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Study on operation of a microbial fuel cell using mesophilic anaerobic sludge

Katalin Bélafi-Bako*, Balazs Vajda, Nandor Nemestothy

University of Pannonia, Egyetem u. 10, 8200 Veszprem, Hungary
Tel. +36-88-624726; email: bako@almos.uni-pannon.hu

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ABSTRACT

A two-chamber microbial fuel cell (anaerobic anode chamber and air-sparged cathode chamber) was designed and built in our laboratory where carbon fibres were used as electrodes and Nafion 0125 protonselective membrane was placed between the two cells. Anaerobic sludge from a local biogas plant was applied in the anode chamber and various substrates were used to study the operation of the system and to measure the electric power generated.

Keywords: Bioenergy; Microbial community; Power; two-chamber cell

1. Introduction

Microbial fuel cells (MFCs) are considered as highly promising renewable green bioenergy sources [1–3]. The MFC is a bioreactor converting chemical energy of organic compounds to electrical energy by catalytic reactions of microbes under anaerobic conditions, i.e., it is a bioelectrochemical system converting biomass spontaneously into electricity through the metabolic activity of the microorganisms [4,5]. The principle of the operation is the release and transfer of electrons from microbial cells onto the anode electrode. This process, however does not always occur readily, in some cases mediators are needed to improve the release and transfer. Considering the mechanisms involved (studied intensively) in electricity generation, the MFCs can be divided into two main groups: mediator less and mediator applying systems [3,4].

A MFC in general consists of an anodic and cathodic chamber divided by a proton selective membrane. Microbes in the anodic cell – mostly attached to the electrode surface forming a biofilm – oxidize the substrates and generate electrons and protons in the process. Electrons are attracted by the anode and are transported to the cathode through an external circuit (wire). Protons are passing through the membrane and enter the cathode cell where they combine with oxygen to form water.

In the last decade MFCs have been intensively studied, fast development can be observed and several reviews on MFCs have been published [6,7]. MFC-s can be operated by either monoculture (e.g. *Geobacter sulfurreducens*, *Shewanella oneidensis*, *Lactococcus lactis*) – where the species release electron to the anode electrode directly or with the use of electroactive metabolites –, or multiculture (microbe consortia) system, which can be found in e.g., sewage sludge acting in a similar way [6,8]. However it has not yet been reported what mechanisms are involved in such an ecosystem.

In MFCs substrate is considered as one of the most important biological factors affecting electricity generation [9]. The effect of various substrates (e.g., lactate, glucose, xylose) on the effectiveness has been widely investigated [8–10]. It has turned out recently that electricity generation in the MFCs can be coupled with the degradation of organic matters even e.g., waste water treatment processes [11–15]. In these kinds of MFCs a

*Corresponding author.

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microbial community carry out the degradation as consortia, resulting in a real environmental-friend process. Various types of waste waters were investigated (e.g. beer brewery waste water, food industrial waste water) where the degradation can be followed by COD removal determination [15–17]. In MFCs applied for treatment of organic matters, the feed can be enriched with various substrates. It has been noted that non-fermentable substrates are superior to fermentable substrate as the electron donor for power output and electron recovery. E.g., it was reported that an acetate enriched MFC produced higher power output than a glucose enriched MFC [18]. To find out the intrinsic reasons, the microbial community should be studied and phylogenetic analysis should be conducted.

The architecture, construction of the cells (including e.g. electrode designs) also has a high impact on the electricity production [19,20]. The surface area of the anode should be quite high to provide a surface for biofilm. One of the key parameters in the architecture of MFCs is the proton selective membrane. Cation selective membranes (used mainly for electrodialysis) are usually applied in the system, which allows high rate of proton transport [15,16].

The power generated in the MFCs is quite low and the main aim of the current studies in this area is to improve it significantly. We think, however, that not only the power should be increased, but the stable operation has to be maintained longer, as well. Moreover it seems that combination of MFCs with degradation of wastes is considered beneficial. However, the sludge itself does not provide enough nutrient for the microbes, it should be completed with substrates. Various substrates were studied so far, but the list is not complete [9]. Thus in this work the effect of various substrates (fermentable and non-fermentable) added to the initial mesophilic anaerobic sludge on the electricity generation was investigated experimentally.

2. Materials and methods

A two-chamber MFC was designed and constructed; its scheme is depicted in Fig. 1. Both cells have a 240 cm^3 volume, the membrane between them was a Nafion N115 proton selective membrane, its surface area was 42 cm^2 and thickness was 125 µm. In the anodic cell a complex mesophilic anaerobic sludge (from a local working biogas plant, initial COD value was 70,000 mg/l), while in the cathodic cell distilled water was used. Both electrodes were carbon cloth, their surface area was 50 cm^2. The electrodes were connected via a resistor (10 Ω) and the voltage data were continuously quantified by

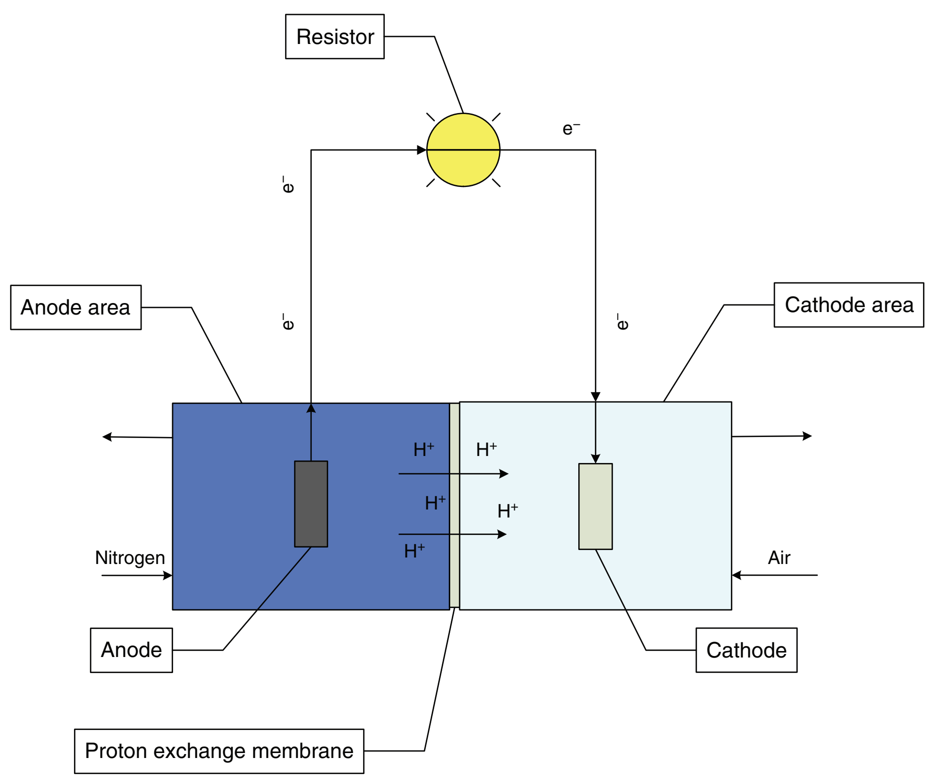

Fig. 1. Scheme of the MFC.

Fig. 2. Picture of the MFC constructed.

a parallel measuring system. It contained a 100 MΩ resistor and the voltage data were directly collected by a data acquisition device (National Instruments USB-6008/6009). The data were recorded by the LabVIEW program. Based on the voltage and resistance data the current values were calculated, thus the electric power (in mW units) was possible to provide. The cumulated electricity data were summarized (in mWh) taken into account the operating time.

The picture of the MFC is presented in Fig. 2.

The anaerobic sludge applied in the anodic cell was pretreated prior to usage. During the pretreatment no nutrients were added (approximately 2 weeks), thus the microbial consortia was exhausted (starving), only the most viable microorganisms have survived in the rather poor medium. Thus the weaker methanogenic and acetogenic strains – which are characteristic members of an anaerobic sludge, but are not really desirable in an operating MFC – were perished. This pretreatment resulted in a less heterogenic consortia, which provided measured data with much higher reproducibility, i.e., the behaviour of the pretreated sludges – obtained from the local biogas plant in various time interval, with different compositions – was comparable in our experiments.

The MFC was placed in a thermostated container, where the liquids in both cells were possible to circulate and stir. In the cathodic cell air was entered continuously by a pump to ensure aerobic environment, while N_2 was sparged through the anodic cell to assure the anaerobic conditions. The MFC reactor was initially inoculated with the pretreated anaerobic sludge. Then the microbial consortia started to operate in the cell and they were allowed to adapt the actual conditions and colonise locally.

3. Results

In the first experiments the operation of the MFC was studied, where the voltage data as a function of time were detected (Fig. 3). As it can be seen a quite smooth curve is observed and voltage between 4 and 5 mV was detected for a longer time period.

The MFC was inoculated with the pretreated sludge, and – as a result – a more stable, reliable and reproducible operation was possible to achieve.

Initially the pH of the anodic cell was between 6.5 and 6.8 and it has not changed till the level of nutrients was enough for the microbes. When the nutrients were consumed, the activity of the microbial community has declined which was indicated not only by the falling in voltage data, but by the decreasing pH, down to 4-4.3.

To study the stability and the limitations of the MFC system, a serial of experiments was planned and carried out, where various nutrients were added to the anodic cell to enrich the medium and their effects were recorded. Various volumes of 10% glucose and acetate solution were added in certain time of the experiment. As it is summarized in Table 1, 50, 100 and 200 µl substrate solutions were added to the chamber, resulting in a glucose or acetate input in the anodic cell. The voltage (and power) data were measured and presented in Figs. 4 and 5 for the glucose and acetate feeding, respectively.

Acetate as a substrate in MFCs has been intensively studied [9]. It is a single compound and used as a carbon

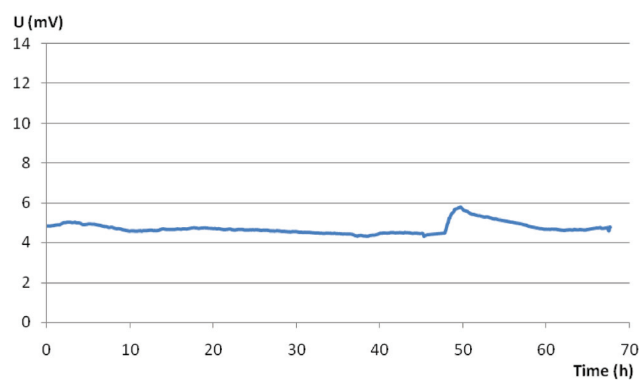

Fig. 3. Voltage data versus time without feeding.

Table 1
Data on substrate feeding

	Feed 1	Feed 2	Feed 3
Volume of substrate solution added (µl)	50	100	200
Glucose or acetate input (mg)	5	10	20
Substrate concentration in the anodic cell (mg/l)	21	42	83

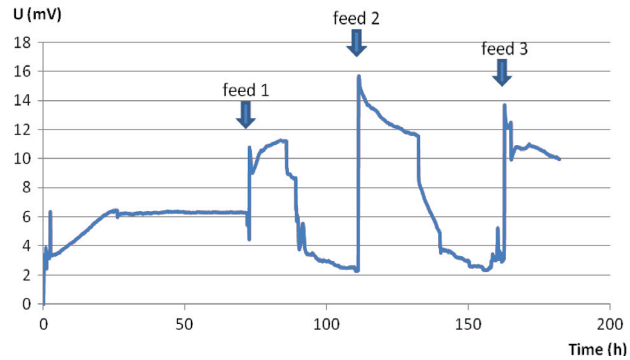

Fig. 4. The effect of glucose feeding on the voltage data.

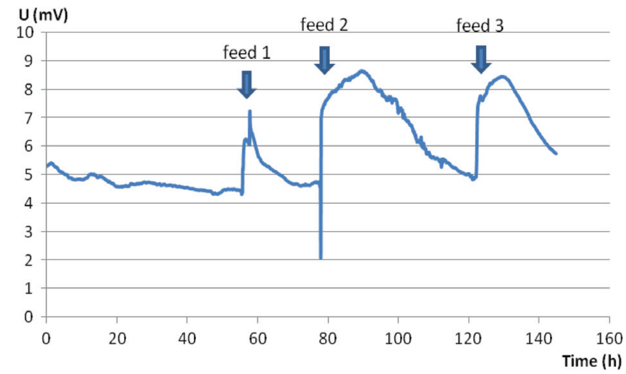

Fig. 5. The effect of acetate feeding on the voltage data.

source to induce electro-active bacteria. Moreover acetate is commonly applied as a substrate because of its inertness towards alternative microbial conversions (fermentations and methanogenesis). Glucose is another widely used substrate in MFCs. Glucose was found to generate less power and its energy conversion efficiency was lower than for acetate. In this serial of experiments the electricity generation ability of MFC working with anaerobic sludge enriched with acetate or glucose as substrate from time to time was aimed to determine.

As it can be seen from Figs. 4 and 5 a fast lift up of the voltage (for glucose it was above 10 mV) – compared to the experiment without feeding – was observed in all cases after the substrate addition followed by a slower and gradual decreasing period. Its length has depended on the amount of the substrate.

In case of acetate substrate the raising period for the voltage data was lower than for glucose substrate implying that glucose is the preferred substrate in this case. The unexpected behaviour can be probably explained by the fact that we applied – unlike the other data reported in literature papers – pretreated sludge, not a "fresh" one. The remaining living members of the microbial consortia have consumed more from the added fermentable substrate, glucose for their own metabolism to strengthen them, thus they were able to process more organic matters available to generate more power. Acetate as a non-fermentable substrate could not produce greater effect under the particular circumstances.

The voltage data obtained were between 10 and 16 mV in the case of glucose feedings. Since a 10 Ω resistor was used in the circuit, the current density (normalized to the 50 cm^2 carbon cloth electrode) was calculated between 200 and 320 mA/m^2. These values are comparable or even higher than certain current density data from literature, where e.g., food industrial wastes and sludge were applied in the MFC [17]. The power density values calculated from the current density and voltage data were between 2.0 and 5.1 mW/m^2 which are – similarly – comparable to the data published in literature.

The power density values were maintained for various time periods (measured, too), which made it possible to calculate energy data (in mWh/m^2 unit). Thus we were able to determine how long the operation time could be maintained in the particular MFC and how much energy could be obtained from the system (e.g., to charge a battery). Therefore these energy data were added and the cumulated values were presented in Fig. 6. Now it was clear that altogether more than 2500 mWh/m^2 energy could be obtained during 200 h operation time under the given circumstances.

In Fig. 6 the cumulated energy data also confirmed, that glucose was the preferred substrate in this sequence of experiments: higher power output was obtained for glucose than in acetate.

Based on the experimental data we concluded that MFCs are able to work with higher efficiency if proper, degradable organic substances are available, thus more power can be generated for longer time period. More types of substrates and further studies on stable operation are planned in our experiments in the future.

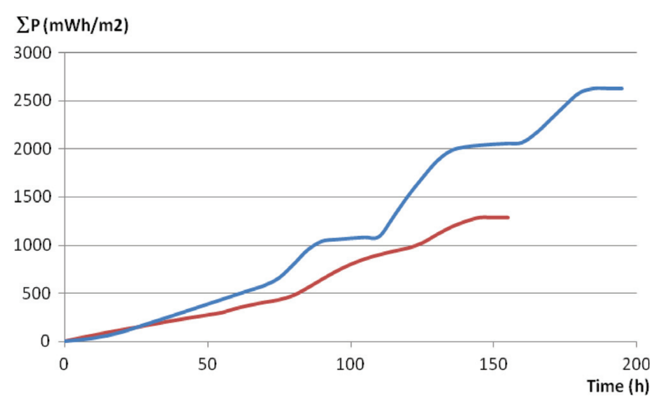

Fig. 6. Cumulated energy data for glucose (blue line) and acetate (red line) feeding.

4. Conclusion

A two-chamber MFC was designed and built in our laboratory where carbon cloth (fibres) were used as electrodes and Nafion 0125 protonselective membrane was placed between the two cells. Pretreated anaerobic sludge from a local biogas plant was applied in the anode chamber. Experiments where the feed was enriched with two substrates: glucose and acetate were carried out to study the efficiency and stability of the system and to measure the electric power generated. It has turned out that glucose had higher effect on the electricity generation that acetate, and power data obtained for glucose enriched system were found similar to the data published in literature, i.e., comparable performance was achieved in our MFC system.

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