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Microbial fuel cell technology as a downstream process of a membrane bioreactor for sludge reduction

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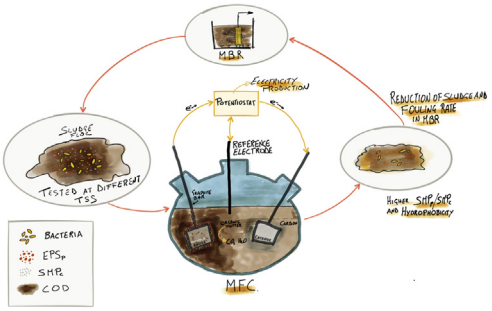
HIGHLIGHTS

- Sludge degradation and reduction were influenced by TSS concentration.
- Higher tCOD and VSS specific removal rates at lower sludge content.
- Acetate and MBR sludge oxidation took place at a similar formal potential.
- Greater electricity productions were observed at higher sludge concentration.
- Increase of SMPp/SMPc and sludge hydrophobicity in the MFC and in the control test.

GRAPHICAL ABSTRACT



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ABSTRACT

Recently, microbial fuel cells (MFCs) have been integrated with membrane bioreactors (MBRs), either in an internal or an external configuration, for wastewater treatment and energy recovery. In an external configuration, MFCs could be applied for an efficient sludge reduction since they can simultaneously address energy issue and environmental concerns associated with sludge treatment.

In the present study, a potentiostatic controlled microbial fuel cell (MFC) was fed with activated sludge from a membrane bioreactor (MBR) at different total suspended solid (TSS) concentrations (1–10 gTSS L^{-1}) in order to assess the electrochemical response of the system and the impact of the bioelectrochemical treatment on sludge characteristics and membrane fouling parameters. The MFC showed COD removals 30% higher than the control test and a reduction of volatile suspended solids (VSS) up to 43% with concomitant production of energy (maximum current density of 2.0 A m^{-2}). The electricity production increased with the increase of TSS content. In both MFC and the control test, an increase of soluble microbial products (SMP) ratio in terms of proteins and carbohydrates (SMPp/SMPc) and an average 50% increase of sludge hydrophobicity were observed. This could limit membrane fouling in the case that the sludge is recirculated to the MBR. The electrochemical characterization indicated that both, acetate and sludge oxidation took place at a similar formal potential of −0.2 V vs. SHE indicating that both used the same electron transfer mechanism. Hence, this study shows that a MFC could oxidize, reduce and stabilise MBR sludge producing electricity and affecting membrane fouling parameters.

1. Introduction

The growth in demand and the shortage of water resources along with more stringent effluent regulations have given remark-

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able impetus to development of advanced technologies for wastewater treatment and reclamation. In this framework, membrane bioreactors (MBRs), which separate the treated water and activated sludge by filtration instead of sedimentation, are being increasingly applied in wastewater treatment and reuse [1]. However, maintaining membrane permeability and preventing membrane fouling are major challenges in operation of membrane processes [2]. As a result of the interaction between sludge suspension and membrane system, membrane fouling decreases filtration performance, leading to frequent chemical/physical cleanings, the supply of excessive amount of air and high energy consumption [3].

Therefore, there is an urgent need to use an energy-efficient and environmental friendly technology for reducing fouling and offsetting this energy consumption [4]. Bioelectrochemical systems (BES), such as microbial fuel cells (MFCs), are a promising approach for simultaneously treating wastewater while generating electricity [5]. Recently, different studies have reported about the combination of BES with MBRs [6,7]. In most of them, ultrafiltration (UF) membranes have been immersed in the MBR reactor as an internal configuration. Wang et al. [8] achieved an average current production of 1.9 ± 0.4 mA and a COD removal efficiency of 89.6 ± 3.7% in an aeration tank of a MBR used as the cathode chamber of a MFC treating wastewater. Tian et al. [6] observed a reduction of membrane fouling through the decrease of the less loosely bound extracellular polymeric substances (LB-EPS) and filamentous bacteria submerging the anaerobic chamber of a MFC into a MBR, which worked as the cathode. In the study of Xu et al. [9], an aerobic MBR, serving as the cathode of a dual-chamber MFC, achieved a COD, NH_4–N removal efficiencies equal to 92.5% and 70.6%, respectively, along with membrane fouling mitigation. Finally, Su et al. [10] applied a MFC to treat the excess sludge from a conventional MBR achieving a sludge reduction 5.1% higher than the conventional MBR and a decrease equal to 22% of LB-EPS with a mitigation of membrane fouling when the sludge was recirculated to the reactor.

The application of a MFC as a downstream process for the treatment of the MBR sludge needs to be further explored. To the best of the authors' knowledge, the main extracellular electron transfer (EET) mechanism governing the anode electro-active biofilm in MFCs fed with different concentrations of MBR sludge has not been investigated yet. Furthermore, literature studies did not report the effect of different sludge concentrations on the performance of a MFC as well as the influence of bioelectrochemical processes on relative sludge flocs hydrophobicity, whose decrease causes higher membrane fouling.

For this reason, this work aimed at evaluating the influence of total suspended solids (TSS) concentration on the performance and electrochemical response of a MFC fed in batch with MBR sludge. The effect of bioelectrochemical processes on the organic matter degradation, sludge content reduction and main parameters that influence fouling in MBRs were also investigated.

2. Materials and methods

2.1. Experimental setup

Two membraneless three-neck 0.5 L round-bottom flasks (MFC) were operated one under potentiostatic controlled with a three-electrode arrangement and one at open cell voltage (OCV MFC) as control test to distinguish between biotic and abiotic activities (Fig. 1). Two carbon clothes (3 × 3 mm, NuVant's ELATs LT2400 W, FuelCellsEtc, USA), electrically connected through titanium wires to two graphite rods (250 × 5 mm, Mersen Iberica, Spain), were used as the electrodes. An Ag/AgCl reference electrode

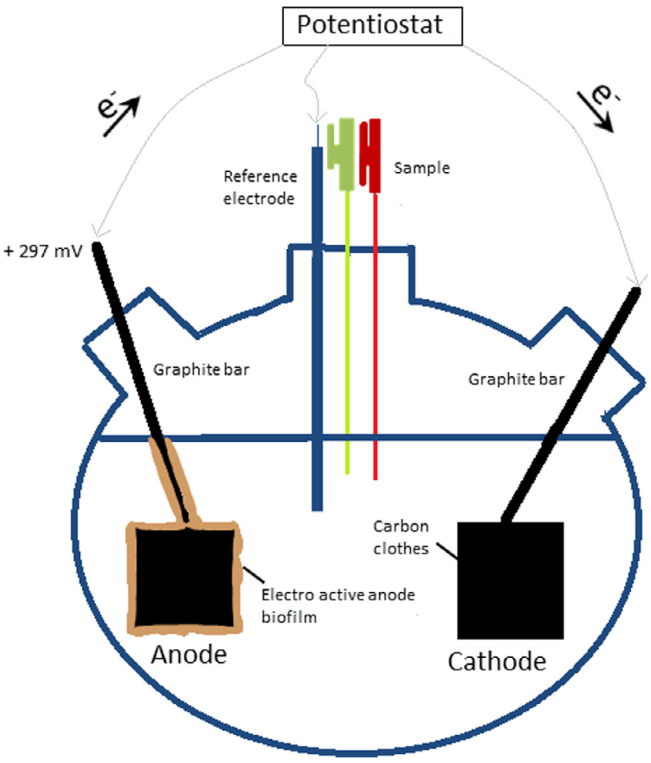

Fig. 1. Experimental setup of the membraneless three-neck round-bottom flask MFC used in the study.

(0.197 V vs. SHE, model rE-5B BASi, United Kingdom) was placed in between both electrodes. The cells were continuously stirred in order to prevent mass transport limitations. The systems were in a thermostatically controlled room at 22 ± 1 °C and at atmospheric pressure.

2.2. Start up and operating conditions

Initially, the round-bottom flasks were fed in batch mode with an acetate containing medium in order to promote the growth of an electroactive biofilm in agreement with the same methodology described in Pous et al. [11]. The medium was prepared with deionized water sparged with nitrogen gas. The medium contained 0.410 g L^{-1} of CH_3COONa as organic electron donor, 0.1 g L^{-1} of NH_4Cl, 0.5 g L^{-1} of NaCl, 0.1 g L^{-1} of $MgSO_4{\cdot}7H_2O$, 0.015 g L^{-1} $CaCl_2{\cdot}2H_2O$, 10 mM of PBS and 1.0 ml L^{-1} of trace elements (concentration per litre: 1000 mg L^{-1} EDTA, 1000 mg L^{-1} $FeSO_4{\cdot}7H_2O$, 146 mg L^{-1} $ZnSO_4{\cdot}7H_2O$, 100 mg L^{-1} $MnCl_2{\cdot}4H_2O$, 6 mg L^{-1} H_3BO_3, 130 mg L^{-1} $CaCl_2{\cdot}6H_2O$, 2 mg L^{-1} $CuCl_2{\cdot}2H_2O$, 24 mg L^{-1} $NiCl_2{\cdot}6H_2O$, 36 mg L^{-1} $Na_2Mo_4{\cdot}2H_2O$, 238 mg L^{-1} $CoCl_2{\cdot}6H_2O$). The reactors were inoculated per 0.5 L of synthetic medium with a mixture of 0.025 L of aerobic activated sludge from a MBR pilot plant treating synthetic wastewater, characterized by TSS and VSS concentrations equal to 10.1 g L^{-1} and 8.4 g L^{-1} respectively, 0.015 L of anode effluent from a parent BES treating swine manure [12] and 0.015 L of cathode effluent from a denitrifying BES treating nitrate contaminated groundwater [13]. Once inoculated and during all of the experiments, the anode was poised at a potential of +100 mV vs. Ag/AgCl (+297 mV vs. SHE) using a potentiostat (BioLogic, Model SP50, France), based on a three-electrode configuration. To establish a mature anodic biofilm capable to oxidize acetate, the reactors were operated in fed-batch mode for four different fed-batch cycles. The acetate concentration was doubled in the last two cycles (0.6 g L^{-1} of CH_3COOH). Once the system