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Short Communication

Elimination of voltage reversal in multiple membrane electrode assembly installed microbial fuel cells (mMEA-MFCs) stacking system by resistor control

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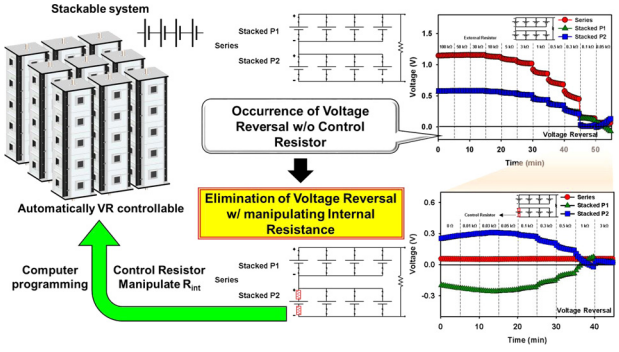
GRAPHICAL ABSTRACT

If the MFC has a structure capable of controlling the internal resistance when a voltage reversal occurs in stacked MFCs due to various causes, it is possible to easily eliminate the voltage reversal by controlling the current produced by manipulating the internal resistance with automatically controllable system based on computer programming.



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ABSTRACT

Voltage reversal (VR) in series connection of multiple membrane electrode assembly installed microbial fuel cells (mMEA-MFC) is eliminated by manipulating the resistor control. Discharge test results collected from two mMEA-MFCs initially operated (designated as P1 and P2) confirm that the performance of P2 exceeds that of P1. Thus, driving P1 and P2 as serially stacked MFCs generate the VR in P1. Controlling the inserted resistor adjust the current production of P2 to maintain balance with P1, and the VR in P1 is eliminated in the operation of stacking mode. Thus, manipulating the internal resistance provide an applicable approach to suppress VR in the stacking of mMEA-MFCs system.

1. Introduction

A voltage reversal (VR) in a stacked microbial fuel cells (MFCs) has been commonly occurred and thought to be one of big difficulties in scaling-up of MFCs by modulation (Kim et al., 2015a; Papaharalabos et al., 2017). Actually, it is apparently simple phenomenon but very complicated to find out exact reason(s) why it is occurred (Aelterman et al., 2006; An & Lee, 2014; Kim et al., 2017b; Kim et al., 2015b; Oh and Logan, 2007). VR in stacked MFCs indicates that the voltage in some of the unit cells connected in series is reversed (An and Lee, 2014;

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Table 1
Studies on voltage reversal in microbial fuel cell technology.

Main point	Remarks	Research Group [Refs]
• First Introduction & Called 'Cell Reversal' No identification for root cause (Present various possibilities) • Introduced the term 'Voltage reversal' Suggested 'fuel starvation' resulting loss of the bacterial activity	Interpret the effect of microbial limitations on the characteristics of MFCs.	W. Verstraete (Aelterman et al., 2006) B. E. Logan (Oh and Logan, 2007)
• Identified root cause based on the difference of anodic reaction rate Suggested voltage reversal caused by cathodic kinetic limitation • Revealed voltage reversal occurred by limitation on the cathodic kinetic	Confirmed that kinetic imbalance between connected cells is the root cause	H. S. Lee (An and Lee, 2014) H. S. Lee (Kim et al., 2015b)
• Control method by critical current density manipulation • Control manner by providing an assistance current with auxiliary electrode • Define Max. current value can be used as indicator of voltage reversal	Attempt to adjust current balance to improve kinetic imbalance Series	H. S. Lee (An et al., 2015b) I. S. Chang (Kim et al., 2015b) I. S. Chang (An et al., 2016b)
• Prevention by series connection of parallel connected MFC • Prevention by series connection of parallel connected MFC with digital switch converter	Attempts to prevent by improving current production of MFC itself	I. S. Chang (An et al., 2016a) I. Ieropoulos (Papaharalabos et al., 2017)

Kim et al., 2015b). It could significantly damage bio-anodes and reduce the lifetimes of MFCs (Kim et al., 2015a). Table 1 summarizes the studies on voltage reversal in microbial fuel cell technology to date. When the first VR was determined in the MFCs, most researchers thought that it was caused by the limitation of the anodic reaction, which is the characteristic limit of MFCs (Aelterman et al., 2006). Factors that affect the microbial community and microbial activity in the anode, such as fuel starvation, had been suggested as the root cause and had been taken for granted (Oh and Logan, 2007). However, in recent years, it has been confirmed that the root cause of VR could be due to the "imbalance of kinetic origin" in all the electrodes, not in the anode only, but in the cathode as well (An et al., 2015a; An and Lee, 2014). After the root cause was suggested, attempts were made to improve the way of VR suppression. Although the root cause of VR was indicated as kinetic imbalance, to maintain the kinetic balance in system operation is a very challenging task. Actually, it is impossible to control the anodic kinetics which depended on the microbial metabolism. Thus, previous researchers have attempted to prevent VR by controlling current, the final product of kinetic (Bard et al., 1980), rather than controlling kinetic of the electrode (An et al., 2016b; An et al., 2015b; Kim et al., 2015b).

In a way this study attempts to control the VR that can occur in a serial connection of two multiple membrane electrode assembly MFCs (mMEA-MFCs) which were initially constructed and separately operated. Note that each mMEA-MFC system has a structural feature consisting of 4 MEAs installed in one reactor sharing the anodic solution where the organic substance is existed, and it was proposed as the system that capable of modulation for MFC scaling-up (Kim et al., 2013). The whole internal resistance of the circuit is manipulated by inserting a variable resistor, which can act as the ohmic resistance inside the MFC system, i.e. inside the circuit of the system. The practicality of the proposed method was confirmed by designing the mMEA-MFC that readily permitted reconfiguration of the inner electric circuit in the MFCs connected in parallel.

2. Materials and methods

2.1. Cell configuration and operation conditions

A cube-type reactor was used to prepare the mMEA-MFC, such that each sidewall included a pair of MFCs (Kim et al., 2017a; Kim et al., 2013; Kim et al., 2015b). The four MFCs were configured by installing four anodes (BASF Co., USA; 35 mm × 35 mm, BIA, non-wet-proof carbon cloth) on the inside of the wall to share the analyte, and four cathodes (BASF Co., USA; 35 mm × 35 mm, BIA 10 wp, 10% wet-proof carbon cloth) were positioned on the outside and exposed to air. A 0.5 mg cm^{-2} Pt catalyst coating was applied uniformly onto the cathode surface. Between each anode and cathode pair was inserted a polymeric separator (Nafion® NAF NR212; DuPont Co., USA; 60 mm × 60 mm) to maintain the anaerobic conditions of the analyte. In this study, two reactors were fabricated in the same configuration.

Next, the inoculum source collected from a sludge tank in Gwangju first sewage treatment plant (Gwangju, South Korea) was poured into the reactor over one week to start preparation of the MFC bio-anode (Kim et al., 2017a). As the organic concentration of sludge was decreased, the sludge was continuously replaced with artificial wastewater contained 10 mM acetate for fuel, a salt solution, and trace minerals needed to grow electrochemically active bacteria, and phosphate buffer (1 M, pH 7.2). Prior to using the artificial anolyte, N_2 (purity 99%) gas was supplied to purge any dissolved oxygen. The artificial anolyte allowed the MFCs to be operated in a continuous mode over a hydraulic retention time of 24 h. The bio-anode was fully enriched over three months by operating all MFCs in the closed-circuit mode with a 100 Ω external resistance. Thereafter, the main experiments were conducted.

2.2. Discharge tests for the MFCs

The MFC performances were measured using a discharge test. Both voltage and electrode potentials (versus an Ag/AgCl electrode) were collected via a data acquisition system comprised of a computer and a multimeter (Keithley 2700, Keithley Instruments Inc., USA). All MFCs were fully charged under open-circuit conditions for 1 h. An external resistance was then applied such that the external resistance decreased stepwise over the values 100 kΩ–0.01 kΩ every 5 min during the test for 70 min (Kim et al., 2017a). The performances of the unit cell MFCs were characterized by conducting discharge tests using the eight unit cells. After confirming the unit cell performance, all unit cells were fully charged to their initial open-circuit voltages (OCVs) for 1 h, each of the four MFCs in the reactors were connected in parallel, and the discharge test was conducted (P1, parallel connected MFCs of the 1st reactor). Next, the MFCs connected in parallel (P1 and P2) were fully charged to their initial OCV value over 1 h. VR in the stacked MFCs was measured by connecting P1 and P2 in series (S-MFC, serially connected MFCs comprising P1 and P2). The discharge tests were then conducted. During the S-MFC discharge test, VR was generated.