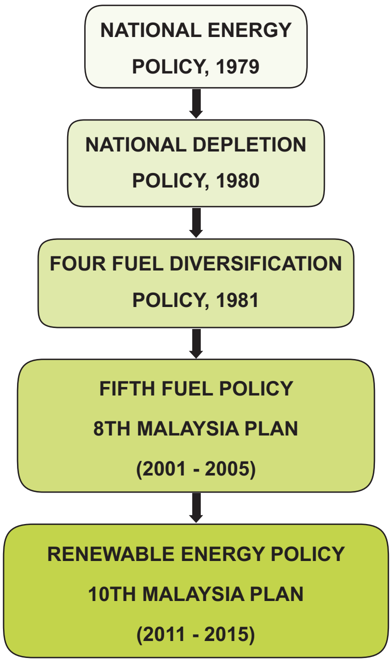

Figure 1: National Policies on Energy

The focus on renewable energy was introduced through the 5th Fuel Policy where alternative sources, such as solar, solid waste and biomass were proposed to be utilised as energy generators. This paper highlights an innovative method of generating renewable energy through the Microbial Fuel Cell (MFC) technology.

MICROBIAL FUEL CELL

Microbial Fuel Cell (MFC) constitutes a new approach for electricity generation and wastewater treatment. It is similar to a Chemical Fuel Cell (CFC) as both cells convert chemical energy into electricity. However, the major difference lies in the catalyst used to speed up the oxidation process. A CFC uses an elemental catalyst to accelerate the process while the MFC uses live bacteria to catalyse the fuel oxidation (Seop *et al.*, 2006).

MFC is a bioreactor which converts chemical energy into electrical energy through catalytic reactions of microorganisms under anaerobic conditions (Kim *et al.*, 2007). It is also a promising technology in wastewater treatment as it can address the issue of bioenergy and wastewater treatment concurrently with reduction in sludge production (Moon *et al.*, 2006). Treating wastewater using MFC can reduce the amount of sludge production substantially due to the fact that only a small fraction of the energy is consumed by the microorganisms for growth (sludge production) whereas a large fraction is used for bioenergy conversion (Kim *et al.*, 2007).

A typical MFC consists of an anode and a cathode chamber. The organic matter from the substrate or wastewater which is placed in the anaerobic anode chamber is oxidised by the bacteria, causing electrons and protons to be generated in the process. Carbon dioxide (CO_2) is the oxidation product. The resulting electrons are transferred to the electrode of the anode chamber and subsequently to the electrode of the aerobic cathode chamber via an external resistor while the protons are diffused through a Proton Exchange Membrane (PEM). This transfer of electrons is caused by the difference in potential between the two electrodes. Oxygen reduction which takes place at the cathode utilises the electrons, protons and oxygen to produce water.

The oxidation and reduction equations are as follows :

$$(CH_2O)n + nH_2O \longrightarrow nnCO_2 + 4ne^- + 4nH^+ \text{ (Anode:Oxidation Reaction)}$$

$$4e^- + 4H^+ + O_2 \longrightarrow 2H_2O \text{ (Cathode : Reduction Reaction)}$$

The end results of the overall reaction is the degradation of the organic matter and the production of electricity (Seop *et al.*, 2006).

At the anode chamber, the substrate acts as the electron donor (ED) while the anode (electrode) is the electron acceptor (EA). At the cathode chamber, the cathode (electrode) is the electron donor whereas the oxygen is the electron acceptor. The electron transfer process is shown in Figure 2.

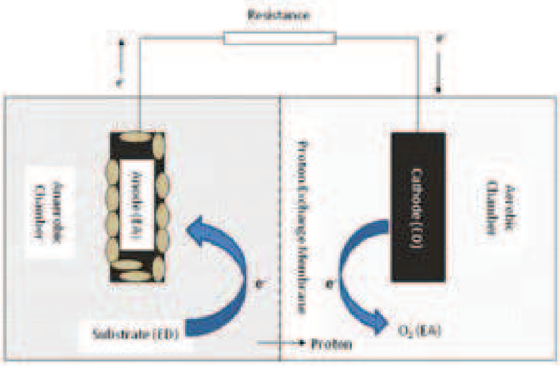

Figure 2: Schematic diagram of a typical two-chamber MFC (Source: Du et al., 2007)

MICROBIAL METABOLISM IN MFC

Microbial metabolism is the process in which the microorganisms gain energy required for living and reproduction. There are various types of metabolism routes that can be used by the microorganisms. In an MFC, the electron transport involves the transfer of electrons from the substrate in the anode chamber to the final electron acceptor in the cathode chamber. Since electron transport chains are redox processes, therefore, two sets of redox couple are required (electron donors and electron acceptors). For example, if NADH is the electron donor and O_2 is the final electron acceptor, the redox couples are NAD/NADH and O_2/H_20. Not every combination of electron donor-acceptor is thermodynamically possible. Therefore, in order to obtain a thermodynamically favourable combination of donor-acceptor, the redox potential of the acceptor must be more positive compared to the redox potential of the donor. Table 1 shows the redox potential for selected organic and inorganic redox couples compared to the Standard Hydrogen Electrode (SHE) potential at pH7.

From Table 1, the oxidation potential for oxygen is +820 mV which indicates that oxygen has the highest oxidation potential. This explains why most MFC's cathodes are abiotic (no electrolyte). Only in the absence of oxygen that other electron acceptors are utilised.

ABIOTIC CATHODES VS. BIOCATHODES

Cathodes which use oxygen as the terminal electron acceptor are known as abiotic cathodes. Oxygen is the most frequently used for an MFC mainly because of its high redox potential, plentiful in the air, readily available and only produces water as the end product, making it sustainable to the environment. However, due to poor oxygen reduction kinetics, abiotic cathodes need to employ a catalyst to overcome the problem. The most common type of cathode catalyst for oxygen reduction is platinum. Nevertheless, the application of platinum is limited as it is expensive, especially if it is to be applied on a large scale basis. As a result, researchers are now embarking on the concept of applying biocathodes in MFCs.

Biocathodes basically means utilising bacteria as catalyst for the cathode instead of platinum. Unlike abiotic cathodes which are half biological as wastewater is being placed only in the anode chamber, biocathodes are fully biological due to the fact that wastewater is being used in both chambers as electrolytes. The main advantage of biocathodes over abiotic cathodes is the low operational cost for not having to use platinum as the cathode catalyst. As a substitute for the platinum, wastewater which is available in abundance will be used as a catholyte to provide the biocatalyst needed for the electron transfer. Biocathodes can be classified as aerobic or anaerobic biocathodes, depending on the terminal electron acceptor.

For aerobic biocathodes, oxygen will be invariably used as the terminal electron acceptor. On the other hand, for anaerobic biocathodes with the absence of oxygen, other electron acceptors (NO^{3-}, NO^{2-}, SO^{4-}, CO_2, fumarate) will be used, depending on which electron acceptors are available.

Table 1: MFC electrode redox pair and corresponding redox potentials

Oxidation/Reduction Pair	E^0 (mV)
CO_2/Glucose	-430
H^+/H_2	-420
NAD/NADH	-320
CO_2/Acetate	-280
S^0/H_2S	-280
S^0/HS^-	-270
CO_2/CH_4	-240
SO_4^{2-}/H_2S	-220
Pyruvate^{2-}/Lactate^{2-}	-185
Methylene Blue $_{Ox/Red}$	+11
Fumarate^{2-}/Succinate^{2-}	+31
Thionine $_{Ox/Red}$	+64
Ubiquinone $_{Ox/Red}$	+113
O_2/H_2O_2	+275
NO^{3-}/NO^{2-}	+421
NO^{2-}/NH_4^+	+440
O_2/H_2O	+820

(Source: Du et al., 2007)

APPLICATION OF MFC

Generally, all types of wastewater can be used as substrate for an MFC. Table 2 shows some of the examples of wastewater that have been reported in the literature.

Table 2 : Examples of organic wastewater used as electrolytes in the anaerobic anode chamber of MFCs

Types of Wastewater	Researcher
Palm Oil Mill Effluent (POME)	Cheng *et al.*, 2010
Brewery Wastewater	Zhang *et al.*, 2009
Chocolate Industry Wastewater	Patil *et al.*, 2009
Starch Processing Wastewater	Lu *et al.*, 2009
Confectionery Wastewater	Sun *et al.*, 2009
Swine Wastewater	Min *et al.*, 2005
Municipal Wastewater	Liu *et al.*, 2004

In Malaysia, the use of POME as electrolytes for the MFC would be of great potential. The nature of POME which has a very high organic load and abundance in terms of volume makes it a suitable source of substrate (electrolyte) for MFCs. Utilising POME in MFCs would not only generate electricity but at the same time treat the wastewater with a much lesser sludge.

CONCLUSION

It can be concluded that MFCs can be categorised as green technology for energy generation as it does not bring harmful effects to the environment. In addition, it helps in reducing the existing environmental problem by utilising POME as electrolytes for the MFC. However, this technology is considered still at its early stage in Malaysia. The Research and Development (R&D) on this technology needs to be greatly enhanced so that it can be adopted in the near future. ■

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