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Development of bioelectrochemical systems using various biogas fermenter effluents as inocula and municipal waste liquor as adapting substrate

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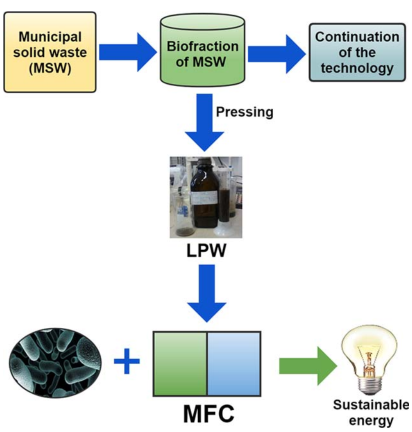
GRAPHICAL ABSTRACT



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ABSTRACT

The purpose of this research was to improve microbial fuel cell (MFC) performance – treating landfill-derived waste liquor – by applying effluents of various biogas fermenters as inocula. It turned out that the differences of initial microbial community profiles notably influenced the efficiency of MFCs. In fact, the adaptation time (during 3 weeks of operation) has varied significantly, depending on the source of inoculum and accordingly, the obtainable cumulative energy yields were also greatly affected (65% enhancement in case of municipal wastewater sludge inoculum compared to sugar factory waste sludge inoculum). Hence, it could be concluded that the capacity of MFCs to utilize the complex feedstock was heavily dependent on biological factors such as the origin/history of inoculum, the microbial composition as well as proper acclimation period. Therefore, these parameters should be of primary concerns for adequate process design to efficiently generate electricity with microbial fuel cells.

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1. Introduction

Microbial fuel cells (MFC) are emerging applications in the field of bioelectrochemical systems (BES), which is attributed to the offered potential of achieving energy recovery from the environmental-friendly remediation of organic waste materials (Dahiya et al., 2018). Nonetheless, to realize adequate efficiency, BES such as MFCs should undergo a careful design to be concerned with a number of non-biological and biological and factors affecting their performance (Kumar et al., 2017; Santoro et al., 2017). Among the former ones, the properties of materials and constructing elements i.e. electrodes, membranes and their arrangement (often referred as architecture) can be of importance (Rahimnejad et al., 2015; Sleutels et al., 2017; Wei et al., 2011). In the latter group of variables, actual MFC behavior is substantially determined by the characteristics of active biocatalysts, called exoelectrogenic, anode-respiring bacteria (Kumar et al., 2015). These microbes release electrons from substrate conversion, which, to be able to harvest electricity, have to be successfully conveyed to the anode as terminal electron acceptor under anoxic conditions.

From practical point of view, the MFC power output and obtainable treatment efficiency of pollutants are two important parameters and are heavily dependent on the underlying community of electroactive-microbes. Hence, an enriched and better adapted population of these bacteria can be a key to improve the process and help its cost-effective expansion to larger-scales. These electroactive-bacteria are found in a wide range of seed sources such as wastewater, soil, marine sediment, compost, etc. (Chabert et al., 2015; Miceli et al., 2012).

For a process taking into account practicality, mixed communities ought to be used as inoculum because of reasons such as their metabolic flexibility and better robustness to withstand fluctuations in operating circumstances (i.e. process disturbances) relative to pure isolates matching more the demand of fundamental studies (Hasany et al., 2016; Jung and Regan, 2007). However, in case of versatile bacterial consortia applied for MFC inoculation, considerable variations of efficiency can be expected. This may be ascribed to particular differences in the history of the inoculum (i.e. features of its origin) and its population diversity. Consequently, the proper enrichment and adaptation of microbial communities to given operating circumstances can be a requirement to establish a sufficient BES (Kim et al., 2005; Liu et al., 2011; Park et al., 2017) and furthermore, the utilization of feedstock (based on its type and complexity) could be notably influenced by the above-said inoculum traits (Park et al., 2017).

To ensure appropriate start-up of BESs and promote electro-active biofilm formation on the electrode surface, several strategies can be carried out, for example the application of a given fixed anode potential or the addition of an alternative electron acceptor (Liu et al., 2011). However, more commonly, the acclimation can be properly improved by feeding various adapting substrates (among which acetate is the widely-used, or by using pre-enriched effluent of an electrochemical reactor as inocula (Kumar et al., 2017).

Actually, as stated by Ieropoulos et al. (2010), a robust community of microorganisms is a solid requirement for MFC involved in wastewater management, which seems coincide with the findings of Mathuriya (2013), observing the enhancement of MFC performance by adapted (vs. non-adapted) inoculum selection for harnessing electricity from tannery wastewater. In this aspect, it should be achieved as a result of dynamic, competition mechanism between electro-active and non-electro-active bacteria that the former ones grow faster, more in numbers and dominate the consortium (Liu et al., 2017b; Xiang et al., 2017). Hence, screening of seed sources and appropriate choice for a specific substrate might be a beneficial strategy and can be worthy for research.

So far, previous articles applying bioelectrochemical systems have dealt with the degradation of municipal waste streams, in particular a liquid fraction acquired from municipal solid waste by mechanical pressing, referred as liquid pressed waste (LPW). For instance, Rózsenberszki et al. (2015), Koók et al. (2016) and Zhen et al. (2016) tested this substrate in single-stage anaerobic degradation processes involving MFC and microbial electrohydrogenesis cells (MEC). Later on, cascade systems with MFCs attached have been investigated as well (Rózsenberszki et al., 2017). From these research works, it has turned out that several factors i.e. the type of system as well as the operating parameter settings could play a significant role to attain enhanced performance. However, the effect that inoculum properties can have on actual, LPW-fed MFC performance has not been systematically studied so far.

Therefore, the primary objective of this paper is to elaborate the effect of sludge inocula (having different history/background) on the start-up and acclimation of MFCs fed with LPW as substrate. The MFCs were started-up with seed sources of two distinguishable origins:

– In one case, the effluent of anaerobic digester built to a municipal waste water treatment plant was used
– In the other case, the effluent of biogas plant processing sugar manufacturing waste was applied.
– The systems were evaluated for more than three weeks with various loads of LPW based on cell voltages and energy yields and moreover,
– The development of bioelectrochemical system was assessed by undertaking microbial community analysis to follow population shifts taking place in the MFCs with time. This is useful approach to get a better understanding of the process and establish correlations between MFC power output, obtainable treatment efficiency of pollutants and community structure dynamics (Liu et al., 2017a; Zhi et al., 2014).

These points make this work distinguishable from those we have performed in previous studies and in our opinion, the present investigation can have a novel contribution in the sequence of existing literature studies.

2. Materials and methods

2.1. Inoculum (seed) sources and substrate for MFCs

In this work, two different sludges were used as seed source to inoculate MFCs. The first one, referred as MWW-S, had been collected from an anaerobic digester treating the secondary sludge of municipal waste water treatment plant located in a Hungarian countryside city and had the following initial characteristics: pH: 7.8; COD content: 13 g L^{-1}. The second one, denoted by SFW-S, had been taken from the biogas fermenter of Hungarian sugar factory utilizing the processed, solid residue i.e. beet pulp, which is a typical by-product of this manufacturing technology. SFW-S was characterized as follows: pH: 7.8; COD content: 12 g L^{-1}.

An obvious difference occurs in the history of MWW-S and SFW-S, which is the nature of feedstock. In the former case, the sludge (before collection) was continuously processing a diverse mixture of components present in the municipal wastewater. In the latter case, however, the mixed community was routinely fed with a monosubstrate-like organic matter (beet pulp) over a long time. Hence, it was presumed that MWW-S could have a faster/greater adaptation capability to complex LPW than SFW-S, which had not been applied to the treatment of such raw materials before.

Prior to use in MFCs, the anaerobic sludges were sieved by 1 mm mesh to get rid of larger particles. To characterize and compare these inocula sources from a microbiological point of view, initial population structures of both were examined as detailed later on in the Section 3.

As for the substrate, high organic-strength municipal liquid pressed waste (abbreviated as LPW) was applied to feed and adapt the mixed culture MFCs. The technology to produce raw LPW was detailed in our previous publication (Rózsenberszki et al., 2015) and in brief, it includes consecutive shredding, metal separation and trommeling,