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Power generation from unconditioned industrial wastewaters using commercial membranes-based microbial fuel cells

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ABSTRACT

The use of commercially available cation and anion exchange membranes to generate power from industrial wastewater obtained from three different industries (food, alcohol and dairy factories) without the addition of external microorganisms or chemicals by using microbial fuel cells (MFCs) was investigated. The results indicate that the original mixed culture of microorganisms presented in wastewater can act as an effective bio-anode. Overall, the tested wastewaters show a good tendency for power generation in both cation- and anion- based MFCs. However, when compared to anion membranes, cation membranes exhibit a distinctly higher performance for all tested wastewaters. Cation membrane-based MFCs generate 1007 mWm^{-3} of power from food, 627 mWm^{-3} from alcohol, and 507 mWm^{-3} from dairy wastewaters while anion membranes generate 190.5, 164, and 38 mWm^{-3}, respectively. COD analyses and Coulombic efficiency measurements indicate that more organic pollutants are removed and higher efficiency is achieved by using cation membrane-MFCs rather than anion ones. SEM images of the anodes confirmed the formation of active bio-anodes with attached microorganisms, and FT-IR analyses reveal that the anion membranes are slightly affected by the wastewaters, especially by dairy wastewaters while the cation membranes exhibit a comparatively higher stability.

Introduction

Energy conservation and treatment of liquid waste is one of the main problems facing many industries. Millions of tons of wastewater that are generated every year are disposed in agricultural banks and inland lakes without purification, and these wastewaters are still loaded with high concentrations of various organic, non-organic and microbial pollutants. It is

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therefore important to treat these wastewaters before release in order to prevent further environmental pollution. Unfortunately, wastewater treatment processes require a high-energy input as well as elevated investments and operating costs. Moreover, a large amount of greenhouse gases (GHGs), such as CO_2, N_2O and other volatile substances are released into the atmosphere during treatment, and furthermore, the water crisis is leading society to devote more attention to wastewater. Various technologies can decrease the organic load in these wastewaters by implementing aerobic and anaerobic biological treatment processes. Aerobic biological treatments consume a large amount of electricity due to the aeration that is required [1,2], with the average aerobic process requiring forced aeration that consumes 0.5 kWh m^{-3} of energy. Conversely, anaerobic treatments regain energy from the sludge that is produced in the form of components such as methane or hydrogen. Unfortunately, this process is not extensively used due to low efficiency of the recovery of energy (1.4–2.5 mole of hydrogen per mole of feed), high operational costs, and inefficiency for large loads and ambient temperatures [3]. Despite such problems, treatment for wastewater containing organic pollutants still has the potential to be an effective process if suitable technologies are found to exploit this huge amount of wastewater as a source of energy [4,5]. Due to incorporation of high amounts of organic compounds, wastewaters can be considered as a valuable source of energy and resources rather than waste. An increased awareness has led to a shift in our way of handling wastewater and has stimulated the development of various energy-efficient and resource-recovering technologies [5].

Microbial fuel cells (MFCs) are bio-energy systems that are considered as form of promising environmentally-friendly technology. MFCs can generate electricity from wastewater and so can be considered to be a promising technology to meet the continuous increase of energy needs while simultaneously accomplishing wastewater treatment [6–11]. Microbial fuel cells are devices that convert chemical energy stored in biodegradable substrates (such as glucose, sucrose, and starch) or low molecular weight organic acids (such as acetate, oxalate, and amino acids) directly into electrical energy through a catalytic reaction by the microorganisms. The catalytic activity of the electrochemical reactions is due to the attachment of active bacteria on the electrode [12–14]. An MFC consists of anaerobic anodic and aerobic cathodic compartments with a proton exchange membrane that separates these two, as shown in Fig. S1 in the supporting information [15].

Many different factors affect the performance and power generation of MFCs, including the type of microorganisms, type of membrane, solution conditions (such as pH, temperature, ionic strength, and substrate concentration), electrode material and performance characteristics, internal and external resistance, and the distance between the electrodes [15–18]. Many researchers have sought to address the limitations of MFC_S, which have exhibited higher costs and lower levels of power generation relative to other fuel cells, by improving the individual MFC components in order to generate a higher power density at a lower cost. Researchers have also worked to discover the optimum conditions under which to operate MFCs by applying various types of microorganisms [19–22], media (fuel) [21,23], electrode materials/sub materials [24–27], cell configurations [28,29], and membranes [30,31]. The membrane is a highly influential component that affects the performance of the entire system because a large portion of the internal resistance of the MFC is a result of the membrane properties. Moreover, the membrane contributes to more than 38% of the overall capital cost of MFCs. Commonly, the membranes used for MFCs consist of commercially available Nafion, which is a material that is frequently used in fuel cell applications [32,33]. Although Nafion membranes are still considered to be the best membranes for MFCs [34,35], their high cost and high internal resistance result in MFCs that have limited applicability [16]. In addition to Nafion, there are many researchers investigated commercially cation and anion membranes [28,36–41] that are inexpensive relative to Nafion and are also commercially available at a large scale. Several studies have shown that cation exchange membrane (CEM) enhances the performance of MFCs higher than anion exchange membrane (AEM) due to presence $-SO^{3-}$ functional groups in the chemical structure of the CEM membrane which facilitate proton transfer and simultaneously constrain anions passing [42,43]. Moreover, CEMs are less expensive, often structurally stronger than Nafion117 and help to reduce oxygen diffusion into the anode chamber [28,42]. However, AEM can be preferred in case of treatment the feed solution by buffer solutions.

To the best of our knowledge, most of the present reports using MFCs to generate electrical energy from industrial and agricultural waste have used external microorganisms and often mediators. The aim of this study is to investigate the effect of using commercially available cation and anion exchange membranes in MFCs to generate electrical energy (without any external microorganisms or chemicals) from three on-site sources of wastewater (Food, Dairy, and Alcohol) in Jeonju, South Korea. This is the first report to study the influence of different membrane types in the MFCs by using real wastewaters from industrial sources without additional laboratory solutions. The results are very promising since a considerable amount of energy was produced from these three wastewaters.

Materials and methods

Wastewaters

Food, dairy, and alcohol wastewaters were collected from local food, dairy and alcohol factories in Jeonju, South Korea and were used in single cycle batch mode MFCs without any purification. The wastewaters were characterized in the Water Environment Research Center, Jeonju, South Korea, the characterization results are presented in Table 1. Moreover, the cultivation agar test was done to confirm the presence of microorganisms in utilized wastewaters, the agar dishes were observed under the microscope and the number of bacteria was counted as shown in Fig. 1.

MFC construction

The performance of the membranes in the MFC was examined using air-cathode MFCs, as displayed in Fig. S2 of the