Comparison of microbial electrolysis cells operated with added voltage or by setting the anode potential

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Abstract

Hydrogen production in a microbial electrolysis cell (MEC) can be achieved by either setting the anode potential with a potentiostat, or by adding voltage to the circuit with a power source. In batch tests the largest total gas production \(46 \pm 3 \text{ mL}\), lowest energy input \(2.3 \pm 0.3 \text{ kWh/m}^3\) of \(\text{H}_2\) generated, and best overall energy recovery \(\eta_{\text{EC}} = 58 \pm 6\%\) was achieved at a set anode potential of \(E_{\text{An}} = -0.2 \text{ V (vs Ag/AgCl)}\), compared to set potentials of \(-0.4 \text{ V}, 0 \text{ V and 0.2 V}\), or an added voltage of \(E_{\text{ap}} = 0.6 \text{ V}\). Gas production was 1.4 times higher with \(E_{\text{An}} = -0.2 \text{ V}\) than with \(E_{\text{ap}} = 0.6 \text{ V}\). Methane production was also reduced at set anode potentials of \(-0.2 \text{ V}\) and higher than the other operating conditions. Continuous flow operation of the MECs at the optimum condition of \(E_{\text{An}} = -0.2 \text{ V}\) initially maintained stable hydrogen gas production, with \(68\% \text{ H}_2\) and \(21\% \text{ CH}_4\), but after 39 days the gas composition shifted to \(55\% \text{ H}_2\) and \(34\% \text{ CH}_4\). Methane production was not primarily anode-associated, as methane was reduced to low levels by placing the anode into a new MEC housing. These results suggest that MEC performance can be optimized in terms of hydrogen production rates and gas composition by setting an anode potential of \(-0.2 \text{ V}\), but that methanogen proliferation must be better controlled on non-anodic surfaces.

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1. Introduction

Microbial electrolysis cells (MECs) have been shown to achieve efficient biomass conversion to hydrogen gas. These systems use electrochemically active microorganisms to oxidize organic matter at the anode, and catalysts to electrochemically produce hydrogen gas at the cathode from protons in the water and electrons. Electrical energy needs to be supplied to lower the potential of the cathode to generate hydrogen gas [1].

There are two ways to add electrical energy to MEC systems: by adding potential using a direct current (DC) power supply; or by setting an electrode potential using a potentiostat. When using a power supply, the anode potential changes to a value dependent on several factors, including the substrate type and concentration, the applied voltage, and the specific microorganisms present. Anode potentials usually become more positive with higher applied voltages [2–4]. At the same time the anode potential becomes more positive, the cathode potential becomes more positive. Although the electrode potentials can vary, the main advantage of boosting the voltage is that the amount of energy put into the system is well controlled.

A potentiostat can be used to control one of the electrode potentials using a reference electrode inserted into the liquid chamber. The main disadvantage of this system is...
that if one electrode potential is controlled by the potentiostat then the potential of the other electrode will vary. Thus, if the anode potential is set the cathode potential cannot be controlled. The amount of energy input into the MEC will therefore change in response to the overpotential needed at the cathode to sustain the current produced at the anode.

Potentiostats have been used in other bioelectrochemical systems such as microbial fuel cells (MFCs) to investigate the effects of various anode potentials on electricity generation. Bacteria in bioelectrochemical systems can theoretically gain more energy if anode potential (external electron acceptor) is more positive, as shown by

$$\Delta G^\circ = -nF(E_{\text{donor}}^\circ - E_{\text{acceptor}}^\circ) \quad (1)$$

where $\Delta G^\circ$ is the change of Gibbs free energy at pH 7 and 25 °C, $n$ the number of electrons involved, $F$ Faraday’s constant (96,485 C mol$^{-1}$ e$^{-1}$) and $\Delta E^\circ$ the biological standard potential of the electron donor and acceptor [5]. While anode potentials can be used to control microbial growth and activity in these different bioelectrochemical systems [5–7], there is little agreement in the literature on optimum anode potentials for MFC or MEC operation [5–8]. Increasing anode potential up to 0 V vs a standard hydrogen electrode (SHE), or about $-0.2$ V vs Ag/AgCl, promoted Geobacter sulfurreducens growth and accelerated the startup of MFCs, but more positive potentials did not show increased energy recovery [7]. In a different study G. sulfurreducens produced current at $+0.2$ V (vs Ag/AgCl) but no current was obtained at potential values more negative than 0 V (vs Ag/AgCl) [9]. Cyclic voltammetry (CV) analysis of G. sulfurreducens biofilms in the presence of acetate showed a midpoint potential of about $-0.15$ V (vs. SHE) [10], comparable in another study with a mature G. sulfurreducens biofilm (0.42 V vs Ag/AgCl), suggesting that this voltage is optimal for this exoelectrogen [11]. Most research conducted on bioelectrochemical system performance at different anode potentials have been conducted using MFCs, while fewer investigators have examined the effects of different set anode potentials in MECs. In one MEC study four different anodes were placed in the same chamber and set at potentials of $-0.15$, $-0.09$, $+0.02$, and $+0.37$ V (vs SHE) [12]. The best performance was obtained at $-0.15$ V, where the mixed culture was dominated by G. sulfurreducens.

While MECs have been operated using either boosted voltages [2,13,14] or set anode potentials [12,15], there have been no previous comparisons of these different approaches on MEC performance. In this study we compared these two methods to supply electrical energy in MECs in order to optimize performance in terms of hydrogen production and maximum energy recovery. Four different anode potentials ranging from $-0.4$ V to $0.2$ V (vs Ag/AgCl) were set in MECs operated in fed-batch mode, with performance compared to MECs under otherwise identical conditions but operated with an applied voltage of $0.6$ V with a power supply. Continuous flow operation with the optimal set anode potential was further examined in order to investigate the stability of performance over time with respect to current densities, gas production, and gas composition.

## 2. Material and methods

### 2.1. Reactor set up

Single chambered, cube-shaped MECs (duplicates) were made by drilling a 3 cm diameter hole in a block of Lexan, producing a chamber 4 cm long (working volume of 28 mL). A cylindrical glass tube for gas collection was attached on the top of the cubic reactors as previously described in Ref. [3], and the tube was sealed using a butyl rubber stopper and an aluminum crimp cap. The anode was heat-treated graphite brush (25 mm diameter $\times$ 25 mm length; 0.22 m$^2$ surface area; fiber type; PANEX 33 160 K, ZOLTEK) and the cathode was carbon cloth with 30% PTFE wet-proofing (type B; E-TEK) [3]. The cathode (7 cm$^2$ projected area) contained a Pt catalyst layer (0.5 mg Pt/cm$^2$) on the solution side facing the anode. Reactors were equipped with an Ag/AgCl reference electrode (RE-5B; BASi) in order to set anode potentials or measure cathode potentials ($E_{\text{cath}}$).

### 2.2. Experiments and measurements

Anodes were pre-acclimated in MFCs originally inoculated with wastewater and treating acetate [2,3], transferred to MECs, and initially operated at a fixed added voltage of $E_{\text{ap}} = 0.6$ V during startup. Voltage was added to the circuit using a power source (model 3645A; Circuit Specialists, Inc.) by connecting the negative lead of the power source in series to a 10 Ω resistor and the cathode, with the positive lead on the anode. Experiments were then conducted with the reactors operated at the same added voltage, or with the anode potential at set potentials of $E_{\text{an}} = -0.4$, $-0.2$, 0, and $+0.2$ V (relative to the Ag/AgCl reference electrode) using a potentiostat (Model PG580RM, Uniscan Instrument). Voltages across the resistor (added voltage) or the cathode potential (set anode potentials) were measured using a multimeter (Model 2700; Keithley Instruments, Inc.). All reactors were operated in fed-batch mode except as indicated. All voltages are given here vs Ag/AgCl (+0.197 V vs. a normal hydrogen electrode, NHE).

The optimum anode potential obtained from the batch test was chosen for continuous flow tests. Substrate was supplied from a feed tank to the reactors at a hydraulic retention time (HRT) of 1 day using an infusion pump (AVI Micro 210A, Smiths Medical).

For both batch and continuous tests, the MECs were fed with a solution containing 1.5 g/L sodium acetate and a buffer nutrient medium consisted of a 50 mM PBS phosphate buffer (4.58 g/L Na$_2$HPO$_4$, and 2.45 g/L NaH$_2$PO$_4$, pH $= 7.04$), 0.31 g/L NH$_4$Cl, 0.13 g/L KCl, trace vitamins and minerals [16]. MECs were operated at 30 °C in a constant temperature room.

Gas was collected for analysis in gas bags (0.1 L capacity; Cali-5-Bond, Calibrated Instruments Inc.) with gas volume measured using a respirometer (AER-200; Challenge Environmental). Gas chromatographs (GCs; SRI Instruments) were used to analyze the gas composition in the reactor headspace as well as in the gas bags for H$_2$, N$_2$, CO$_2$ and CH$_4$ as previously described in Ref. [2]. Total chemical oxygen demand (COD) was measured at the beginning and end of each batch (TNT plus COD Reagent; HACH Company).
2.3. Calculations

The performance of the MECs was evaluated as previously described in Ref. [3] in terms of: coulombic efficiency (CE, %) based on total coulombs recovered compared to the initial mass of substrate; cathode hydrogen recovery (\( \gamma_{cat} \), %); and volumetric hydrogen production rate (\( Q, \text{ m}^3 \text{ H}_2/\text{m}^3/\text{d} \)) normalized to the reactor working volume. Energy efficiencies were calculated relative to electrical input \((\eta_e)\) as the ratio of energy content of hydrogen produced to the electrical energy added; and as an overall recovery based on both electric and substrate input \((\eta_{elec})\) taking into account both electric and substrate energy input.

3. Results and discussion

3.1. Batch tests to compare different anode potentials with added voltage

3.1.1. Variations of current and gas generations at different experimental conditions

Adding 0.6 V to the circuit produced an anode potential of \(-0.40 \pm 0.01\) V. Under these conditions, the maximum volumetric current density was \(133 \pm 6 \text{ A/m}^3\). Current densities were the lowest when the anode potential was set at \(E_{An} = -0.4 \text{ V}\) (Fig. 1), with \(79 \pm 0 \text{ A/m}^3\), a value 41% less than that obtained with \(E_{ap} = 0.6 \text{ V}\). More energy was input when adding a fixed voltage of 0.6 V than setting the anode potential at \(-0.4 \text{ V}\), even though the anode potentials were approximately the same for these two conditions. This lower energy input resulted in poorer performance with \(E_{An} = -0.4 \text{ V}\) than with \(E_{ap} = 0.6 \text{ V}\). More positive anode potentials increased the current, with maximum volumetric current densities of \(365 \pm 4 \text{ A/m}^3\) (\(E_{An} = -0.2 \text{ V}\)), \(652 \pm 7 \text{ A/m}^3\) (\(E_{An} = 0 \text{ V}\)), and \(832 \pm 8 \text{ A/m}^3\) (\(E_{An} = 0.2 \text{ V}\)). These maximum volumetric current densities required higher energy input per reactor volume (Table 1). Thus, there was an energy cost for achieving the higher current densities. The current densities obtained here with set potentials of \(E_{An} = -0.2 \text{ V}\) and more positive values were much higher than those found previously with a similar reactor setup and added voltage. For example Call et al. [3] obtained \(292 \pm 1 \text{ A/m}^3\) with acetate at \(E_{ap} = 0.8 \text{ V}\), and Selembo et al. [17] reported \(221 \pm 12 \text{ A/m}^3\) from p-glycerol at \(E_{ap} = 0.9 \text{ V}\). The current densities in these two studies are slightly larger than those found here with added voltage, likely due to the lower added voltage used here (\(E_{ap} = 0.6 \text{ V}\)).

Changing the anodes to more positive potentials reduced cycle times (Table 1). At \(E_{An} = -0.4 \text{ V}\) the cycle time was 40 h compared to 16 h at \(E_{An} = -0.2 \text{ V}\) and only 8 h at \(E_{An} = 0.2 \text{ V}\). As set anode potentials became more positive and cycle time decreased as more energy was applied to the MECs [3]. In tests with \(E_{ap} = 0.6 \text{ V}\), the reaction time was 26 h, although this cycle time could have been reduced by using a higher applied voltage [18,19]. Similar to the higher volumetric current density with the higher set anode potential, hydrogen production rates showed a favorable increase with the increase in anode potential. The highest hydrogen production rate was obtained at \(E_{An} = 0.2 \text{ V}\) (7.9 \pm 0.3 m\(^3\) H\(_2\)/m\(^3\)/d). Lower anode potentials reduced hydrogen production rates (-6.9 \pm 0.8 m\(^3\) H\(_2\)/m\(^3\)/d at \(E_{An} = 0 \text{ V}\), and \(-3.6 \pm 0.6 m\(^3\) H\(_2\)/m\(^3\)/d at \(E_{An} = -0.2 \text{ V}\)). Setting the anode potential at \(E_{An} = -0.4 \text{ V}\) (0.3 \pm 0.1 m\(^3\) H\(_2\)/m\(^3\)/d) resulted in poorer performance than with the applied voltage of \(E_{ap} = 0.6 \text{ V}\) (1.1 \pm 0.2 m\(^3\) H\(_2\)/m\(^3\)/d).

The total gas production (46 \pm 3 mL) and hydrogen production (38 \pm 4 mL) were the greatest at \(E_{An} = -0.2 \text{ V}\). These were 1.4 times higher than those achieved with \(E_{ap} = 0.6 \text{ V}\). Hydrogen content increased from 62 \pm 6% to 94 \pm 0% as anode potential increased from \(-0.4 \text{ V}\) to \(0.2 \text{ V}\), and methane content decreased (Fig. 2). Methane production was reduced at \(E_{An} = -0.2 \text{ V}\) and more positive values (Fig. 2), but it increased to \(10 \pm 3\) % for \(E_{ap} = 0.6 \text{ V}\) and \(27 \pm 6\) % for \(E_{An} = -0.4 \text{ V}\). In accordance with higher energy input and shorter cycle times, the methane contents decreased from \(27 \pm 6\) % to \(3 \pm 0\) % as anode potentials increased from \(-0.4 \text{ V}\) to \(0.2 \text{ V}\). The reduction in methane formation is similar to that previously found using single chamber MECs where methane production was decreased by increasing the applied voltage and shortening cycle times [2,19]. This suggests that certain set anode potentials suppress methanogenic activity on the anode as methanogen biofilms on the anode are known to contribute to

![Fig. 1 – Current generation with an applied voltage (Eap) of 0.6 V and 4 different set anode potentials.](image-url)
methane formation [19,20]. However, as shorter cycle times are also known to decrease methane production [3,19], the two effects of more positive anode potentials and short cycle times could not be fully separated in this study.

The highest energy recovery was achieved at $E_{ap} = 0.6$ V ($E_{s} = 187 \pm 22\%$). This was 1.3 times higher than the best recovery obtained using set anode potentials ($E_{s} = 143 \pm 16\%$ at $E_{An} = -0.2$ V) (Table 1). The highest set anode potential ($E_{An} = 0.2$ V) reduced energy recovery based on electrical energy to less than 100%, indicating that more energy was put into the system than was captured in hydrogen gas. The highest overall energy recovery of $E_{s} = 58 \pm 6\%$ was obtained for $E_{An} = -0.2$ V, which was comparable to 56 \pm 6\% at the boosted anode potential ($E_{ap} = 0.6$ V). The lowest overall energy recovery was $E_{s} = 26 \pm 8\%$ at $E_{An} = -0.4$ V. These results demonstrate the tradeoff in increasing current densities and shortening cycle times that result in lower energy recoveries.

CEs ranged from 79 \pm 4\% to 87 \pm 4\%, and COD removal efficiencies were similar for all conditions ranging from 93 \pm 3\% to 95 \pm 1\% (Fig. 3). The cathodic hydrogen recoveries were the largest at $E_{An} = 0$ V with $r_{cat} = 95 \pm 6\%$, followed by $r_{cat} = 88 \pm 9\%$ at $E_{An} = -0.2$ V, but more energy was required than $E_{An} = -0.2$ V. A lower $r_{cat}$ means that the generated electrons were lost to methane generation rather than allowing recovery as hydrogen gas. Hydrogenotrophic methanogens were most likely responsible for low hydrogen gas recovery which is seen as a very low $r_{cat}$ at $E_{An} = -0.4$ V, where CH$_4$ formation was the highest. The lowest energy input based on the generated hydrogen ($2.3 \pm 0.3$ kWh/m$^3$ H$_2$) and the highest $E_{s}$ of $E_{An} = -0.2$ V were accompanied by high hydrogen production rate and current density. Based on these results a set anode potential of $E_{An} = -0.2$ V was found to be the optimum anode potential as it was effective in terms of hydrogen recovery, energy input and methane reduction.

3.1.2. Comparison of performance based on similar anode potentials

Although we observed that the anode potential measured when using the power supply ($-0.40 \pm 0.01$ V, during maximum current production) was about the same as a set potential at $-0.4$ V, much poorer performance was observed with the set potential of $E_{An} = -0.4$ V than with the added voltage (Fig. 2). We wondered if this was a result of setting the anode voltage too rapidly at the beginning of a cycle. Therefore, we examined the MEC performance at $E_{An} = -0.4$ V under two conditions: in the first 5 cycles we immediately imposed $E_{An} = -0.4$ V; in the next two cycles we gradually decreased the anode potential from $-0.34$ V to $-0.40$ V. Our results show that a sudden decrease in anode potential was not a reason for the reduced performance when setting the anode potential at $-0.4$ V because there was even less hydrogen produced in cycles 6 and 7 than the previous cycles (Fig. 4a).

Over the course of the 7 cycles with a set anode potential $E_{An} = -0.4$ V, hydrogen content gradually decreased from 66\% to 24\%, and this was accompanied by methane increase from 25\% to 67\% (Fig. 4a). However, the hydrogen content was immediately restored to 62\% by adding voltage ($E_{ap} = 0.6$ V), and the gas was consistently composed of more hydrogen (58–68\%) than methane (26–35\%). Even though the cycle times were shorter with adding power than with $E_{An} = -0.4$ V (Table 1), cycle times were all similar through the 11 cycles. The cycle times at $E_{An} = -0.4$ V were 43 ± 4 h when immediately setting the anode potential (Im) and 39 ± 6 h when gradually changing the anode potential (Gr), compared to 42 ± 2 h with $E_{ap} = 0.6$ V. Note that the longer reaction times obtained here with an applied potential of $E_{ap} = 0.6$ V was slightly longer than that previously obtained, likely as a result of the longer cycle time and poorer performance in tests following the previously tested condition of $E_{An} = -0.4$ V. These results suggest that reaction time by itself does not necessarily control methane formation and that the anode potential is important for controlling methane formation. It was also reported by others that less methane production was obtained at higher applied voltages although reaction times did not decrease [17].

These experiments comparing set and added potentials suggest that less methane production at $E_{ap} = 0.6$ V might be due to the higher anode potential after substrate was depleted. Variation in cathode potentials ($E_{ca}$) over time were similar, and thus the cathode potential would not have been a factor in methane production (Fig. 5b). The anode potential at $E_{ap} = 0.6$ V increased as substrate was consumed, eventually reaching $-0.05$ V (vs. Ag/AgCl). It has been observed by others.
that methane is generated later in the fed-batch cycle (using the produced hydrogen gas) when the anode potentials become more positive \[19\]. Also, it has been found that higher applied voltages lead to reduction in methane production, and that these conditions are associated with less negative anode potentials in MECs \[2,4\]. Therefore, it appears that the increase in anode potential at \(E_{ap} = 0.6 \text{ V}\) may have suppressed methanogen activity on the anode surface as more positive anode potentials resulted in less methane production (Fig. 2).

3.1.3. Additional feed-batch tests at \(E_{An} = -0.2 \text{ V}\)

Additional batch tests were performed to demonstrate longer term performance of the MECs at the optimum anode potential. For 13 cycles (19 days) high hydrogen production was achieved and methane content was maintained below 10% (Fig. 5). The mean gas volume was 48 ± 4 mL, with average gas composition of \(H_2 = 82 ± 3\%\), \(CH_4 = 7 ± 3\%\), and \(CO_2 = 11 ± 1\%\). Methane content in the first cycle was 13 ± 2%, but it declined to 6 ± 1% by the last cycle. Total gas production increased slightly from 46 ± 6 mL (first cycle) to 52 ± 0 mL (last cycle). This suggests that the anode activity was enhanced by steady exposure of the anode at \(E_{An} = -0.2 \text{ V}\) throughout the multiple cycles. Overall average values of COD removal efficiencies (95 ± 2%) and cathodic hydrogen recoveries \(r_{cat} = 88 ± 7\%\) were comparable to the results obtained in a shorter number of cycles (COD removal of 95 ± 4%, \(r_{cat} = 88 ± 9\%\) but the CE = 91 ± 5% was slightly higher.

3.2. Continuous flow MECs at a set anode potential

Continuous flow tests were performed for 103 days in order to compare MEC performance under these conditions with those obtained in fed-batch conditions at \(E_{An} = -0.2 \text{ V}\). In the beginning (until day 39), current was stable at 4.1 ± 0.8 mA and a high hydrogen content was maintained and methane production was low (Fig. 6), with averages of 68 ± 8% \(H_2\) and 21 ± 6% \(CH_4\) for a daily gas production of 34 ± 11 mL. COD removal was 90 ± 6% and CE was 81 ± 9%. In contrast to the fed-batch tests at the same potential, there was a much lower cathodic hydrogen recovery rate \(r_{cat} = 47 ± 15\%\) demonstrating a significant loss of generated electrons in continuous flow mode to methane production. This loss of hydrogen
to methanogenesis under continuous flow conditions has also been observed in MECs when voltage was added to the anode [14,20]. The maximum volumetric current density in the batch tests at $E_{\text{An}} = -0.2$ V ($365 \pm 4$ A/m$^3$) was higher than that obtained in the continuous flow tests ($147 \pm 12$ A/m$^3$) due to the lower average substrate concentrations under continuous flow tests.

The proportion of the methane in the gas increased to 34% by Day 46 which is in accordance with a low $r_{\text{cat}} = 31\%$. In order to try to reduce methanogenesis a low pH of 4.6 solution was fed to the reactor for one day because acidic conditions have been shown to inhibit methane formation in fermentative hydrogen production [21,22]. However, the low pH also inhibited exoelectrogentic activity as shown by decreases in current to 2.2 mA, COD removal to 27%, and total gas production to 20 ± 7 mL. Following the low pH treatment, hydrogen content was only 13 ± 7% ($r_{\text{cat}} = 9 \pm 1\%$) and the methane content reached 79 ± 7% by Day 55. These results indicate that a pH shock was not effective for controlling methane production. This finding is consistent with previous results where methanogens were not inhibited at a pH = 5.8 in a single chamber MEC [23], and methane was produced in large quantities during pH variations of 7.0 to 4.9 [24].

Following the pH shock test, performance in continuous flow tests was recovered after day 56 in terms of current (4.2 ± 0.3 mA) but the performance in terms of total gas volume (24 ± 3 mL), percent hydrogen gas (37 ± 6%) and $r_{\text{cat}}$ (24 ± 11%) was much lower than originally obtained in this system. The origin of the methanogenesis was further investigated by placing the anode into a new reactor. After the reactor body and the cathode were replaced on day 85, there were immediate increases in total gas volume to 44 ± 14 mL and hydrogen content to 86 ± 0.2% ($r_{\text{cat}} = 95 \pm 7\%$) (Fig. 6), and a decrease in methane content to 3 ± 1%. This shows that setting the anode potential can help reduce anode-associated methane generation, but growth of methanogens in other parts of the reactor was not affected. In addition, methanogenesis could not have been suppressed by a short HRT in a continuous single chamber MECs due to methanogen growth on anodes and cathodes [20,25,26]. Complete methane suppression in the continuous flow tests is therefore not possible unless methods are found to suppress methanogen growth on all parts of the reactor, including the reactor body and cathode surface.

4. Conclusions

Control of the anode potential at an optimum value $E_{\text{An}} = -0.2$ V in a single chamber MEC increased hydrogen production and reduced cycle time compared other set potentials or an added voltage. At this anode potential of $E_{\text{An}} = -0.2$ V, total gas production (46 ± 3 mL) and hydrogen production (38 ± 4 mL) were higher than those obtained at $E_{\text{op}} = 0.6$ V. The energy input ($2.3 \pm 0.3$ kWh/m$^3$ H$_2$) was the lowest and overall energy recovery ($\eta_{\text{elec}} = 58 \pm 6\%$) was the highest in fed-batch tests. The maximum volumetric current density ($365 \pm 4$ A/m$^3$) and hydrogen production rates ($3.6 \pm 0.6$ m$^3$ H$_2$/m$^3$/d) at $E_{\text{An}} = -0.2$ V were also higher than those previously reported under similar conditions with added voltages. Methane production was relatively low in fed-batch cycles with $E_{\text{An}} = -0.2$ V, but the gas composition became predominantly methane in continuous flow tests. A low pH shock was ineffective at reducing methane production, but switching the anode to a new reactor immediately enhanced hydrogen production. This indicates that the methane originated primarily from non-anode associated microorganisms in continuous flow tests. Additional methods for controlling methane production other than setting an optimal anode potential are needed in order to enhance hydrogen gas recovery in continuous flow MECs.

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References


