Bioanode in MFC for Bioelectricity Generation, Desalination and Decolorization of Industrial Wastewater

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Abstract

The most attractive and eco-friendly technologies in biological treatment is Microbial fuel cells (MFCs). In this work desalination rate, organic pollution removal and energy production in the MFC with and without desalination function were compared. A modified MFC was designed and fabricated for desalination process. The rough surface graphite (RSG) was used as anode electrode in both reactors. The modified MFC for desalination unit improved the cumbic efficiency from 16.8 to 23.4%. Maximum power density and desalination percentage were 13.4 W/m³ and 81.2 %, respectively. A consortium of enterobacter had special potential to remove dye (Acid Red 27) while bioelectricity is generated. The open circuit voltage (OCV) for 0.3 g/L AR27 with 24h retention time at 30 °C was 0.81 V; while, 91 % decolourization was achieved. The obtained results demonstrate that in operated MFC with mixed culture of bacteria was successfully applied for the decolourization of AR27 dye and bioelectricity generation and salt removal.

Keywords: Bioanode; Bioelectricity; Decolorization; Desalination; Microbial Fuel Cells

Introduction

Wastewater treatment, color removal and desalination technologies are known as the energy-consuming processes [1]. The main proportion of the energy usage in treatment processes is provided by fossil fuels [2]. In order to reduce the dependency on fossil fuels, renewable energies are alternative power sources. Microbial fuel cell (MFC) has emerged as the most promising green technology for simultaneous power generation and wastewater treatment to fulfill the energy crises in the last decades [3-5]. MFC is a system with the aid of microorganisms can convert biochemical
energy restored in organic substrates to electrochemical energy; as a result bioelectricity is generated. The biomaterials can be oxidized by microorganisms in anode chamber and the biocatalysts have great potential to deliver and transmit electrons to anode. The unit consists of anode and cathode chambers separated by a cation exchange membrane (CEM) [6]. Microbes in the anode chamber oxidize organic substrates in absence of oxygen. The generated electrons via biochemical reactions are transmitted to anode may lead to cathode while protons passed through CEM and reach to cathode [7,8]. The generated electrons and protons meet on cathode; finally water molecule is formed [9]. Number of research scientists reported that the MFC system is a very good technique for energy production [10]. while several researchers have suggested that the MFC is capable of bringing about the treatment of wastewater and simultaneously producing electricity [11]. Despite the MFC being a novel technology for wastewater treatment and energy production, there are also some major drawbacks which limit the actual use of this technique. For instance, the unsustainability of biocatalysts present on the anode, the configuration of the MFC, which limits the power output and the insufficient biofilm attachment to anode electrode which caused microbes easily flow out from the system. Therefore, the anode compartment needs a stable biofilm to be formed on a suitable and large anode surface area. Furthermore, the characteristics of the anode need to be adapted to the biofilm and suit the use of the application on the MFC system. In this work, cell performance, desalination rate, color and COD removal in microbial desalination cell (MDC) using special type of bioanode electrode were compared to MFC.

**Materials and Methods**

MFCs with and without desalination function were used for the experiment. The MDC and MFC were constructed from methyl methacrylate in cubic shapes. MDC were fabricated similar to MFC with an additional chamber between anode and cathode compartments. Fig. 1 shows the actual image of fabricated MDC. Color and COD concentration were measured according to the standard method using spectrophotometer (UNICO 2100, USA) at a wavelength of 600 nm. The pH was measured using a pH meter (pH211, Hanna, Italy). Salt removal rate was determined by conductivity measurement using a conductivity meter (EC215, Hanna, Italy). The anode compartments of the MFC and MDC were fed with the same phosphate buffered sodium acetate solution, which contains (per litre of deionized water): 1.6 g CH$_3$COONa, 0.53 g KH$_2$PO$_4$, 1.07 g K$_2$HPO$_4$, 0.15 g NH$_4$Cl, 0.5 g NaCl, 0.015 g MgSO$_4$, 0.02 g CaCl$_2$, 0.1 g yeast extract and 10 mL of trace metals mineral solution. The trace-element stock solution was prepared by adding: 0.1 g
ZnSO₄·7H₂O, 0.03 g MnCl₂·4H₂O, 0.03 g NaMnO₄·2H₂O, 0.2 g CoCl₂·6H₂O, 0.02 g NiCl₂·6H₂O, 0.01 g CuSO₄·5H₂O and 0.3 g H₃BO₃ into one litre deionized water. The anodic medium solution was inoculated with matured MFC anolyte, which contained exoelectrogens.

Results and Discussion

Generally, MFCs are designed in dual camber cells and microbes were used as biocatalyst in anode compartment. The microorganisms were placed in the anode chamber under anaerobic condition to oxidize organic matter (fuel), while deliver electrons to the anode. The obtained results for MDC and MFC are summarized in Table 1. The result indicated that open circuit voltage (OCV) and closed circuit voltage for MDC was substantially higher than MFC. Furthermore, the percentage of COD removal for MDC was about 12.5% higher than MFC. The color removal for special bioanode having specific consortia of biocatalyst was about 91% for specific dye (AR27). Results indicated that the open circuit voltage (OCV) in MDC was 810±17 mV, while the OCV in MFC was 623±13 mV. In addition, voltage in closed circuit condition in MDC compared to MFC from 397 mV increased to 433 mV, with lower decrease during every single cycle. It was mainly due to a junction potential or diffusion potential produced in the boundary of two different chambers in MDC. A high difference in concentration of solutions in MDC chambers produces a significant gradients difference [12]. Other studies demonstrated that junction potential can produce an energy production up to 0.2 V [13]. Polarization curves studies showed the internal resistance in microbial desalination cell was 188 Ω. It was substantially higher than internal resistance in MFC.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>MDC</th>
<th>MFC</th>
</tr>
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<tbody>
<tr>
<td>Open circuit voltage (mV)</td>
<td>810±17</td>
<td>623±13</td>
</tr>
<tr>
<td>Maximum closed circuit voltage (mV)</td>
<td>433</td>
<td>397</td>
</tr>
<tr>
<td>Minimum closed circuit voltage (mV)</td>
<td>236</td>
<td>69</td>
</tr>
<tr>
<td>Maximum current (mA)</td>
<td>8.66</td>
<td>7.94</td>
</tr>
<tr>
<td>Minimum current (mA)</td>
<td>4.72</td>
<td>1.38</td>
</tr>
<tr>
<td>Power density (W.M⁻³)</td>
<td>13.4 ± 0.65</td>
<td>10.64 ± 0.72</td>
</tr>
<tr>
<td>Internal resistance</td>
<td>188</td>
<td>121</td>
</tr>
<tr>
<td>Maximum COD removal (%)</td>
<td>75.7 ± 3.5</td>
<td>63.2 ± 5.2</td>
</tr>
<tr>
<td>Coulombic efficiency (%)</td>
<td>23.4</td>
<td>16.8</td>
</tr>
<tr>
<td>pH variation in anode</td>
<td>7.03± 0.075 to 5.8± 0.078</td>
<td>7.03± 0.075 to 6.54± 0.086</td>
</tr>
<tr>
<td>pH variation in cathode</td>
<td>6.98± 0.08 to 8.88± 0.072</td>
<td>6.98± 0.08 to 7.63± 0.09</td>
</tr>
<tr>
<td>Salt removal (%)</td>
<td>81.2</td>
<td>NA</td>
</tr>
</tbody>
</table>

The higher internal resistance in MDC was mainly due to additional anion exchange membrane and desalination chamber in MDC. However, the effect of higher internal resistance in MDC was offset with the effect of junction potential produced between desalination chamber and anode/cathode chamber. Fig. 2 indicates the COD removal and coulombic efficiency during a typical three days batch cycle.

![Fig 2. The COD removal and coulombic efficiency during a batch cycle](image)

As it is indicated both MDC and MFC had up to 60% COD removal in anode chamber. However, adding desalination chamber increased COD removal from 63.2 to 75.7%. In fact desalination chamber improved COD removal in anode chamber. Desalination chamber in MDC can prevent air diffusion from cathode chamber to anode chamber. Since oxygen can cause an inhibition effect on
exoelectrogenic bacterial activities. In addition COD removal in both MFC and MDC increased during every batch cycle. Fig. 3 illustrates salt removal and conductivity variation in MDC during every single batch cycle.

![Graph](image.png)

Fig 3. Salt removal (line graph) and conductivity variation (bar graph) in MDC over a typical batch cycle

MDC had a main advantage over MFC which is attributed to desalination function. The result showed that 81.2% of salt can be removed in desalination chamber of MDC. The conductivity of salt solution decreased from 54 mS/cm to 10.1 mS/cm in batch cycle. The amount of salt removal was higher than reported value in previous literatures [14]. This salt removal caused a significant pH variation in anode and cathode chambers. In fact the more pH variation observed in anode and cathode chambers of MDC can be due to this desalination function. The pH variation in anode chamber of MDC decreased from 7.03 to 5.8 due to proton accumulation and Cl\(^-\) transferring to anode chamber. While the cathode pH increased from 6.98 to 8.88 mainly due to proton consumption in cathode chamber.

**Conclusions**

In this study, fabrication of anode electrode having roughened surface graphite was examined in MDC and MFC reactors. The performance of MDC using different types of anode electrode was
examined and compared in MFC reactor. Addition of desalination compartment to MFC reactor created extra biofilm growth, COD removal and coulombic efficiency; that was probably due to prevention of air diffusion from cathode chamber to anode chamber. The maximum power density in MDC was higher than MFC reactor because of junction potential. In addition, the rough electrode resulted in the highest power production and coulombic efficiency of 13.4 W/m$^3$ and 23.4 %, respectively. There was 81.2% salt removal in the middle chamber. The results here collectively demonstrated that addition of desalination function to MFC has improved power generation, current production, COD removal rate, dye removal and coulombic efficiency with an additional benefit of water desalination. However, MDC also produced more pH fluctuation in anolyte and catholyte solutions.

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References