JOURNAL OF MECHANICAL ENGINEERING

An International Journal

VOLUME 13 NO. 1 JUNE 2016 / ISSN 1823-5514

JOURNAL OF MECHANICAL ENGINEERING

An International Journal

Journal of Mechanical Engineering (ISSN 1823-5514) is published by the Faculty of Mechanical Engineering (FKM) and UiTM Press, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

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An International Journal

Vol. 13 No. 1	June 2016	ISSN 1823-5514

Energy Conversion from Biodegradation of Non-thermal Pre-treated Algae Biomass for Microbial Fuel Cell

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ABSTRACT

Strength and complexity of algae cell wall structures provides difficulty for microbial substrate digestion. Therefore, pre-treatment is required to break the algae cell wall. There are several types of algae cell wall pre-treatment before degradation process. Among of these methods, freeze drying method is able to breakdown algae cell walls and preserve algae cell constituents simultaneously. Freeze dried (non-thermal pre-treatment) Chlorella vulgaris microalgae biomass was used as microbial substrate consumption in double chamber Microbial Fuel Cell (MFC) to generate bioelectricity. As a result, the treatment efficiency obtained in terms of Chemical Oxygen Demand (COD) removal efficiency is 63.5%. Based on the power curve obtained, the maximum power density is 8.94 mW/m^2 using 2.5 g/L of substrate concentration. At substrate concentration of 5.0 g/L, the MFC has COD removal efficiency of 52.38% and maximum power density of 2.87 mW/m^2. At the *substrate concentration of 1.0 g/L, the MFC has COD removal efficiency is 86.8%, and maximum power density of 0.11 mW/m^2. MFC with different freeze dried algae substrate of 1.0 g/L, 2.5 g/L and 5.0 g/L has Coulombic efficiency (CE) of 1.56 %, 18.6% and 13.1%, respectively. These results reveal that the use of freeze dried microalgae biomass could be a promising candidate in the application of MFC.*

Keywords: *freeze dry algae; microbial fuel cell; biomaterials; energy storage and conversion.*

Introduction

The concerns of greenhouse gases emission and limited sources of fossil fuel has encouraged researchers to find alternative energy [1]–[3]. There are many types of alternative energy founded such as solar cell, hydropower, and wind power. Another alternative energy invented based on the conversion of chemical energy to electrical energy by using a special electrochemical device which is called the fuel cell [4]. There are many types of fuel cells invented, and one of the fuel cell is designed to convert waste or organic matter into energy is called Microbial Fuel Cell (MFC). MFC is an unique device compare to other fuel cell because of its anodic solutions are wastewater which is contains microbes that are responsible for digestion of substrate to produce electrons which are used for energy as bioelectricity [5], [6].

Many kind of substrates have been used for investigation of bioelectricity production by using MFC. Dry algae biomass is able to produce highest maximum power density compare to other substrates due to its high carbon sources from its lipid content. However, the bacterial digestion of algae biomass is not simple due to algal strong and complex cell wall structure which is a hindrance for microbial digestion [7]. Therefore, an algae biomass extraction is needed to break the cell wall structure to facilitate the digestion process. Some MFC research using various kinds of extraction methods before used [7]–[9]. Freeze drying is common used for dewatering microalgal biomass [10]. Freeze drying preserving cell constituents without destroying its cell wall. In this work, freeze dried Chlorella vulgaris (algae) biomass is applied to generate bioelectricity by using double chamber MFC.

Methodology

MFC Construction and Design

The MFC reactor was designed and fabricated from acrylic material. It has two chambers, each one volume is 500 ml, and labelled as the anode and cathode, respectively. Both compartments were separated by pre-treated proton exchange membrane (PEM, Nafion 117, l = 7 cm, w = 5 cm). The electrodes were made of stainless steel mesh (l = 10 cm, w = 4 cm), coated with conductive carbon paint (SPI Paint). The cathode chamber was filled with a 50 mM phosphate buffer medium and air flow by an air pump (1000 cc per minute). The electrodes were connected to a digital multimeter (UT803, Uni-Trend Technology Ltd. China) which is connected to computer with data logger software installed (Figure 1).

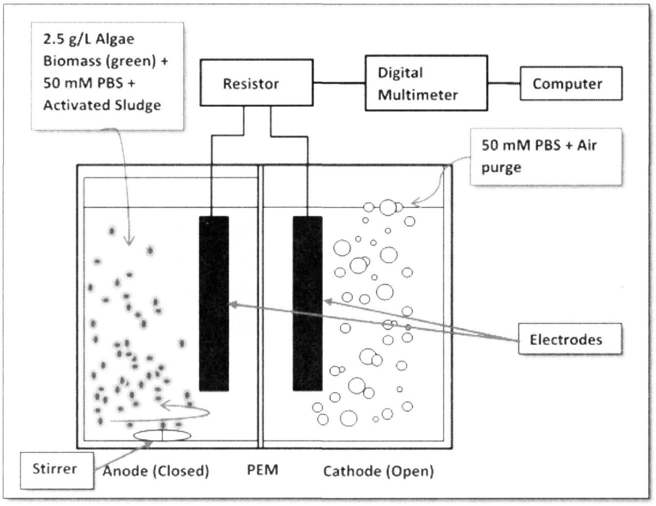

Figure 1: A schematic diagram of freeze dry algae biomass MFC

Preparation and Pre-acclimation

The closed anode chamber was inoculated by pumped in the raw sludge wastewater sample (taken from UiTM wastewater treatment plant). The working volume was used is about 400 ml. The cathode chamber was filled with 50 mM phosphate buffer medium (PBS), consisting of 4.576 g Na_2HPO_4, 2.452 g NaH_2PO_4, 0.31 g NH_4Cl and 0.13 g KCl. After 3 days of inoculation, the wastewater was replaced with mixture of wastewater (10 ml) and freeze-dried *Chlorella Vulgaris* biomass powder. The optimization of MFC was investigated by manipulating three different concentrations (2.5 g/L, 5.0 g/L and 1.0 g/L, Algaetech International Sdn. Bhd.) mixed with 50 mM PBS, and changing it by every two weeks approximately. Microalgal biomass was extracted by bead-milling method and dewatering by using freeze dry method.

Data Collection and Analysis

The digital multimeter was connected to computer with installed data logger software (UT803, Uni-Trend Technology Ltd. China). After a stable voltage generation was occured, a variable resistor was applied to the system (0.5 Ω to 10 MΩ) to determine its polarization curve. Current was calculated by using Ohm's Law, $I= E_{cell}/R_{ext}$ where E_{cell} is cell voltage generated for each load, I is the current for each load, and R is the external load resistor which is applied. Power generation curve was determined by using P = I /E_{cell}, where *P* is power generated for each load, *I* is the current for each load and E_{cell} is the cell voltage for each load.

Some samples were taken for each initial and final of MFC operation to determine its chemical oxygen demand (COD), in mg . L^{-1}, by using reactor digestion method (High Range, 20-1500 mg/l, HACH). The result of COD removal percentage is useful to calculate Coulombic efficiency (*CE*), as fed batch system (Equation 1).

$$CE = \frac{8\int_0^t I\,dt}{FV_{An}\Delta COD} \qquad (1)$$

Where ΔCOD is change of COD concentration (mg/L), I is current (A), t is change in time (s), V_{An} is working volume (volume liquid in anode compartment, L), F is Faraday's constant (96,500 C/mol e-), and 8 is a constant in (1), based on M_{O2} = 32 for the molecular weight of oxygen and b = 4 for the number of electron transferred per mole of oxygen.

Result and Discussion

Effect of Different Concentrations of Freeze Dried Algae Biomass Feedstock

Three different substrates (freeze dried algae biomass) concentration is applied to MFC. From the three different polarization power curves (Figure 2), the power curve produces the highest maximum power point is 8.94 mW/ m^2 at 2.5 g/L of concentration of freeze dried algae biomass. 5.0 g/L of freeze dried algae biomass concentration produces power curve with maximum power point of 2.87 mW/m^2 while 1.0 g/L of freeze dried algae biomass concentration produces 0.11 mW/m^2. In this case, different concentration has an effect on the power production. 2.5 g/L substrate concentration produce more power than 1 g/L substrate concentration. Therefore, the more concentration of substrate is applied, more power is produced by MFC [8].

The concentration freeze dried algae biomass of 5.0 g/L produces low power density compare to 2.5 g/L, maybe due to many reasons such as the anode, cathode, chemical species in electrolyte, proton exchange membrane (PEM), application of microbes species, the configurations of fuel cell and the condition of the operation [11].

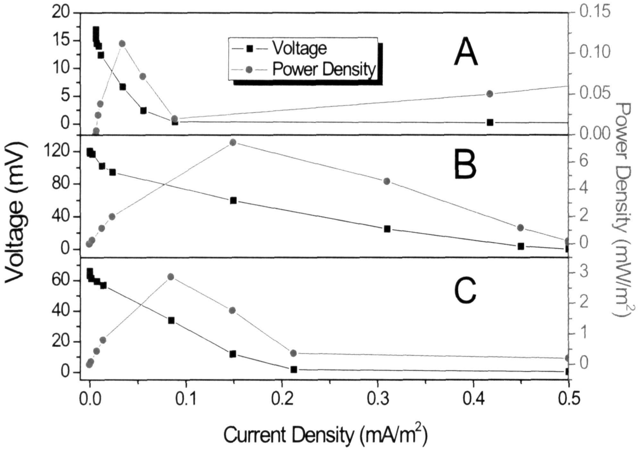

Figure 2: Three different polarization curves corresponding to different freeze algae biomass concentrations as feedstock for MFC. A) 1.0 g/L B) 2.5g/L and C) 5.0 g/L of freeze dried algae biomass concentrations were used.

Chemical Oxygen Demand (COD) Removal and Coulombic Efficiency

COD of MFC operation is taken to determine its percentage removal of organic matter in water. Three different substrate (freeze dried algae biomass) concentrations is applied to MFC (Figure. 3). The percentage of COD removal at 1 g/L of substrate concentration is 86.8 %, 2.5 g/L shows 63.5 % and 5.0 g/L shows 52.38 %. The differences of COD between the initial and final of MFC operation determines the coulombic efficiency (CE). At 1.0 g/L of substrate concentration, CE result is about 1.56 %. At 2.5 g/L, the CE result is 18.6 % while 5.0 g/L only produce CE about 13.1 %. These results show that MFC is not only able to generate power but it able treat wastewater and increase the quality of water, as well.

From the data (Figure. 3.), 1 g/L has the highest COD removal but lowest CE while 2.5 g/L has the highest CE but lower than 1 g/L. 5 g/L has lowest COD removal but higher CE than 1 g/L and a little bit lower than 2.5 g/L. From these differences, low COD removal has relatively high CE, significantly shown between 1 g/L and 2 g/L. There is a little differences between 2.5 g/L and 5 g/L (CE in range of 15-20%). *Velasquez-Orta et al.* [8] shows that the relationship between COD removal and CE shows that the CE is high (28 % for C. *Vulgaris* and 23 % for *U. Lactuca*) at range of low COD removal (range of 100 to 500 g/L) and reached 10 % plateau and decrease of CE beyond 600 mg/L of substrate concentrations. Consequently, the more substrate concentrations produce the higher COD removal efficiency but CE reaches plateau and decreases. The decrease of COD removal at low power generation is probably due to large size of organic matter for fermentation, aerobic respiration and bacterial growth [9].

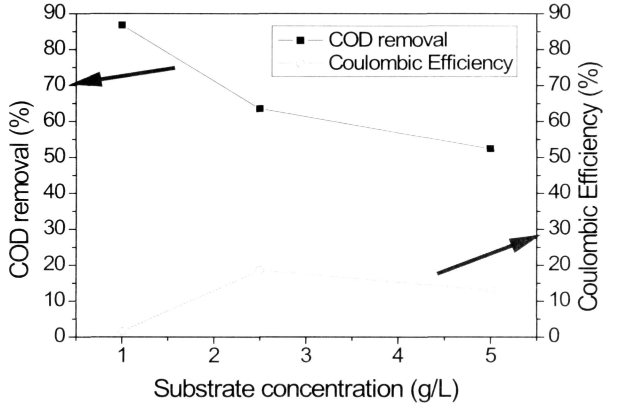

Figure 3: The percentage of chemical oxygen demand (COD) removal and coulombic efficiency in response to different substrate concentration.

Conclusion

Bioelectricity production from a freeze dry pre-treated microalgae, *Chlorella vulgaris* examined in a double chamber Microbial Fuel Cell (MFC). Freeze dry pre-treated C. *vulgaris* is a common pre-treatment method due to its high lipid recovery by preserving the algal cell constituents. As a result, the maximum power density is 8.94 mW/m^2 and COD removal efficiency of 63.5 % with 2.5 g/L of substrate concentration. MFC with freeze dried algae substrate of 1.0 g/L, 2.5 g/L and 5.0 g/L has coulombic efficiency of 1.56 %, 18.6 % and 13.1 %, respectively. Therefore, the bacterial substrate consumption of freeze dry pre-treated *Chlorella vulgaris* algae biomass able to produce bioelectricity in MFC.

Acknowledgement

The authors are gratefully thanks to Ministry of Education (MOE) for supporting this research under the RAGS grant (600-RMI/RAGS 5/3 (12/2012)), and Universiti Teknologi MARA (UiTM) for the facilities provided in succeeding this research.

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