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Testing various food-industry wastes for electricity production in microbial fuel cell

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ABSTRACT

Three food-industry wastes: fermented apple juice (FAJ), wine lees and yogurt waste (YW) were evaluated in combination with two sources of inoculum, anaerobic sludge and garden compost, to produce electricity in microbial fuel cells. Preliminary potentiostatic studies suggested that YW was the best candidate, able to provide up to 250 mA/m^2 at poised potential +0.3 V/SCE. Experiments conducted with two-chamber MFCs confirmed that wine lees were definitely not suitable. FAJ was not able to start an MFC by means of its endogenous microflora, while YW was.

Both FAJ and YW were suitable fuels when anaerobic sludge or compost leachate was used as inoculum source. Sludge-MFCs had better performance using YW (54 mW/m^2 at 232 mA/m^2). In contrast, compost-leachate MFCs showed higher power density with FAJ (78 mW/m^2 at 209 mA/m^2) than with YW (37 mW/m^2 at 144 mA/m^2) but YW gave more stable production. Under optimized operating conditions, compost-leachate MFCs fueled with YW gave up to 92 mW/m^2 at 404 mA/m^2 and 44 mW/m^2 in stable conditions.

1. Introduction

Microbial fuel cells (MFCs) are electrochemical devices that use the metabolic activity of microorganisms to oxidize fuels, generating electric current by direct or mediated electron transfer to electrodes (Rabaey et al., 2007; Schröder, 2007). In the anodic compartment, organic matter is oxidized by microbial metabolism, which transfers the electrons to the anode. In the cathodic compartment, oxygen or oxidized compounds are reduced either via an abiotic process or by microbially mediated reduction (He and Angenent, 2006).

Early studies on fuels in MFCs dealt with low molecular weight substrates, carbohydrates like glucose, fructose, xylose, sucrose, maltose and trehalose (Chauduri and Lovley, 2003; Kim et al., 2000), organic acids like acetate, propionate, butyrate, lactate, succinate and malate (Bond and Lovley, 2005; Holmes et al., 2004; Min and Logan, 2004), alcohols like ethanol and methanol (Kim et al., 2007) and inorganic compounds like sulfate (Rabaey et al., 2006). Later, the interest in complex substrates led to tests on starch, cellulose, dextran, molasses, chitin and pectin (Melhuish et al., 2006; Niessen et al., 2005, 2006; Rezaei et al., 2007). In parallel, the use of domestic wastewater as fuel and microbial source was largely reported (Liu et al., 2004; Rabaey et al., 2005). Research on domestic wastewater was extended to a large variety of industrial wastewaters, e.g. from starch (Gil et al., 2003) and wastewaters coming from the meat packing industry (Heilmann and Logan, 2006), swine farms (Min et al., 2005) and cereal- (Oh and Logan, 2005) and potato-producing units (Rabaey et al., 2005). Solid agricultural wastes such as corn stover (Zuo et al., 2006) and manure (Scott and Murano, 2007) have also been tested as fuel after being pretreated. Numerous variants of the experimental conditions affected the results but the power density obtained in these studies was generally in the range of 1–3600 mW/m^2, with most values lying between 10 and 1000 mW/m^2.

The choice of the inoculum source is a key parameter in MFC design. The most common sources of electroactive microorganisms have been domestic wastewater, activated and anaerobic sludge and marine sediments (Erable et al., 2009; Kim et al., 2007; Liu et al., 2004; Rezaei et al., 2007). Alternative sources have been reported: heat treated soils (Niessen et al., 2006), garden compost (Parot et al., 2008a), manure (Scott and Murano, 2007) and rumen (Rismani-Yazid et al., 2007). However, very little research has investigated electroactive native microflora in agro-industrial wastes although numerous agro-industrial wastes are rich in mixed populations.

The present work tested three kinds of waste coming from different sectors of the agricultural and food industries: fermented apple juice (FAJ), wine lees (WL) and yogurt wastewater (YW). Each waste was tested for its possible capacity to form electroactive biofilms from its endogenous flora. The same wastes were then tested as fuels to feed bioanodes that were formed with two different sources of inoculum: anaerobic sludge and garden compost. Anaerobic sludge (actually aerobic sludge driven to anaerobic conditions during an acclimating period) was chosen because of its common use as MFC inoculum. Bioanodes formed in garden

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compost have shown efficient electroactive properties with acetate (Parot et al., 2008b) and have revealed a rich microbial flora with remarkable electroactive capabilities (Parot et al., 2009). It was consequently expected that such bioanodes might be appropriate for a large variety of different substrates.

2. Methods

2.1. Waste media

To simulate a leachate of apple farm wastes, fermented apple juice (FAJ) was prepared by pressing Braeburn 65/75 apples; the juice was fermented in a sealed container at room temperature for at least 15 days. Flasks of 500 mL were filled and stored at 3 °C. Lees coming from the wine making process (WL) were obtained from a local wine grower. Yogurt waste (YW) was collected from the yogurt production line of a local dairy. Samples of both substrates were stored in 1.5 L plastic bottles at 3 °C or were deep-frozen for long-term storage.

When indicated, the media were diluted (1:20) with the buffer solution described below. pH and conductivity were systematically measured using a Schott Gerate pH-meter CG 882 and a Metrohm 660 conductimeter (Swiss). Total chemical oxygen demand (COD) was measured in anolytes and raw substrates following the standard method 8000 for 0–1500 mg COD/L (HACH France S.A.S.). Characteristics of the raw media and after dilution are reported in Table 1.

2.2. Inoculum sources and acclimation

Aerobic sludge was obtained from an urban wastewater treatment plant. Sludge was distributed in fully filled, closed 0.5 L bottles and acclimated to the different waste media by daily addition of 1 mL of raw substrate with a syringe placed in the screw cap. Substrate was added daily for 16 days and the whole acclimatizing period was one month. During the acclimating period, the sludge evolved rapidly to anaerobic conditions; for this reason we refer to anaerobic sludge in what follows.

The microbial flora was extracted from the garden compost by lixiviation. 10 mM NaCl solution was added to 1 L of compost to give a final volume of 3 L. This mixture was placed in 2 or 3 L Erlenmeyer flasks, stirred for 24 h and then filtered through felt cloth. The filtrate was placed in 0.5 L fully filled flasks and acclimated by addition of 1 mL waste media twice a week for 30 days; it was used one month after the last addition.

2.3. Electrochemical tests

The experimental unit was a cap-sealed three-electrode cell of 50 mL, or 500 mL when indicated, with graphite felt ($2 \times 2 \times 0.5$ cm, RVG, Carbone Loraine, France) as the working electrode, an Ag/AgCl or an Standard Calomel Electrode (SCE) reference electrode and a platinum mesh (2×5 cm) as counter electrode.

Chronoamperometry was performed at different potentials and cyclic voltammetry was recorded in the range −1.0 to +1.0 V/SCE at 10 mV/s in triplicate, using an SVP multichannel potentiostat (Bio-Logic Science Instruments; EC/Lab 2.0 software).

2.4. Microbial fuel cell studies

The two-chamber MFC was similar to the design already reported (Min et al., 2005). Two culture flasks (500 mL) were connected by a glass tube with a proton exchange membrane (3 cm diameter) in the middle (Ultrex, CMI-7000 Membranes International, Inc., USA). Graphite felt ($2 \times 5 \times 0.5$ cm or $2 \times 2 \times 0.5$ cm, RVG, Carbone Loraine) and platinum mesh (2×5 cm) were used as the anode and cathode respectively. Anolyte and catholyte had a volume of 500 mL. Four kinds of anolyte systems were used as follows:

(a) diluted substrate without exogenous inoculum;
(b) anaerobic sludge or compost leachate as inoculum with sodium acetate 2 mM as model substrate;
(c) sludge inoculum fed with different diluted substrates;
(d) compost leachate inoculum fed with different raw substrates.

The catholyte consisted of NaCl phosphate buffer (g/L): Na_2HPO_4, 2.75; NaH_2PO_4, 3.67; NaCl, 0.584 g/L; pH 6.7, conductivity 5.2 mS/cm. This buffer solution was also used in substrate dilutions. Gas diffusers were placed in both compartments to inject nitrogen into the anodic compartment and air into the cathodic compartment when indicated. Nitrogen was supplied from a laboratory line and air was supplied by an aquarium pump (1.5–2 L/min). Anolyte and catholyte were stirred with magnetic barrels (350 rpm).

The electrical circuit was closed with an external resistance of 1000 Ω. The cell potential drop U_{cell} (V) was recorded with a multimeter (Integra series 2700, Keithley Instruments, Inc., USA) interfaced with a computer. Current density J (A/m^2) was calculated as $J = U_{cell}/(R \cdot A_g)$, where R (Ω) is the external resistance and A_g (m^2) is the anode projected surface area. The power density (W/m^2) was measured as a function of current density by varying the external resistance from 100 to 56 324 Ω over a 3-min period.

2.5. Scanning electron microscopy (SEM)

SEM micrographs were taken with a Leo 435VP microscope (Germany) using the software SRV-32. Samples were fixed with 4% glutaraldehyde solution, post-fixed with 2% OsO_4 solution, gradually dehydrated with acetone 50%, 70%, 100% solutions, and finally coated with gold to be observed in SEM at 7.5 kV.

3. Results and discussion

3.1. Formation of electroactive biofilms under chronoamperometry with three different waste media (FAJ, WL and YW)

Chronoamperometry of three waste media: fermented apple juice (FAJ), wine lees (WL) and yogurt waste (YW) was performed at different potential values in the range +0.3 to +0.7 V/SCE with

Table 1
Characteristics of raw and diluted substrates.

Substrate	Conductivity[a] mS/cm	pH[a]	COD[a] mg/L	Dilution	COD[b] mg/L	Conductivity[b] mS/cm	pH[b]
FAJ	4.20	4.01	52 514 ± 19 926	1:20	3501 ± 2510	4.77	6.14
WL	1.45	3.69	349 250 ± 39 527	1:20	10 843 ± 3904	5.12	6.06
YW	4.82	4.05	136 542 ± 37 983	1:20	8169 ± 2568	4.53	6.15

[a] Raw substrate.
[b] Diluted substrate.