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Energy Harvesting From River Sediment Using a Microbial Fuel Cell: Preliminary Results

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Abstract: We have built a sedimentary fuel cell or Sediment Microbial Fuel Cell (SMFC). The device works on the principle of microbial fuel cells by exploiting directly the energy contained in sedimentary organic matter. It converts in electricity the sediment potential, thanks to microorganisms able to waste electrons from their metabolism directly to a solid anode instead of their natural electron acceptors, such as oxygen or nitrate. The sediment microbial fuel cell was made of a non-corrodible anode (graphite) buried in anoxic sediments layer and connected via an electrical circuit to a cathode installed in surface water. We present the first results of laboratory sedimentary fuel cell and a prototype installed in the river.

Keywords: Sediment, Bio-electricity, Fuel cell.

1. Introduction

A sustainable feeding of wireless microsensors is a major concern in water monitoring. They are typically powered by dry cell batteries, requiring frequent maintenance. Despite significant advancement in electronic components, the lifetime of remote wireless sensors is limited by the power source life. A possible solution to this problem is to produce power locally, where i is used.

A microbial fuel cell (MFC) converts energy, available in a bio-convertible substrate, directly into electricity. Sediment Microbial Fuel Cell (SMFC) [1], or Benthic Microbial Fuel Cell (BMFC) [2], is a kind of MFC powered by the metabolism of microorganisms living in anaerobic sediments. The microbial communities metabolize the available organic matter. During metabolism, organic matter is oxidized (electrons are released) and some electron acceptor is reduced (electrons are gained). Some particular bacterium strains naturally present in water bodies are able to directly transfer electrons to a solid acceptor, such as the MFC anode, without any mediator, instead of their natural electron acceptors, such as oxygen or nitrate. This transfer can occur either via membrane-associated components, or soluble electron shuttles. Some of electrochemically active strains involved in the reduction of metal surfaces, as Clostridium sp; like C. butyricum [3] and *C. beijerinckii* [4] a sulphate-reducing bacterium as *Desulfotomaculum reducens* [5], *Shewanella putrefaciens* [6], or *Aeromonas hydrophila* [7], have membrane-bound cytochromes. Other bacterium species, as Geobacter sp., having *pili* on their external membrane (*pilus* is a kind of microbial nanowire), are also able to transfer their electrons via these *pili* [8]. The potential of the anode will therefore determine the redox potential of the final bacterial electron shuttle, and therefore, the metabolism.

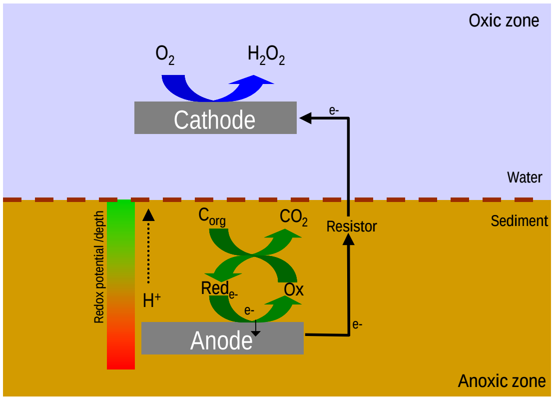

Fig. 1. Principle of a sedimentary microbial fuel cell (SMFC).

Several different metabolism routes can be distinguished based on the anode potential: high redox oxidative metabolism; medium to low redox oxidative metabolism; and fermentation. Hence, the organisms reported to date in MFCs vary from aerobes and facultative anaerobes towards strict anaerobes [9]. MFCs are attractive because they offer a relatively safe, environmentally friendly, continuous, simple power supply available from most freshwater sediments. There have been many attempts to demonstrate that SMFCs can produce electricity, in marine [2, 10, 11] or in freshwater [1, 12, 13] environments.

In this study we show the possibility of extracting energy from stream sediment, downstream of a combined Sewer Overflow (CSO).

2. Materials & Methods

2.1. Experimental Site

The river SMFC was installed in an artificial weir, downstream a CSO, in the Chaudanne Stream, a left-side tributary of the Yzeron River, a right-side tributary of the Rhône river (France), mostly located in the periurban zone of Greater Lyon, situated in the South-East of France. Consequently it is impacted by many polluted urban runoffs and CSO [14]. As polluted eco-systems showed higher power yield [12] we choose to install our device downstream the CSO of Grézieu-la-Varenne town (45° 44′ 54″ North, 4° 41′ 28″ East).

Sediment from this place was sampled (0–10 cm below sediment–water interface) in order to build a SMFC in the laboratory.

2.2. Sediment Microbial Fuel Cell (SMFC)

We constructed four SMFCs, one in river and three in laboratory. The anodes (50×10×3 cm) were made of HLM extruded graphite (Final Matériaux Avancés, Wissembourg, France) and its projected surface area was 0.136 m^2. The cathodes (25.5×25.0×0.5 cm) were made of graphite felt and their geometrical area was 0.133 m^2. For electrical connections, we used insulated wires, which were glued to graphite using conductive epoxy (Radiospares, France) and a stainless steel eyebolt, screwed at its end, is used to moor the electrodes in the riverbed. Electrodes were used without any surface treatment or catalytic impregnation.

2.2.1. Stream SMFC

The anode was installed in sediment at 20-30 cm depth in the anoxic zone and the cathode made of graphite felt floating on the surface water (Fig. 2).

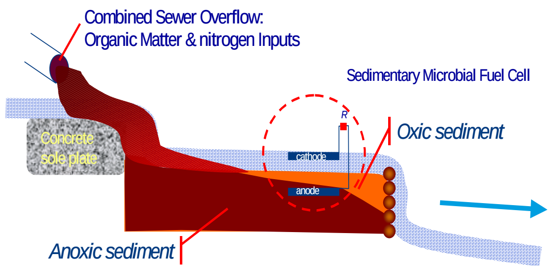

Fig. 2. SMFC in an artificial porous weir in a river.

The wires from the anode and the cathode were 5 m long, which was sufficient to connect to the SMFC to the multimeter placed on the riverbank.

2.2.2. Laboratory SMFC

Three laboratory SMFCs were built made of sediment and water collected in the river Chaudanne in order to reproduce the conditions actually existing on site. These SMFCs are constituted by a tank filled with 37 L of wet sediment. The top of sediment was filled with 13 L of stream water. Water is aerated by means of an air bubbler connected to an air pump for aquarium. The anode was buried below the sediment surface at a depth of 5 cm and the cathode floated on water surface. The surfaces of the cathodes were 0.028 m^2; 0.055 m^2 and 0.133 m^2.
The external circuit resistance was fixed at 1000 Ω. A lid minimized water loss via evaporation during operation and we maintained the water level constant by river water replenishing.

2.3. SMFC Characterization

The SMFC was run open circuit for the first two month from March 6 to April 17, 2012. The open circuit potential of the anode and the cathode of the SMFC were measured using a digital multimeter PAN 2035.

On April 17 and July 10, the current and power generation of the SMFC were characterized by polarizing the SMFC [1]. In the polarization experiment, the resistor between the anode and the cathode was changed from 10 kΩ to 5 Ω. Each resistor was applied for one minute before the potential was read and the change to the next resistor was made.

The power depends both on the voltage U (V) and the current I (A). Ohm's law links these latter factors to the fuel cell resistance R (Ω):

$$I = \frac{U}{R}, \tag{1}$$

The power P (W) was calculated from the measured cell potential U and the applied resistor R as follows:

$$P = U \times I = \frac{U^2}{R}, \tag{2}$$

The current density and the power density were calculated by dividing the calculated current and power by the anode surface area (0.13 m^2). To observe long-term power generation, a 1 kΩ resistance was connected between the electrodes continuously.

3. Results and Discussion

3.1. Laboratory SMFC

Experiments evidenced the feasibility of harnessing energy in the form of electricity in freshwater bodies by means of electrode assembly. The power density limits are around 9 mW/m^2 (Fig. 3). Higher power densities were observed in marine sediments: 28 mW/m^2 [15], 34 mW/m^2 [2] and in freshwater sediment 12 mW/m^2 [1], 15.6 mW/m^2 and 35.1 mW/m^2 respectively in running and still water bodies in tropical countries [12].

Our results are higher to those of Dumas *et al.* who, with a stainless steel electrode (area 0.12 m^2) measured in the sediments of the Mediterranean Sea (Italy) a power density of 4 mW/m^2 after 17 days of operation [11]. Note however that the power densities seem to vary according to the operating time (Fig. 3). Thus, a maximum of 34 mW/m^2 is achieved by Reimers *et al*, between the 20th and 31st day of operation, then they measured a power density equal to 6 mW/m^2 from 103rd to 114th day of operation [2], which corresponds to the duration of the presence of our electrodes in sediments Chaudanne (105 days).

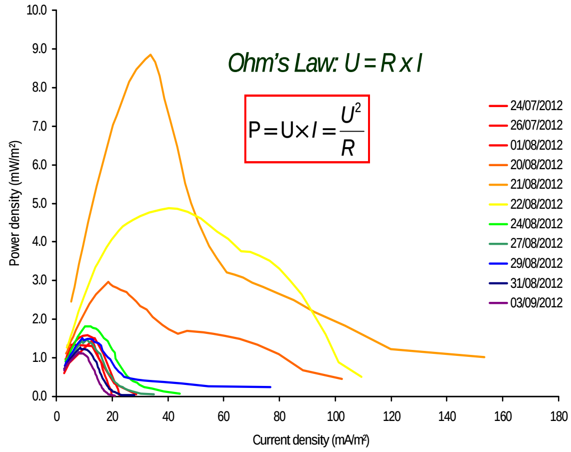

Fig. 3. Electric power supplied by the lab SMFC.

For all laboratory SMFCs we note an increase in power density during the first month of operation, then a fall (Fig. 4). These variations can be caused by the depletion of the amount of organic matter assimilated by microorganisms but also it could be a temperature effect on microbial metabolism. In fact, when the temperature increases by 10 °C, the coefficient of reaction rate is multiplied by a factor of 2 to 3 (Arrhenius equation).

If we compare the power density measured during the two months of operation with the average daily temperature (Fig. 4), we find a relatively good fit of the temperature curve with the evolution of the energy amount collected. This is not surprising, temperature is involved in both the Nernst equation to determine the voltage, and in the Arrhenius equation to determine biological activity.

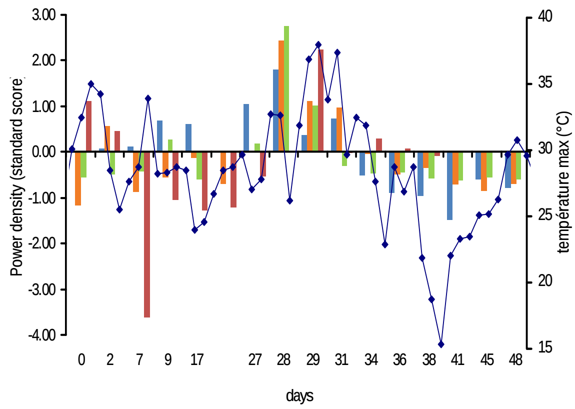

Fig. 4. Daily maximum temperatures superimposed on the power densities of SMFCs. (Standard score representation).

3.1 River SMFC

May and July measurements are shown Fig. 5. The maximum power density increases from 1.9 mW/m^2 in May (open circuit) to 8.8 mW/m^2 in July (closed circuit with 1 kΩ resistance).

The circuit closing leads to a quadrupling of the power density. This indicates that we must continuously extract the electrons wasted on the anode, by microbial biomass, in order to promote and maintain an electro-active biofilm. The nature of this electro-active biofilm should be verified by amperometric study of colonized anodes.

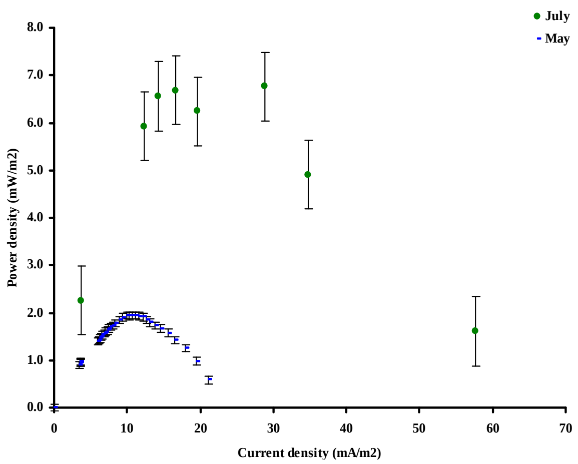

Fig. 5. Electric power supplied by the river SMFC.

With a power peak maximum equal to 8.8 mW/m^2, the SMFC installed in the river delivers electrical power comparable to the laboratory ones. Unfortunately, due to a severe low water during summer, we were not able to measure the potential of this SMFC during the two months of experimentation.

6. Conclusions

These preliminary results show that small amounts of electricity are extractable from river sediment. This energy must be continuously extracted to maintain maximum production.

Also, for operational use, this low energy supplied requires a storage and concentration device of harvested energy (capacitor) for periodic use (power management).

This energy source can be coupled with other sources present in the environment, such as energy piezoelectric or thermoelectric. Also, the production & consumption of electricity in situ require a new design of the energy management in sensor networks.

Acknowledgements

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