The 2012 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM' 12)
Seoul, Korea, August 26-30, 2012

Inherent overpotential generated by characteristic of microbial fuel cells with multiple membrane electrode assemblies

Bongkyu Kim[1)], Junyeong An[1)], Daehee Kim[1)], Taeyoung Kim[1)], and *In Seop Chang[2)]

[1), 2)] *School of Environmental Science and Engineering, Gwangju Institute of Science and Technology, Gwangju 500-712, Korea, Phone 82-62-715-3278*
[2)] *ischang@gist.ac.kr*

ABSTRACT

A microbial fuel cell (MFC) installed with multiple semi-membrane electrode assembly (mMEA-MFC) was developed in order to fulfill the scalability of MFC for actual application in wastewater treatment process. In the mMEA-MFC system, inherent characteristic of overpotential was existed because charge transfer (e.g., electron and cations transfers between each anode and cathode) related to current production did not work individually. In order to determine the impact of this characteristic, we operated mMEA-MFC which was installed with four MEAs sharing electrolyte solution. Open circuit voltage and current production of all of each MEA were almost similar within 2 weeks of operation. Interestingly, when current production of one MEA in a single reactor was interrupted by shifting operation mode, close to open circuit modes, the current production of the other MEAs in the same reactor was positively affected toward current increase. However, sum of three MEAs' net current increase did not reach to theoretical current up which was equal to current of one MEA which was interrupted current production. We cautiously investigated that reacting ions related to charge balance for production of current were competed by each other MEAs. This competition phenomenon of electrolyte solution was mainly occurred by the competition to cations which are transferred to cathode compartment for charge balance. We assumed that this overpotential is a kind of inherent characteristic in mMEA-MFC system and the minimizing of this overpotential is a critical issue when mMEA-MFC is employed to use an energy harvesting system from organic waste.

1. INTRODUCTION

The microbial fuel cell (MFC) has a big attention because of bi-beneficial characteristic as wastewater treatment and energy recovery (Lefebvre 2010). In order to apply MFC system to an actual wastewater treatment process, a structure of the MFC was consisted with multiple electrodes in one reactor (Kim et al 2012). This MFC structure was attracted attention because this construction has benefits related operation condition with feeding and discharging than other MFC construction which is

[1)] Graduate Students
[2)] Professor

two chamber systems and high electrode surface area with respect to the reactor volume (Wang 2008). Also, this structure has an architectural feature generated by sharing electrolyte solution between installed multiple electrodes in common reactor. Therefore, we suggested that an undisclosed impact cloud be existed caused by the architectural feature. The reason was the current production from MFC was generated by an interaction between anodic reaction which was oxidation and metabolism of organic materials by microorganism and catiodic reaction which was oxygen reduction reaction. In addition, to fulfill the current production, not only flow of the produced electron by anodic reaction from anode to cathode but also transfer of electrolyte must be generated (Chang 2006). Hence, we proposed that an interference of electrolyte solution related current production effect performance of electrodes installed in common reactor. In this study, multiple membrane electrode assembly MFC (mMEA-MFC) which is type of as early mentioned MFC structure was operated and, current interruption manner was applied to determine presence of the drawback.

2. MATERIALS AND METHODS

2.1. Cell configuration and operation

The mMEA-MFC was constructed by rectangular shape having internal space; 530 ml (internal dimensions 8 cm × 8 cm × 8 cm) (Fig. 1). MEAs were consisted detached anode electrode (BIA, BASF Co. NJ, USA; 35 mm × 35 mm) with assembled cathode electrode (BIA 10wp, BASF Co. NJ, USA; 35 mm × 35 mm) and proton exchange membrane (Nafion NAF NR212, Dupont Co. Wilmington, USA; 60 mm × 60 mm). The carbon cloth for using as cathode contained Pt catalyst (0.5 mg/cm^2 of Pt). The MEAs were cohered to wall of a reactor with 4 mm interval between each electrode of MEA. Current collector was prepared as quadrangular ring shape by using stainless steel (width: 2 mm, thickness: 0.2 mm, length: 34 mm) and placed between each electrode side of MEA and acrylic plate. Collected anaerobic digestion sludge was diluted two times with anaerobically prepared artificial wastewater containing 5 mM glucose as inoculum source. The inoculum solution was inserted to reactor using pump during 6 days. After microbial inoculation in the electrode, the glucose with artificial wastewater was fed to the MFCs.

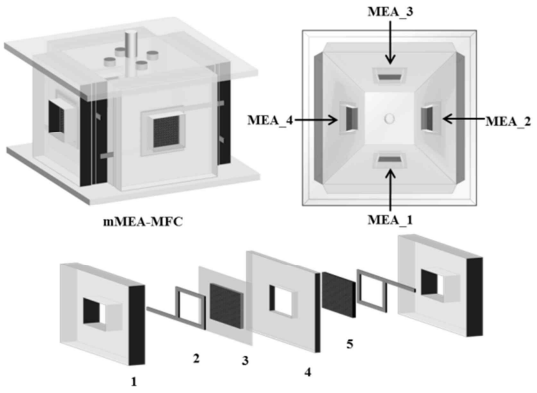

Fig. 1 Configurations of mMEA-MFC (1: acryl holder; 2: current collector; 3: carbon

cloth as anode electrode; 4: gasket; and 5: carbon close assembled ion exchange membrane as cathode part.

3. RESULTS

3.1 Inherent overpotential generated by characteristic of mMEA-MFC

In order to determine an presence of inherent overpotential generated because multiple MEAs were installed with sharing electrolyte solution, mMEA-MFC were operated as current interrupt method by shifting operation mode as closed-circuit mode (CCM) to open-circuit mode (OCM) gradually. When the current production of MEA 4 in mMEA-MFC was interrupted by detaching external resistance, the current of MEA 4 was dramatically decreased to zero as generally expected. However, interestingly, at the same time the current production of other MEAs in the same reactor were also increased even though little amounts as 9 μA, 7 μA, and 11 μA respectively (Fig. 2, point A). When the changed the circuit mode of MEA 3 CCM to OCM, the current production of MEA 1 and 2 were risen by each 13 μA and 12 μA (Fig. 2, point B). Finally, circuit situation of MEA 2 was altered from CCM to OCM (Fig. 2, point C). In this case, the generated current of MEA 1 was increased by 18 μA. However, sum of other MEA's current increase was not reached to theoretical enhanced current which was equal to current production of MEA interrupted. Based on this result, it is determined the inherent overpotential was existed in mMEA-MFC by reactor characteristic which were sharing electrolyte solution at each MEA installed in same reactor and microbial activity on anode electrodes.

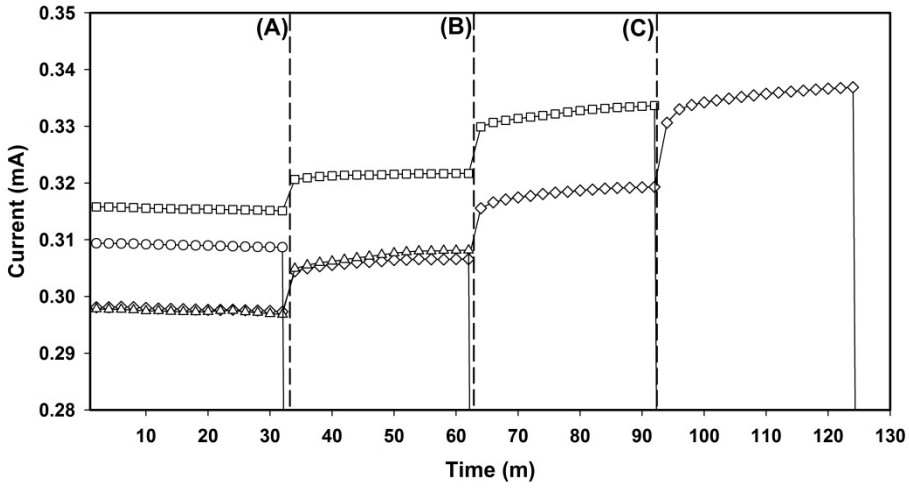

Fig. 2 Increased current of three MEA by inherent overpotential in mMEA-MFC (point (A), (B), and (C) operation mode of MEA 4, MEA 3, MEA 2 switched from CCM to OCM receptivity; ◇: MEA 1; □: MEA 2; △: MEA 3; ○: MEA 4).

3.2 Evidence for inherent overpotential generated in mMEA-MFC

To determine this phenomenon more detail, the electrode potentials of three MEAs in mMEA-MFC were measured by using Ag/AgCl reference electrode. When the circuit mode of MEA 4 was switched to OCM, the electrode potentials of three MEAs in same reactor with sharing electrolyte solution were dramatically changed differently. The anode potential of MEA 1, 2, and 3 were raised to positive by 6 mV, 6 mV, and 4 mV respectively. The cathode potential of the MEAs were increased by each 15 mV, 13 mV, and 15 mV. In terms of all electrode potential were increased to positive value and the cathode potentials were raised more than anode potentials, it is noted that momentary enhanced performances of cathode electrodes would have more consumed passed electrons from anode electrode. In case of one of the MEAs was switched operation mode from CCM to OCM, usable amount of the rivalry materials on other MEA was increased. Base on the Nernst equation '$E = E^{\acute{0}} + RT/nF\ In(C_O/C_R)$', the concentration of reactant on the electrode is very important to conforming electrode potentials. Based on the higher variation of cathode potential than anode potential variation (Fig. 3), the material involved to conforming cathode potential was more affected than that of anode potential. However, the exactly caused material was not investigated because artificial wastewater solution contained very many ions complexly was used for operating mMEA-MFC system. Nevertheless, we assumed that this overpotential was a kind of inherent characteristic in mMEA-MFC system and the minimizing of this overpotential was a critical subject when mMEA-MFC was employed in order to apply an energy harvesting system from organic waste.

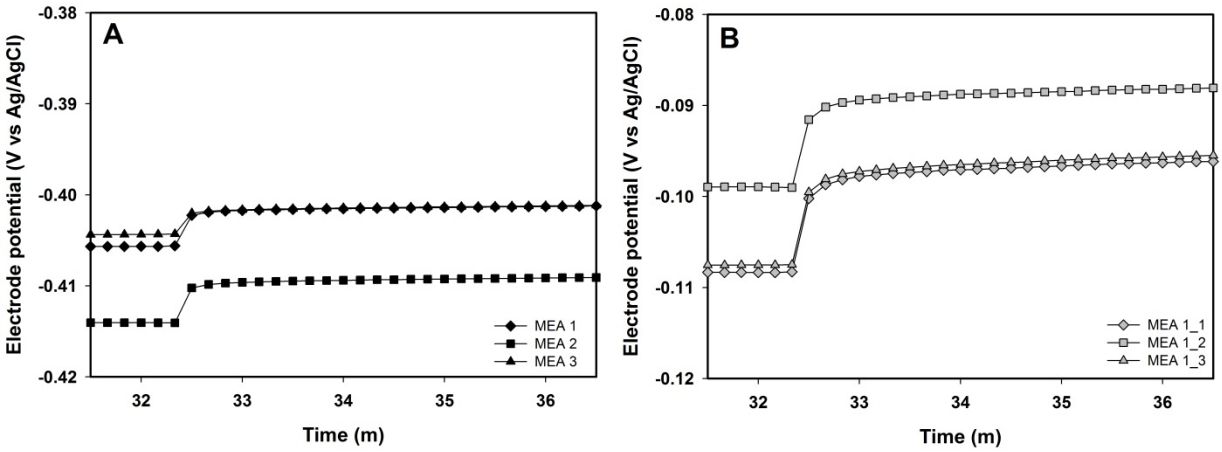

Fig. 3 Electrode potentials of four MEA installed in common mMEA-MFC (A: potentials of anode electrodes; B: potentials of cathode electrodes)

4. DISCUSSION

4.1 Inherent characteristic of mMEA-MFC

The mMEA-MFC has inherent characteristic incurred drawbacks because an electrolyte solution was shared between all electrodes of MEA installed common reactor. The first drawback was well known as potential drop generated at self-series connection with MFC installed in same reactor, and the reason was investigated as

short circuit. The second drawback was discussed in this study as inherent overpotential caused by interference of electrolyte solution. Among the many electrolytes in solution, we regard cations transfer to cathode compartment for charge balance as important rivalry materials in shared electrolyte solution. The reason was discussed as current production of MFC related anodic activity by microbes and cathodic reaction by reduction reaction. In this study, the anodic activity on electrodes was not changed on the basis of 29.54 ± 0.01% of chemical oxygen demand removal rate indicated that remaining substrate in the reactor was not shortage (Pant 2010). In addition, because the potential change was generated instantly the possibility of effect about population increase of microorganisms in anode electrode increasable anodic activity was excluded. In this case, all MEAs were consisted of carbon cloth contained Pt catalyst in order to minimize limitation of cathodic reduction reaction (Cheng 2006). Even the external resistance of mMEA-MFC was not changed. These debates would have more confirm that reacting cations related to charge balance for current production were rivalry interacted on each MEAs. In typical fuel cell, the cation related charge balance in oxygen reduction reaction is proton produced anodic reaction and existed in electrolyte solution (O'Hayre 2006). Even though the proton was also main cation for charge balance in MFC, the MFC used bulk electrolyte solution included high concentration of salt. Therefore, driving force of proton was affected other cation, and the exactly caused material was not investigated due to artificial wastewater solution contained very many ions complexly for operating mMEA-MFC system.

REFERENCES

Lefebvre, O., Uzabiaga, A., Chang, I.S., Kim, B.-H., Ng, H.Y. (2010), “Microbial fuel cells for energy self-sufficient domestic wastewater treatment—a review and discussion from energetic consideration” *Appl. Microbiol. Biot.*, **89**(2), 259-270.

Kim, D., An, J., Kim, B., Jang, J.K., Kim, B.H., Chang, I.S. (2012), “Scaling-Up Microbial Fuel Cells: Configuration and Potential Drop Phenomenon at Series Connection of Unit Cells in Shared Anolyte” *ChemSusChem*. **5**(6), 1086-1091.

Wang B, Han J-I. (2008), “A single chamber stackable microbial fuel cell with air cathode”, *Biotechnol. Lett.* **31**(3)**,** 387-93.

Chang, I.S., Moon, H., Bretschger, O., Jang, J.K., Park, H.I., Nealson, K.H., Kim, B.H. (2006), “Electrochemically active bacteria (EAB) and mediator-less microbial fuel cells” *J. Microbiol. Biotechnol*, **16**(2), 163-177.

Pant, D., Van Bogaert, G., Diels, L., Vanbroekhoven, K. (2010), “A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production” *Bioresource. Technol.*, **101**(6), 1533-1543.

O'Hayre, R.P., Cha, S.W., Colella, W., Prinz, F.B. (2006). *Fuel cell fundamentals*. John Wiley & Sons Hoboken, NJ.

Cheng, S., Liu, H., Logan, B.E. (2006) “Power densities using different cathode catalysts (Pt and CoTMPP) and polymer binders (Nafion and PTFE) in single chamber microbial fuel cells” *Environ. Sci. Technol.*, **40**(1), 364-369.