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# The influence of operational conditions on the performance of a microbial fuel cell seeded with mesophilic anaerobic sludge

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ABSTRACT

In this work, the influence of operational parameters such as organic load, pH and temperature on power generation and methane production was studied in a continuous flow air-cathode microbial fuel cell (MFC) seeded with mesophilic anaerobic sludge. Power generation was accompanied by methane production, when fed with either glucose or acetate, however the ratio of methane-to-electricity production strongly depended on operational conditions. At a pH of 7, electricity production exhibited an Andrews-like dependence on carbon source concentration, whereas methane production followed a Monod-like dependence. pH-stat tests showed maximal power output at a pH of 6.3, which coincided with a decreased methane production. Cathode heating to 62 °C resulted in increased electricity generation with an insignificant increase in methane production.



## 1. Introduction

Electricity production in a microbial fuel cell (MFC) offers an alternative method of power generation, where a broad range of renewable carbon sources can be used [1–7]. In a MFC, anodophilic microorganisms degrade organic matter and transfer electrons to the anode via membrane-bound proteins, nanowires, or by self-produced mediators [8–10]. MFC studies suggest that electricigenesis is widespread among microbial communities. Diverse sources of anodophilic microorganisms, such as anaerobic sludge [11], activated sludge [12], domestic wastewater [13], and marine sediments [14] have successfully been used for MFC inoculation.

Application of MFC technology for wastewater treatment might require the presence of a mixed microbial consortium capable of hydrolysis and fermentation of long-chain carbohydrates and proteins to readily degradable substrates such as volatile fatty acids, which is why an anaerobic mesophilic sludge with its diverse microbial community of hydrolytic, fermentative, acidogenic, and acetogenic microorganisms is a good inoculum choice. However, the anaerobic sludge also contains significant methanogenic population, which is expected to compete with the anodophilic microorganisms for acetate, thereby decreasing the apparent Coulombic efficiency of power generation [15–17]. Previous studies have evaluated power production from a variety of carbon sources [3,4,6] and have shown the co-existence of methanogenic and anodophilic microorganisms [17,18] as well as the influence of pH, organic load, and temperature on MFC performance [19–24], but their focus was mainly on electricity production. Also, most of the previous tests were conducted in fed-batch MFCs [21,23,24], which complicated the analysis of the process kinetics. In this study, a steady state approach was used to evaluate the impact of operating conditions on the electricity and power production in a continuous-flow MFC.

## 2. Materials and methods

### 2.1. MFC design and operation

Two single chamber MFCs with air-cathodes [25] were used. The cathodes were gas diffusion electrodes (GDE) with a Pt load of 0.5 mg $cm^{-2}$ (GDE-LT-120EW, E-TEK Division, PEMEAS Fuel Cell Technologies, Somerset, NJ, USA). To prevent water losses through the cathode surface, a silicon spray (Silicone Water-Guard, Atsko Inc., Orangeburg, SC, USA) was used to create a hydrophobic coating on the side of the cathode exposed to air. The anodes consisted of a 5 cm × 10 cm piece of carbon felt (Speer Canada, Kitchener, ON, Canada) with a thickness of 5 mm.

The anodic chambers were made of polycarbonate plates. One MFC (MFC-1) was assembled using two plates and had a volume of 110 mL. The distance between the electrodes in this MFC was 1.5 cm and the anode occupied only 25% of the chamber volume.

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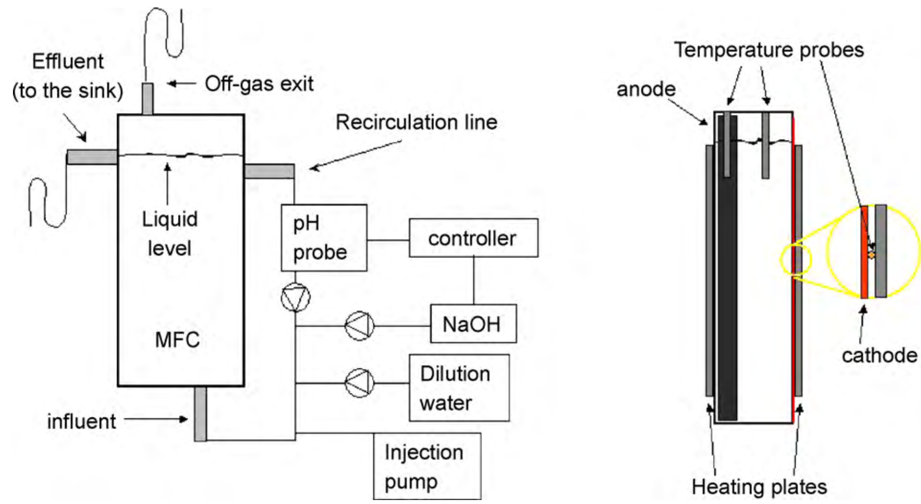


**Fig. 1.** Diagram of continuous flow MFC setup (left panel) and anodic chamber diagram showing positions of heaters, thermocouples, and electrodes (right panel).

Another MFC (MFC-2) contained one anodic plate so that the chamber volume was reduced to 50 mL. In this MFC a layer of J-Cloth® was used to separate the electrodes, providing an electrode spacing of approximately 1 mm and reducing electrolyte ohmic resistance.

Mixing in the anodic chamber was achieved by liquid recirculation at 0.57 L $h^{-1}$ by a peristaltic pump placed in the external recirculation loop (Fig. 1). Gas production was measured by electronic bubble counters (Innoray Inc., Montreal, Canada) installed at the gas exits. The anodic chamber pH was maintained at a preset level by a pH controller using 0.05N NaOH.

Temperature was measured by thermocouples installed in the carbon felt, in the anodic liquid between the electrodes, and between the cathode and the heating plate. The temperature was controlled using a temperature controller (JCR-33A, Shinko, Osaka, Japan) and a 5 cm × 8 cm heating plate placed on anodic chamber wall. An additional heating plate was installed on the cathode side of the MFC-1 chamber as shown in Fig. 1. Graphite rods (2 mm diameter) were placed between this heating plate and the cathode to allow for air circulation. Unless specified, the anodic liquid thermocouple and the heater installed on the anode side were used for temperature control.

The MFCs were operated in a continuous flow mode with a retention time of 12 h. Stock solutions of glucose or acetate and nutrients were combined in a single concentrated solution and fed at a rate of 5 mL $day^{-1}$ by an infusion pump (NE-1000, New Era Pump Systems Inc., USA). Dilution water was fed with a peristaltic pump and combined with the nutrient stream before entering the anodic chamber. MFC operation was carried out at several combinations of organic load, pH, and temperature, as described in Tables 1 and 2. Each set of operational parameters was maintained for at least 3 days to insure steady state conditions. Experimental results obtained at steady-state were used for performance evaluation. Overall, each MFC was operated for about 4 months.

### *2.2. Inoculum, media composition, and analytical methods*

The anodic compartments of the MFCs were inoculated with 3 mL of homogenized anaerobic mesophilic sludge (VSS = 50 g $L^{-1}$) (A. Lassonde Inc., Rougemont, Quebec, Canada). The stock solution of nutrients contained (g $L^{-1}$): yeast extract (0.93), $NH_4Cl$ (18.68), KCl (148.09), $K_2HPO_4$ (64.04), $KH_2PO_4$ (40.69), and glucose or acetate. The stock solution of microelements contained (in g $L^{-1}$): $FeCl_2{\cdot}4H_2O$ (2), $H_3BO_3$ (0.05), $ZnCl_2$ (0.05), $CuCl_2$ (0.03), $MnCl_2{\cdot}4H_2O$ (0.5), $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$ (0.05), $AlCl_3$ (0.05), $CoCl_2{\cdot}6H_2O$ (0.05), $NiCl_2$ (0.05), EDTA (0.5) and concentrated HCl (1 μL). 1 mL of this stock solution was added to each litre of dilution water. The concentration of sodium acetate (anhydrous) in the stock solution was varied from 27.3 to 109.3 g $L^{-1}$ and glucose concentration was varied from 4 to 160 g $L^{-1}$ in order to obtain the desired organic load. All stock solutions were filter-sterilized. The influent solution, which combined dilution water, microelements, and nutrients, had a conductivity of 14–16 mS $cm^{-1}$.

Glucose and lactate concentrations were measured by high-performance liquid chromatography (HPLC, Waters Chromatog-

**Table 1**
Operational conditions and MFC-1 performance observed in glucose, pH, and temperature tests. The MFC was operated at $R_{ext}$ = 200 Ω.

| Test | OLR ($g\,L_A^{-1}\,day^{-1}$) | pH | Anodic liquid temp (°C) | $P_{200\,\Omega}$ ($W\,m^{-3}$) | $CE_A$ (%) | $CH_4$ prod. ($L(L_A\,day)^{-1}$) | $CH_4$ yield ($L(g\text{-}COD)^{-1}$) | COD removal (%) |
|---|---|---|---|---|---|---|---|---|
| Glucose | 0.19 | 7 | 25 | 2.7 | 42.1 | 0.01 | 0.06 | 92.7 |
| | 0.47 | | | 4.8 | 23.1 | 0.02 | 0.06 | 89.7 |
| | 0.93 | | | 7.9 | 15.3 | 0.11 | 0.13 | 87.1 |
| | 1.86 | | | 7.8 | 7.0 | 0.26 | 0.16 | 87.9 |
| | 3.72 | | | 8.2 | 4.1 | 0.49 | 0.16 | 82.3 |
| | 7.44 | | | 6.6 | 2.0 | 0.66 | 0.12 | 74.3 |
| pH | 1.86 | 6.5 | 25 | 9.8 | 8.1 | 0.15 | 0.09 | 91.2 |
| | | 6.25 | | 9.6 | 8.6 | 0.10 | 0.06 | 85.3 |
| | | 6 | | 8.8 | 9.1 | 0.12 | 0.09 | 77.2 |
| | | 5.5 | | 2.2 | 5.2 | 0.002 | 0.002 | 67.6 |
| Temp. | 3.72 | 6.25 | 25 | 9.4 | 4.7 | 0.16 | 0.06 | 76.6 |
| | | | 32 | 9.8 | 4.8 | 0.5 | 0.17 | 77.7 |
| | | | 36 | 10.4 | 5.2 | 0.19 | 0.07 | 74.0 |