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Anode acclimation methods and their impact on microbial electrolysis cells treating fermentation effluent

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ABSTRACT

There is a lack of standardized acclimation procedures for evaluating treatability of different wastewaters, and such tests are often conducted using different types of microbial electrolysis cells (MECs). Two different types of MECs (mini or cube) were therefore acclimated using two different substrates (acetate or domestic wastewater) to see the impact of these procedures on the resulting treatment efficiency using the same cellulose fermentation effluent. COD removal was slightly larger using mini MECs (81–86%) than cube MECs (79–82%). Pre-acclimation of mini MECs to domestic wastewater increased COD removal slightly compared to non-acclimated tests with fermentation effluent, but acclimation differences for the cube MECs were not statistically significant. Gas production was not significantly different for cube pre-acclimated MECs compared to those acclimated only to the fermentation effluent. Current densities were higher for the cube reactors than the mini MECs, but they were unaffected by acclimation procedure (pre-acclimation or direct use of fermentation effluent). These results show that mini MECs acclimated to a readily available complex source of organic matter (domestic wastewater) can produce equivalent or slightly superior results for tests with a different complex wastewater (fermentation effluent), and that mini MEC performance is comparable to that of cube MECs. The similarity of reactor performance allows the use of simple and inexpensive mini MECs that can be acclimated to domestic wastewater and subsequently used to test different types of industrial effluents.

Introduction

Advances in anaerobic biological treatment technology have redefined what can be considered "waste" by demonstrating that useful products can be generated or recovered from a wide range of domestic, industrial and agricultural byproducts [1,2]. Electricity, hydrogen, methane and various chemicals can be generated through these processes, but hydrogen is especially attractive because it is a valuable product that has a high energy density and it has broad use in different industrial applications [3–5]. Waste products, such as crop

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biomass, food waste, and industrial wastewaters rich in carbohydrates can be used as renewable energy sources to produce hydrogen gas by dark fermentation [6–11]. However, while 1 mol of glucose can stoichiometrically be converted to 12 mol of hydrogen, maximum yields of only 2–3 mol H_2/mol glucose are typically observed because other end products, like acetate and butyrate, are also produced along with hydrogen [1,7,9,12]. The effluent from a dark fermentation process is therefore rich in organic acids, ethanol, and other organics that cannot be further fermented to produce hydrogen, which limits conversion efficiencies and energy recovery [8,11,13].

To improve overall yields of substrate conversion to hydrogen gas, dark fermentation processes can be integrated with post treatment systems such as microbial electrolysis cells (MECs) [12]. MECs utilize exoelectrogenic microbes that can readily convert organic acids, such as acetate, into electrical current, making them useful for treating fermentation effluent and recovering additional energy [14–17]. Exoelectrogenic microbes form a biofilm on a conductive anode, which is coupled with a hydrogen-evolving cathode to complete the cell. MECs require a source of electrical power to drive the hydrogen evolution reaction at the cathode, with 0.5–1.0 V of additional potential typically applied to supplement the potential generated by the anode [18–21]. This power can be generated by renewable sources, such as solar and wind, or from salinity gradient energy derived from natural or artificial solutions [22,23].

A combined treatment process using a small (cube type) MEC with a dark fermentation effluent was shown to increase hydrogen yields to nearly 10 mol H_2/mol glucose from a cellobiose feedstock, compared to 1.65 mol H_2/mol glucose by dark fermentation alone [24]. However, this comparison was made on the basis of only volatile fatty acids and alcohols. Fermentation of cellulosic substrates can also result in a high concentrations of protein in the effluent due to the production of celluosomes, for example by *Clostridium thermocellum*, that are needed to break down the cellulose into sugars [37,38]. Proteins can be degraded in MECs, but they have been infrequently studied in these systems [36,38]. Since proteins can be used as a substrate in MECs, their concentrations will also be important when examining reactor performance on the basis of COD removal.

MECs used in tests with complex wastewaters have been acclimated using different approaches, but the impact of these different methods has not been well studied for complex wastewaters such as fermentation effluents. When a single substrate such as acetate is used in an MEC, it has been shown that using effluent from a reactor pre-acclimated to that substrate improves performance [39,40]. However, in some studies with complex wastewaters, for example, fermentation effluents of glycerol and molasses wastewaters, the reactors were acclimated using only acetate prior to tests on these wastewaters that contained a rich mixture of alcohols and volatile fatty acids [10,25]. The impact of pre-acclimation to the fermentation effluent or another complex wastewater on treatment was not examined. It has been shown by others that pre-acclimation of MECs to a complex source of organic matter and high concentrations of bacteria (domestic wastewater) improves performance of MECs treating an industrial wastewater compared to reactors acclimated only to the industrial wastewater [41,42]. The microbial diversity of anode communities is known to increase for complex organic matter sources compared to single substrates. Exoelectrogenic microbes that produce electricity in MECs can only use a relatively limited number of different substrates [43,44], and therefore microbial communities that develop in reactors fed a single substrate, such as acetate, are primarily dominated by various *Geobacter* species [45–47]. However, communities that develop in reactors fed a complex source of organic matter, such as domestic wastewater, are much more rich and diverse [14,27,28,48]. Therefore, it is not known to what extent the pre-acclimation process can affect the performance of MECs treating complex wastewaters such as fermentation effluents.

Various types of MECs have been used to convert residual organic matter in fermentation effluent into hydrogen [10,13,24–26], but there have been no comparisons of treatability using these different types of reactors. Most tests on fermentation effluents have been done using small, cube-shaped reactors with 25–32 mL per single-chamber, fed-batch test [13,24,32–34], although some have also been done using two-chamber MECs [10,35] or continuous flow conditions [36] that can use larger volumes of 350 mL per batch [36] or 137 mL for a set hydraulic retention time [36] which is typically one day or less. Inexpensive (~$1-2 each) mini MEC reactors can be easily manufactured from readily available materials [49]. They also have a very small liquid volume (5 mL) and can be operated with a large number of reactors in parallel, making them useful for studying a wide variety of conditions or substrates [41,42]. Cube reactors are relatively expensive to make ($100 each or more) and they use somewhat larger volumes of liquid (which typically must be transported from distant sites to the laboratory). For example, a two-month long test using cube reactors in duplicate (assuming new solution every two days, and 32 mL for each reactor) would require ~2 L of a sample, compared to less than half a liter for mini-MECs run in triplicate. To reduce liquid sample collection and shipments, tests with cube MECs are often made with a single reactor (sometimes duplicates) but not in triplicate. Mini MECs could be used as a less expensive platform for treatability testing, and reduce volumes of samples that need to be shipped, but the two types of reactors have not been previously compared using an industrial wastewater or fermentation effluent.

The goals of this study were to examine the impact of pre-acclimation procedures (using different inocula), and to compare two different reactor configurations relative to treatment efficiencies using a cellulose fermentation effluent. We compared commonly used MEC pre-acclimation procedures for complex effluents, based on first using acetate or domestic wastewater [18,42], with acclimation of MECs only to fermentation effluent. The two reactor types examined here were inexpensive small-volume mini MECs that utilize commonly available parts and materials, and more standardized cube-type reactors. Performance of these MECs was evaluated in terms of COD and protein removal, along with gas recovery and coulombic efficiencies.