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In situ continuous current production from marine floating microbial fuel cells

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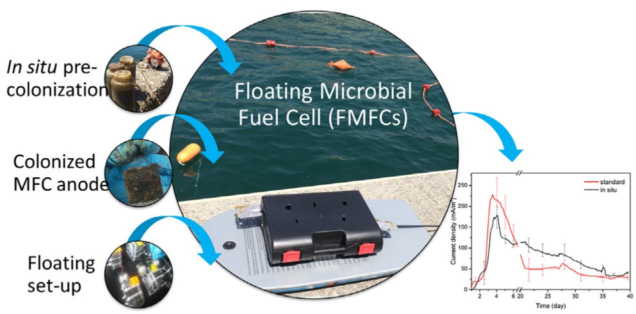
HIGHLIGHTS

- Marine floating microbial fuel cells exploited as portable power supplies.
- Novel devices able to continuously produce electricity using seawater as fuel.
- Average power density of 6 mW/m^2 during summertime and wintertime.
- The concept of floating microbial fuel cells Livestock is proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to power remote sensors and/or data transmission devices in an aquatic environment, sedimentary microbial fuel cells and floating microbial fuel cells have been proposed in the literature, representing a continuous source of renewable and sustainable energy. However, both classes of devices are characterized by large dimensions and are immobilized in the environment within which they are working. Accordingly, when portability and small dimensions are strict requirements, these configurations cannot be exploited.

The present work proposes a novel, compact and cost-effective floating set-up based on small-scale microbial fuel cells. A method for *in situ* anodic biofilm formation was validated through experiments conducted in laboratory and in a real marine environment. Carbon felt-based anodic electrodes were used to build different replicas of floating microbial fuel cells. Their overall performance was evaluated during two field measurement campaigns carried out in the Mediterranean Sea. The study demonstrated a high stability of the floating microbial fuel cells even in a real, uncontrolled environment. The devices were able to continuously produce electricity using seawater as fuel and electrolyte.

This study suggests that these devices can be used as portable power supplies for sensors in a complex environment such as the open sea due to the easy preparation of anodic electrodes, together with the simple architecture of floating microbial fuel cells.

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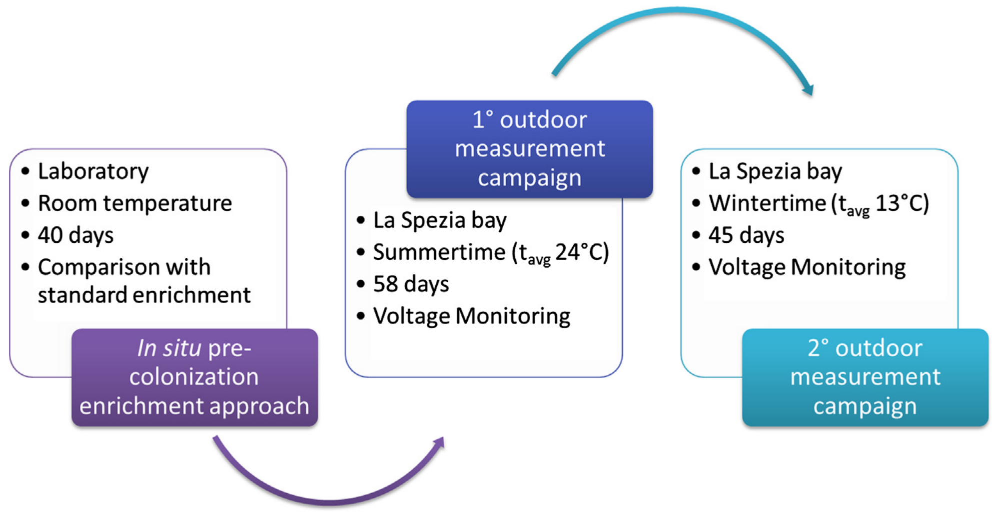

Scheme 1. Overview of the structure of the experimental work.

1. Introduction

Microbial fuel cells (MFCs) are bioelectrochemical devices that convert the chemical energy stored in organic compounds into electricity [1,2]. They represent a viable and low-cost solution for wastewater treatment, while simultaneously producing electrical energy [3,4]. According to Trapero et al. [5], MFC technology is now ready to enter the market for substituting conventional activated sludge. As opposed to common fuel cells, in MFCs the oxidation of the organic matter is carried out by microorganisms, called exoelectrogens [6], mainly proliferating under anaerobic conditions and usually arranged in the form of a biofilm onto the anodic electrode [7]. At the cathodic electrode, the circuit is closed through a reduction reaction. The most common reaction involves molecular oxygen, which is reduced to water exploiting protons and electrons from the anode. In order to speed up the kinetics of this reaction, a Pt-based catalyst is often employed [8]. When dealing with applications in aquatic environments, sedimentary microbial fuel cells (SMFCs) are usually exploited [9]. In this configuration, the anode is completely buried in sediment, which is rich in organic matter, while the cathode is suspended in overlying water [10]. The anoxic conditions are preserved at the anode due to the presence of the sediment and the device can work for long time with low or null maintenance costs [11]. Usually, SMFCs are characterized by large dimensions [12,13], and thus, after deployment, they are used *in situ* [14]. SMFCs were employed by Tender et al. to supply power to a meteorological buoy in river and salt marsh environments [11]. Arias-Thode et al. fabricated a 30 m-long linear array of SMFCs to power a seafloor magnetometer for the detection of passing ship movements [15]. Zhang and Angelidaki reported the use of a SMFC based on two pieces of bioelectrodes to remove nitrates and nitrites from eutrophic lakes [16]. Nevertheless, SMFCs are characterized by some disadvantages, including low operating voltages [17], large ohmic losses due to a large distance between the electrodes [18], restricted dissolved oxygen availability which limits cathode performance [19] and difficulty in providing continuous power [20]. In order to overcome some of these limitations, floating MFCs (FMFCs) have recently been proposed for aquatic applications, either with wastewater [21] or seawater [22]. This configuration is similar to an air cathode single-chamber MFC [23], in which both electrodes share the same reactor volume, using oxygen from air for the reduction reaction at the cathode [24]. Since FMFCs can float on the water surface, the cathode is directly exposed to air. Moreover, to limit the ohmic losses, the interelectrode distance is reduced. FMCFs with dimensions up to 0.3 m^2 were employed in the denitrification tank of a wastewater plant [21] and in a “floating garden” over a pond [25], to power remote environmental sensors and data transmission devices.

In all the works described above, the devices were immobilized in the environment in which they worked, either providing power to an external load or acting as water treatment elements. However, portability and small dimensions are strict requirements for several applications, for example when the device to be powered (sensor, instrumentation, etc.) is moving in the water or along its surface. To this aim, this work proposes a novel and compact floating set-up, based on small-scale single-chamber MFCs, able to continuously produce electricity when working in a real marine environment using seawater as fuel and electrolyte. To the best of our knowledge, this is first application of small-scale FMFCs in a real marine environment, in view of a future exploitation as portable power sources for low-power sensors and devices. To minimize manual operation and to exploit the potentiality of the marine biological community as a catalyst [26,27], the present work proposes an *in situ* pre-colonizing enrichment approach and compares it to standard enrichment procedure. Moreover, to boost microbial metabolism, especially during the start-up phase, the anodic electrode is used in conjunction with an agar-based synthetic solid-state electrolyte (SSE), containing carbonaceous and nitrogen sources, recently proposed by our group [28] and employed here for the first time in outdoor experiments. In this configuration, the SSE ensures nutrients for microbial growth and provides a physical filter for O_2, thus maintaining the anode partially anaerobic. No catalyst layer was applied to the cathodes, allowing the spontaneous formation of an aerobic cathodic biofilm able to carry out the oxygen reduction reaction, like that exploited by Wetser and co-workers [29]. The devices were successfully tested in our laboratory and then in a marine environment in the bay of La Spezia (north of Italy), exploiting a dedicated set-up for data acquisition and transmission. Field tests were repeated twice during summer and winter, in order to investigate the effect of seasonal changes and temperature on the microbial activity and consequently on MFCs’ performance.

2. Materials and methods

2.1. Structure of the work

The work was structured as described in the following and resumed in Scheme 1. Initially, the *in situ* pre-colonization enrichment approach was validated in laboratory tests. For this purpose, MFCs were fabricated using anodic electrodes prepared through: (1) the novel *in situ* pre-colonization enrichment approach based on seawater sediment (named *in situ* MFCs); (2) a standard enrichment approach performed in laboratory (named standard MFCs). The performance of *in situ* MFCs