Using olive mill wastewater to improve performance in producing electricity from domestic wastewater by using single-chamber microbial fuel cell

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HIGHLIGHTS

- Olive mill wastewater (OMW) represents a problem for its disposal and treatment.
- Single-chamber MFC was used to produce electricity from OMW and wastewater (DW).
- MFCs fed with DW plus OMW gave 0.38 V (1 kΩ) and a power density of 124.6 mW m^{-2}.
- TCOD and BOD$_5$ of DW plus OMW mix was reduced of 65% and 50% respectively.
- Microbial characterization of electrodes bacterial communities indicate anode differences.

ARTICLE INFO

ABSTRACT

Improving electricity generation from wastewater (DW) by using olive mill wastewater (OMW) was evaluated using single-chamber microbial fuel cells (MFC). Doing so single-chambers air cathode MFCs with platinum anode were fed with domestic wastewater (DW) alone and mixed with OMW at the ratio of 14:1 (w/w). MFCs fed with DW + OMW gave 0.38 V at 1 kΩ, while power density from polarization curve was of 124.6 mW m^{-2}. The process allowed a total reduction of TCOD and BOD$_5$ of 60% and 69%, respectively, recovering the 29% of the coulombic efficiency. The maximum voltage obtained from MFC fed with DW + OMW was 2.9 times higher than that of cell fed with DW. DNA-fingerprinting showed high bacterial diversity for both experiments and the presence on anodes of exoelectrogenic bacteria, such as *Geobacter* spp. Electrodes selected peculiar consortia and, in particular, anodes of both experiments showed a similar specialization of microbial communities independently by feeding used.

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1. Introduction

Oil reservoirs depletion and climate changes, are currently topics of major concern to explore renewable sources of energy, by developing sustainable and environment-friendly technologies. One of the main goal of research is the efficient use of biomasses, especially wastes from agricultural and municipal processes, that are, nowadays, mainly burnt, land-filled or accumulated as excess biomass representing an economic burden for communities and industries.

Conventional biological wastewater treatments, such as activated sludge processes are energy demanding because of aeration requirements (Logan, 2008); moreover they produce large amounts of residual solids (sludge) which are costly to be treated and disposed (Murray et al., 2008). Aiming at operational costs reduction and energy efficiency improvement, new biological processes have been recently developed and studied for energy production and wastewater reduction; these processes included: methanogenic anaerobic digestion, biological hydrogen production and ethanol fermentation (Pham et al., 2006).

Microbial fuel cells (MFCs) that belong to this categories, consist in a bio-electrochemical process that converts the chemical energy of biodegradable organic compounds into electricity by anaerobic oxidation. Responsible of the process are specific bacterial species, the so-called "exoelectrogens", mainly belonging to the gamma- and delta-subgroups of *Proteobacteria* (e.g. *Shewanella*, *Geobacter* and *Pseudomonas* genera). These bacteria colonize the anode and produce electrons and protons from the organic matter, with CO_2 and biomass as final products (Lovley, 2010).

Several lab-scale studies were conducted to investigate power generation from artificial (Moon et al., 2006) or real wastewaters, such as vegetable wastes (Kannaiah Goud et al., 2011), brewery wastewater (Feng et al., 2008), cereal wastewater (Zuo et al., 2006), palm oil effluent (Cheng et al., 2010), paper wastewater (Nimje et al., 2012) and swine wastewater (Min et al., 2005). The power generated has been reported to be within the range of 40–300 mW m^{-2} depending on inoculum and substrate used, and reactor architecture. Power generated corresponded to a reduction of wastewater organic load, expressed as total chemical oxygen demand (TCOD), of 60–80% (Liu et al., 2004).

Literature suggests that MFC could be a readily applicable technology, especially with industrial and agricultural wastewaters with a high content of easily degradable organic material, resulting in a net positive energy production. Domestic wastewater (DW) has been widely exploited in MFC to substitute conventional aerobic disposal treatment, that involves high capital expenditure, high sludge production to be disposed, and considerable operational and energy consumption costs. It has been reported, for example, the ability of MFC to generate 26 mW m^{-2} of power, removing the 80% of the TCOD from domestic wastewater (Liu et al., 2004).

Olive oil is one of the main agricultural products in the Mediterranean area, that contributes for 95% to the annual worldwide oil production (over 30 million m^3 per year). The disposal of wastewaters coming from olive processing represents a huge environmental problem. This is particularly true for Italy that is one of the main olive oil producers in the world, with 1.2 million ha of land used for olive culture, yielding 3.2 Mg ha^{-1} of oil (Source: EUROSTAT, 2004–2007). This means that about 2×10^6 m^3 of olive mill wastewater (OMW) are produced annually in Italy, with a cost for their disposal of 30–50 € m^{-3} (ENEA, 2007).

According to olive fruit variety, cultivation conditions and extraction method used, OMW organic load (TCOD) may vary from 40 to 220 g L^{-1}, with a polyphenols content ranging from 200 to 8000 mg L^{-1} (Azbar et al., 2004). Within this range polyphenols can potentially have inhibition effect on bacteria activity involved in OMW biological treatment (Ntaikou et al., 2009). As consequence of that, OMW disposal requires physicochemical treatment, such as coupled evaporation and combustion, chemical coagulation and sorption, and oxidation (Kestioglu et al., 2005), although microbiological treatments, such as anaerobic digestion have, also, been tested (Bertín et al., 2010).

OMW has been extensively studied to be treated by anaerobic digestion, alone or in co-digestion with other biomasses, to reduce COD and to produce energy (S1). Nevertheless all studies indicated that it was necessary to operate a wastewater dilution to eliminate microbial inhibition (Azbar et al., 2004). For example Azbar et al. (2004) by diluting OMW, removed the 85% of TCOD at 35 °C, with an organic load (TCOD) below 4 g L^{-1}. Higher TCOD concentration than that indicated, or the use of undiluted OMW, inhibited the biological process (S1). Although studies cited indicated that diluted OMW can be anaerobically treated, no researches on the use of OMW by MFC are reported in the literature (Azbar et al., 2004). However OMW can be used to feed MFC by its dilution with other wastewater streams in order to reduce potential inhibition, allowing direct electricity production.

In this study it was investigated the effectiveness in using olive mill wastewater mixed with effluents coming from denitrification process of domestic wastewater (DW), in producing electricity in an optimized single-chamber open air cathode microbial fuel cell (scMFC). At the same time, the efficiency of the process in terms of TCOD and BOD$_5$ removed, was tested. Bacterial populations selected in the microbial fuel cells were studied and microbial community coming from wastewater and wastewater plus olive wastewater were compared and discussed.

2. Methods

2.1. Wastewater

Domestic wastewater (DW) were collected from a wastewater treatment plant in Northern Italy. Olive mill wastewaters (OMW) were collected from Frantoio Confraternita Seconda, Contrada Breccelle (Isernia, Italy) using a three phase oil mill grinder. Samples were placed on ice, shipped overnight to the laboratory, and stored at 4 °C; wastewaters were characterized upon arrival.

2.2. MFC reactors: manufacture, configuration and operation

Single-chamber, air–cathode MFCs containing graphite fiber brush anodes were constructed as previously described (Logan et al., 2007). Each reactor consisted of a liquid chamber 4 cm long by 5 cm in diameter, with a liquid volume of 28 mL. Brush anodes were made of a core of two titanium wires with graphite fibers (PANEX33 160 K, ZOLTEK) cut to 2.5 cm in outer diameter and 2.5 cm long. Each brush had an estimated surface area of 0.22 m^2 or 18,200 m^2 m^{-3}-brush volume for the brush, with 95% porosity (Logan et al., 2007).

The cathodes (3.8 cm diameter, 7 cm^2 total exposed surface area) were made by applying a platinum catalyst (0.4 mg Ptcm^{-2}, BASF) on the liquid-facing side of a 30 wt.% wet-proofed carbon cloth (type B-1B, BASF, US), while four PTFE diffusion layers were added on the air-facing side (Cheng et al., 2006).

MFCs were firstly inoculated with a mixture (60:40 v/v) of domestic wastewater (Canegrate Wastewater Treatment Plant, Italy) (60:40 v/v) and buffer solution containing 1 g L^{-1} sodium acetate (PBS 100 mMol L^{-1}; Na$_2$HPO$_4$ 9.152 g L^{-1}, NaH$_2$PO$_4$·H$_2$O 4.904 g L^{-1}, NH$_4$Cl 0.62 g L^{-1}, KCl 0.26 g L^{-1}; 982.5 mL PBS, trace minerals 12.5 mL L^{-1}, vitamins 5 mL L^{-1} for each liter (Liu and Logan, 2004). The initial pH of the solution was 7.2 ± 0.1. When the maximum voltage output was similar for three consecutive cycles (0.4 ± 0.05), the buffer solution and the sodium acetate were gradually omitted, until only DW or OMW were fed into the cells.

The test was conducted as follow: the cells (in triplicate) were run simultaneously for three batch cycles for each feeding substrate, i.e. undiluted domestic wastewater, and a mixture of DW and OMW. The DW + OMW mixture ratio was 14:1, to create an appropriate feedstock for the MFC process (Logan et al., 2006) i.e., pH of 6.38 ± 0.06 and the organic load of 4.3 ± 0.4 kg TCOD m^{-3}. Feeding solutions were replaced when the voltage dropped below 40 mV, forming one complete cycle of operation. All the tests were performed at room temperature (23 ± 3 °C).

2.3. Measurements and chemical analyses

The cathodes and anodes were connected with titanium wire and the voltage was measured by an external resistor (R_{ex} = 1 kΩ) every 15 min using a multimeter (2700; Keithley, United States) connected to a personal computer. Current generation was calculated by using the $I = E/R$ equation, while power output of the cells by using the $P = I*E$ equation, where I (A) is the current, E (V) the voltage, R (Ω) the external resistance and P (W) the power. Coulombic efficiency (CE), the ratio between Coulombs recovered and total Coulombs in the substrate, was calculated as previously described (Logan et al., 2006).

Polarization curves were obtained by varying the external resistance (10–10,000 Ω) every 30 min. and measuring the cell voltage. Power density (mW m^{-2}) and current density (mA m^2) were based on the surface area of one side of the cathode (7 cm^2) in