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Electricity Generation from Citronella Bagasse (CB) Using Dual Chamber Microbial Fuel Cell

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ABSTRACT

The aim of this project is to produce electricity from citronella biomass using isolated microbes from wastewater as biocatalyst in a dual chamber microbial fuel cell (MFC). MFC is one such system that not only reduced biomass, which contains mostly waste products but can also liberate electricity from them. MFC system is well-established and using lignocellulosic biomass as fuel is one step to future energy generation. Trials of MFC experiments have been conducted but using citronella bagasse (CB) as fuel source. Furthermore, pre-treatment of the biomass was done using NaOH pre-treament and effluent treatment wastewater from a palm edible oil company as a source for microorganism. The end results indicate that bioelectricity production from CB is possible though very low yield in the present MFC.

Keywords: Microbial fuel cell, citronella bagasse, bioelectricity

INTRODUCTION

Bioelectricity production using microbial fuel cells (MFCs) has drawn much attention recently as a future renewable energy production (Lovley, 2006). Electricity can be generated in MFCs using many types of substrates mainly any form of biodegradable organic matters (Pant *et al*., 2010). Simple carbohydrates such as glucose, sucrose, xylose and polymeric starch have been utilized as fuel for electricity generation using a dual-chambered MFCs, proved to be successful though at low yield production (Catal *et al*., 2008; Behera & Ghangrekar, 2009; Niessen *et al*., 2004). In contrast, though extracting bioelectricity from lignocellulosic biomass is not new but advances are rather slow in terms of development compare to biofuel

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(e.g bioethanol) due to low power production. It was reported current output of 0.2 mA has been generated using an H-type MFC fed with cellulose and enriched with paddy field soil microorganisms (Ishii *et al.,* 2008). Another advance of bioelectricity production from lignocellulosic biomass was the study conducted by Wang *et al.* (2009). Direct conversion to electricity has been demonstrated using corn stover with a maximum power of 331 mW/m^2 and pre-treated corn stover with a maximum power produced was 406 mW/m^2.

In this study similar power generation studies was conducted with a different kind of lignocellulosic biomass; citronella bagasse (CB). Treated and untreated CB was applied in a dual-chambered MFC and the performance of MFC in terms of power generated will be presented.

MATERIALS AND METHODS

MFC design and set-up

Dual chambered MFC was fabricated as shown in Fig.1. Two chambers was constructed and separated with a proton exchange membrane (PEM), Nafion 117 (Dupont Co. DE). The PEM was pretreated by boiling in H_2O_2 (30 %) in deionized water, followed by another boiling in 0.5 M H_2SO_4 in deionized water for one hour for each boiling before storing in deionized water prior to use. Both anode and cathode were carbon rods connected with copper wire. The anode and cathode compartments were filled with 1.1 L of 50 mM potassium phosphate buffer (KPi), together with 50 g of pretreated lemon grass and 60 mL of inoculum. For cathode chamber, 1200 mL of 50 mM potassium phosphate is poured and 0.15 g of potassium permanganate is added as electron acceptor. No sparging of air was done in any MFC trials; instead the upper part of cathode chamber side was open for air to come in.

Fig.1: Dual chambered microbial fuel cell

Inoculum preparation

Wastewater taken from Anfil Tower (anaerobic tank), Effluent Treatment Plant, Pan Century Edible Oil (M) Sdn Bhd, Pasir Gudang was kept in refrigerated condition before used. The wastewater was added into a dual chambered MFC anode and acetate (20 mM) was used as an energy source for enhancing bacterial growth. After period of time (3 months of enrichment), the inoculum was centrifuged at 6000 rpm, 10 minutes and 4 ˚C which supernatant was discarded and pellet was resuspended by adding 20 mL of autoclaved 50 mM potassium phosphate buffer (pH 7.0) for each of the inoculum without any other modifications such as pH adjustment or addition of nutrients or trace-metals.

CB pre-treatment

CB leaves was oven-dried prior to use. The CB was ground in using household blender, subsequently sieved to obtain particle sizes of 0.25 mm to 1.0 mm. 50 g of grinded CB was mixed with 0.75 (w/v) % of NaOH solution and autoclaved for 15 min, under 121◦C and 15 psi. The pre-treated CB was recovered by filtration through porcelain Buchner funnel and was washed with several times of distilled water (approximately 4 L) to neutralize the pH. The pre-treated CB was immediately added to MFC. All CB was freshly pre-treated in every MFC operations.Pre-treated CB was analyzed for compositional content (cellulose, hemicelluloses and lignin) using standard analysis (Han & Rowell, 1996).

Calculation

Voltages produced by MFCs were recorded every 2 hrs using digital multimeter with data recorder (Fluke, USA). Current density (i, A/m^2) was calculated according to Ohm's Law $i = V/RA$, where V (V) is the voltage measured, R (Ω) is the external resistance, and A (m^2) is the projected surface area of the anode. Power density was calculated as P (mW/m^2) = 1000iV, where 1000 is needed for the given units.

RESULTS AND DISCUSSION

CB pre-treatment

Lignocellulosic biomass like CB can be used as the substrate in MFC. In fact, it is the promising feedstock for cost effective energy production. Anyway, it has to be pre-treated first to remove lignin, hemicelluloses and reduce the crystallinity of cellulose so that bacteria can utilize this biomass as substrate (Kumar *et al*., 2009). Before pre-treatment, dry CB was analyzed and its composition determined as of 29.64 % hemicellulose, 35.05 % cellulose, 19.81 % lignin, and 17.53 % others including extractives and ash. After the pre-treatment procedure, which was combination of diluted NaOH and steam hydrolysis, only 4.1 % of the cellulose was removed and more than 80 % of lignin and hemicelluloses was removed (data not shown). The composition of xylan, mannan and arabinan, that made up the hemicellulose component were not further detected since this study only focused on the reaction of the cellulose component. The chemical composition of the citronella in this study was slightly different from citronella reported by Rolz *et al.* (1986). The remaining cellulose was used for MFC trials.

TABLE 1
Chemical composition of citronella bagasse (CB)

Component	wt%, dry basis in biomass
Cellulose	35.05
Hemicellulose	29.64
Lignin	19.81
Extractive	12.35
Ash	5.18

Cell concentration effect

Dual chambered MFC trials have been conducted in duplicates to validate the data in terms of consistency. In addition, to achieve the same starting (Open circuit voltage) OCV, the dual chambered MFC was operated first without any CB, until stable OCV was reached. Then fresh medium was added with CB prior to flushing out the previous medium. To achieve different concentrations of cells, mixed cultures used were centrifuged, and cells were resuspended in 10 mL of 50 mM KPi (pH 7.0) and this was considered as initial suspension for the MFC. Prior to use, this suspension was diluted to 10-fold and 100-fold dilution with the same buffer for lower concentration of cells.

Fig.2 shows the influence of cell concentration on the voltage output of the dual chambered MFC with pre-treated citronella bagasse. Different cell concentrations show significant effect on maximum voltage generated. A maximum voltage of 0.35 V was obtained at the initial cell suspension used, and 0.29 V and 0.2 V achieved for both 10-fold and 100-fold dilution respectively. Since the pre-treated CB mass was the same in all MFC trials, the rate of degradation of CB and the utilization of degraded CB products (mainly glucose) seems to be the rate-limiting factor here. Pre-treated CB (mainly cellulose, data not shown) gave different final concentration of cellulose and glucose after 100 hours of operation time. 80 %

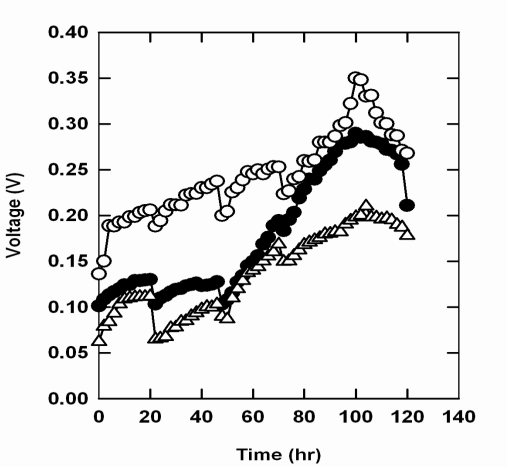

Fig.2: Voltage generated versus time using different cell concentrations. Symbols: Intitial (○), 10-fold (●) and 100-fold (△) cells concentration. Operation time was 120 hrs for each

of cellulose degradation has been achieved for high cell concentration compare to the lower cell concentration. In bacterial reproduction, most electrons generated through oxidation are consumed for metabolism; only small fractions remain to be transferred to the anode, resulting in low net efficiencies. As results, with high concentration of cells could suggest fast degradation from cellulose to glucose and finally to a point which electrons produced were more concentrated and probably enough to produce more power. It was difficult to analyze the amount of electrons consumed or transferred directly from these observations, but MFC performances can be assessed using polarization curves.

Polarization curve

When the OCV of MFC achieved plateau phase, the resistance (0 – 10,000 Ohm) between the electrodes was lowered stepwise and at each resistance value, voltage was measured and the power and current output were calculated. Fig.3 shows polarization curves that along with the external resistance increasing, the power output decreased. Fig.3 shows current density-power relationships for pre-treated CB and as control carboxymethyl cellulose (CMC) was used. Both experiments were conducted with initial cell suspensions. The maximum power density was 30 mW/m^2 at 0.24 mA/m^2 with pre-treated CB compared to 20.5 mW/m^2 at 0.36 mA/m^2 with CMC. The results were not surprising since CB is a complex substrate, which not only contains cellulose, as shown in Table 1. Other constituents probably had been degraded and produced additional electrons for power generation. In terms of power generated, low power density observed for both treat and untreated CB.

Even much lower values achieved with untreated CB. The low power density could also due to the different microbes in a mixed culture in addition to the complexity of CB itself. In the mixed culture, microbes that able to degrade cellulose, subsequently convert glucose to electrons, probably compete in terms of electron consumption for metabolism and transferring electrons. Such electron analysis studies are not in the scope of our research. Furthermore, the

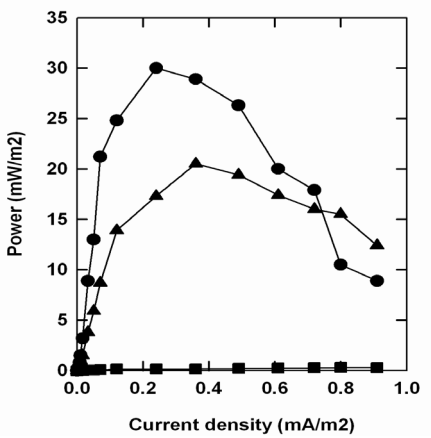

Fig.3: Power versus current density obtained in treated and untreated. Symbols: Pre-treated (●) CB with NaOH and autoclaving, CMC as control(▲) and un-treated (■) CB.

untreated CB has suggested that pre-treatment is very important to overcome the recalcitrant of lignin and exposed cellulose for microbial degradation.

Microbial community

To understand the microbial constraints on various fuel-powered MFCs, several groups have characterized microbial communities. Microbial communities from various systems are very different and often diverse, ranging from well-known metal- and anode-reducing bacteria to unknown electric generating bacteria. In many of MFC operations conducted, biofilm has been observed on the anodic electrode and was tested on nutrient agar and subsequently tested for CMC degradation using CMC (1.0 % w/v) agar plates. One culturable species have been isolated that able to degrade CMC (Fig.4) and two others which grew well on nutrient agar plates but not CMC. Based on microscopic analysis and gram identification all microbes showed bacilli rod like shape and negative in gram staining.

In most studies in biofilm microbial community, diverse microbes consist of electrochemically active and fermentative microbes (Zhang *et al*., 2009). In the anodic compartment no chemical mediators were added and at some extend there are probably some species that can directly or via self-mediated substances transfer electrons to electrode. Due to some constraints, the microbes isolated in this study were not identified and furthermore more analysis needed for a thorough characterization of these microbes. It is also important to confirm unculturable microbial community that may also involved in mediating electron transfer (Lovley, 2006; Zhang *et al*., 2009; Kim *et al*., 2004).

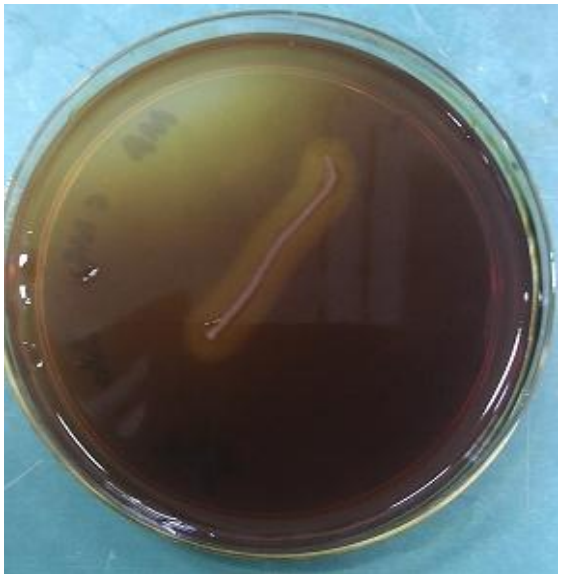

Fig.4: *CMC degradation.* Pure culture of microbes were streaked on CMC (1.0 % w/v) agar plates and after an overnight incubation, Lugol's iodine solution was poured on the plates and incubated in room temperature (11 and 12).

CONCLUSION

It was demonstrated that citronella bagasse (CB) could be used as a substrate for electricity generation in dual chambered MFC. CB is a complex biomass and difficult to be utilized biologically. The power densities produced were not high enough compare to other substrates and not comparable with those achieved with glucose. In order to increase performance of MFC and production of electricity, more studies should be made in terms of efficiency of CB saccharification (more glucose produced) and optimization of degradation of CB.

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