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The influence of sludge retention time on mixed culture microbial fuel cell start-ups

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ABSTRACT

In this work, the start-ups of air-cathode microbial fuel cells (MFCs) seeds with conventional activated sludge cultivated at different solid retention times (SRTs) are compared. A clear influence of the SRT of the inoculum was observed, corresponding to an SRT of 10 days to the higher current density exerted, about 0.2 A m^{-2}. This observation points out that, in this type of electrochemical device, it is recommended to use high SRT seeds. The work also points out that in order to promote an efficient start-up, it is not only necessary to use high SRT seeds, but also to feed a high COD concentration. When feeding 10,000 ppm COD and keeping SRT of 10 d differences of current densities up to 0.1 A m^{-2} were observed within a cycle. Additionally it was observed that SRT influences direct and indirect electron transfer mechanisms, being the direct mechanisms the most relevant ones, accounting for more than 95% of the total electricity production.

1. Introduction

In recent years, research programs that focus on alternative technologies for the treatment of wastewater have attracted great interest [1,2]. One of the main objectives of these technologies is to develop self-sustainable wastewater treatment plants (WWTPs), able to reduce the significant energy consumption of conventional aerobic processes. In general, approximately one-third of the total operating cost of a WWTP is due to the energy requirements, and the energy consumed for the aeration represents approximately 60–65% of the total energy consumption [3]. Some of the most potentially promising technologies able to achieve self-sustainable WWTPs are the bio-electrochemical ones, which may attain in a single step the depletion of pollution and the conversion of the chemical energy contained in the pollutants into electrical energy. Amongst bio-electrochemical technologies, one of the most widely-studied in recent years is the Microbial Fuel Cell (MFC) [4–6], which is a complex device where the respiration of microorganisms is carried out, coupled to various electrochemical processes. In the MFC, the combination of biotechnology and electrochemistry leads to a very interesting field: bio-electrochemistry. Due to the complexity of bio-electrochemistry, there are many operating variables influencing the performances of an MFC [7].

In the existing literature it has been stated that the optimal performance of MFCs is obtained when the pH is within the range of 6.5–8.5, because this range stimulates the growth of electrogenic microorganisms [8]. MFC operation is also strongly affected by temperature, either due to kinetics and mass transfer (activation energy and mass transfer coefficient) [9], thermodynamics (free energy and electrodes potential), the external resistance [10], the feed rate [11,12] hydrodynamics [13], anode geometry [14] or the nature and the distribution of microbial communities [15,16]. The contribution of all these parameters makes the MFC a very worthy topic for investigation [17,18].

Regarding the start-up phase, it has been reported to be influenced by the external resistance [19–21] and the poised potential [22], because both parameters are related to the metabolic pattern of electrogenic microorganisms [23,24]. In addition, when dealing with the start-up of an MFC, it is also important to evaluate the influence of the culture type (pure or mixed). When comparing pure and mixed cultures, it can be stated that mixed culture MFCs generally need a longer time to obtain a stable power output [22]. However, the use of mixed culture is preferred since it reduces the operational costs and presents a better adaptive capacity, owing to microbial diversity [16,25,26].

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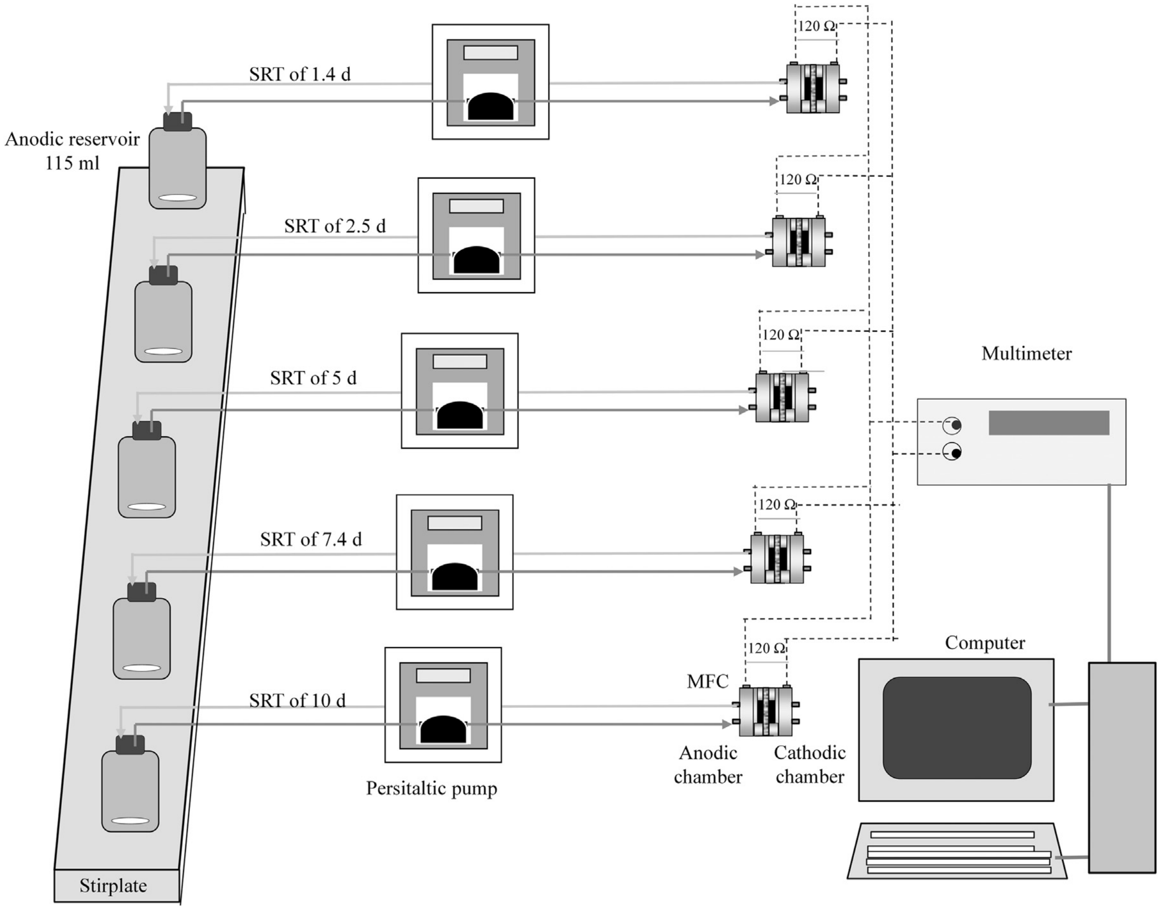

Fig. 1. Scheme of the air breathing MFCs used in the tests.

Concerning the mixed microbial communities, a well-known selective parameter for almost all the bioprocesses is the sludge age, also known as sludge retention time (SRT) [27]. This is because this parameter controls the microorganisms growing in the system. Microorganisms unable to grow in the defined retention time are washed-out, allowing only the growth of fast growing microorganisms in the liquid bulk [25]. In the case of the start-up of an MFC, only the microorganisms growing in the liquid bulk are able to attach to the electrode. Thus, the population in the electrode of a mixed culture MFC clearly depends on the SRT of the inoculum and on the SRT fixed during the operation.

In spite of the high influence of the SRT, only studies related to the SRT on the operation have been published and, to the knowledge of the authors, no studies have been focused on the SRT influence over the start-up of an MFC. Because of that, the objective of this research was to evaluate the effect of the SRT on the start-up stage of an MFC.

2. Materials and methods

Five different fed-batch air-breathing MFCs were simultaneously seeded under different SRTs, chosen in a large range in order to identify the best operative conditions for the start-up stage. In order to ensure the reproducibility, three runs were performed.

The MFC used in this work was made of methacrylate material, consisted of two chambers of 0.346 cm^3, separated by a commercial high ion exchange capacity (0.9–0.02 $meq\,g^{-1}$), high ionic conductivity ($8 \times 10^{-2}\,S\,cm^{-1}$) and a low electronic conductivity ($<10^{-10}\,S\,cm^{-1}$) Sterion® proton exchange membrane (Alfa Aesar, Heysham, UK). Toray carbon papers (Fuel Cell Store, Texas, USA) were used as electrodes with an active area of 0.86 cm^2 in both chambers: 10% of the anode's and 20% of the cathode's structure was Teflon because of its mechanical properties [28]. Additionally, an homogenous catalytic layer of 0.5 $mg\,Pt\,cm^{-2}$ was deposited on to the microporous layer of the cathode according to the literature [9]. This catalytic layer increases the reduction rate of the oxygen from the air entering upon the cathodic chamber [28]. Anodic and cathodic electrodes were connected by an external circuit with a resistance of 120 Ω. This load is commonly used when operating with air-cathode MFC [9,29]. The electrodes and the proton exchange membrane underwent a process of assembly to reduce the internal resistance. To do that, the electrodes were introduced between two stainless steel blocks equipped with heating surfaces brought under progressive and controlled heating until a temperature of 120° C was reached and, at this temperature, a load of one ton was applied for four minutes. More information about the assembly process can be found in the literature [9]. Every MFC was connected to an auxiliary reservoir of about 125 mL. Initially the reservoir was used to seed the MFC. Once seeded the MFC, the reservoir was used to store the wastewater used for feeding the MFC. Moreover, the daily purge was carried out from the reservoirs. A scheme of the MFC configuration can be seen in Fig. 1.

At the beginning of the test, 114 mL of synthetic medium was added to the auxiliary reservoir of anodic compartment. The reservoirs were purged with nitrogen gas in order to ensure anaerobic conditions thorough the MFC operation. The concentration in the medium was 5.8 $g\,L^{-1}$ of sodium acetate as the sole carbon source (4000 ppm of COD), supplemented with the following trace minerals: 0.26 $g\,L^{-1}$ of sodium carbonate, 0.18 $g\,L^{-1}$ of ammonium sulfate, 0.11 $g\,L^{-1}$ of potassium dihydrogen phosphate, 0.09 $g\,L^{-1}$ of magne-