Study the effect of aeration on cathode overpotentials in a sediment microbial fuel cell using electrochemical impedance spectroscopy

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Abstract

Sediment microbial fuel cells (SMFCs) are devices that produce electricity through oxidation of organic matter in sediments using microorganisms which act as biocatalysts in anode. In the present study, the cathode resistances in an aerated-cathode SMFC were investigated when aeration was stopped. Electrochemical impedance spectroscopy (EIS) was carried out to determine the resistances. Total resistance and mass transfer resistance of 984.1 and 953 Ω, respectively, were obtained in the SMFC when aeration was stopped. Findings revealed that mass transfer resistance was significantly high without aeration, demonstrating the sigificant contribution of presence of sufficient electron acceptor to the decrease in mass transfer resistance of cathode.

Keywords: Sediment microbial fuel cell; Cathode; Electron acceptor; Mass transfer resistance

Introduction

Sediment microbial fuel cell (SMFC) is a developing technology, capable of producing electricity and simultaneously removing the pollutants in sediments [1]. This occurs through the biocatalysis of oxidation reaction in anode using microorganisms [2]. Electrons are produced from oxidation reactions in the sediment, which can be transferred via an external circuit to cathode of SMFC where they are consumed by an electron acceptor and electrical current is produced [1]. Sediment contaminants are also removed during the oxidation reactions taking place in sediments [3].

There are some resistances (overpotentials) involved in the SMFCs that prevent proper operation of these cells. The resistances present in SMFCs include activation overpotential, ohmic overpotential, and concentration overpotential. Activation overpotential is caused by the resistance against electron transfer and oxidation-reduction reactions in anode or cathode. Ohmic overpotential is due to the resistances to the movement of ions in the electrolyte or of electrons through the electrodes and electrical connections. Concentration overpotential results from the resistance against mass transfer of substrate and electron acceptor in anode and cathode, respectively [4]. Each of the resistances may lead to the poor performance of SMFCs. Therefore, it is essential to determine the resistances in SMFCs so that they can be minimized through appropriate approaches for enhancement of SMFC electrical output.

Electrochemical impedance spectroscopy (EIS) is an effective tool for identification of electrochemical characteristics of SMFCs and evaluation of resistances in these systems [5]. In this study, EIS was used to detect the resistances in an aerated and non-aerated cathode-SMFC to identify the contribution of mass transfer resistance. Nyquist and bode plots were investigated to obtain an appropriate understanding of the system.

Experimental

The SMFC reported in our previous study [6] was utilized in the present study. The SMFC chamber was a 1 liter beaker. Circlular electrodes with an area of 50.24 cm^2 made of carbon felt (PANEX35, ZOLTEK) were used as anode and cathode. A distance of 5 cm was set between electrodes. Sediment was collected from AquaPlus fish farming, Mashhad, Iran, and used as anolyte for the SMFC while BG11 medium was added above the sediment as catholyte. External resistance of 1000 Ω was placed in the circuit of the SMFC. EIS was carried out to evaluate SMFC resistances using a potentiostat/galvanostat (Autolab, 302N). For this purpose, the three-electrode mode including cathode, anode and Ag/AgCl electrode as working, counter, and reference electrode, respectively, was applied at a signal amplitude of 5 mV and frequency range of 100 kHz-0.01 Hz. For the aerated SMFC (aerated), the EIS was performed when the SMFC produced a stable voltage after 25 days [6], and for the non-aerated SMFC (Non-aerated) the EIS was performed after 1 hour of stopping the aeration.

Results and discussion

Bode plot for the two EIS results is illustrated in Fig. 1. Three peaks are observed in the plot in the low, middle, and high frequency regions, indicating that the cathode showed three time constants [7] which could be associated with mass transfer, charge transfer, and other processes taking place in the cathode of SMFC. It is obvious that the peaks located in the high and middle frequency region are almost identical for the aerated and non-aerated case while the peak in the low frequency region is different in the two cases, suggesting that the difference in the two cases is in the mass transfer resistances in cathode.

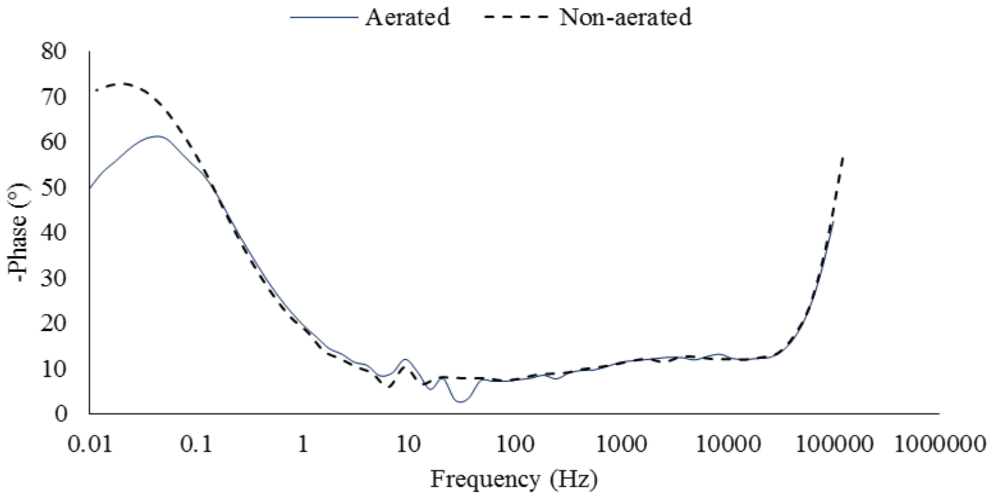

Fig. 1. Bode plots of aerated and non-aerated cases

To further evaluate the resistances in the cathode, Nyquist plot was drawn (Fig. 2). The first semicircle in the right side of the curve related to low frequency region is attributed to mass transfer resistance [8]. In addition, the semicircle in the middle of the curve (shown in detail in Fig. 2(b)) related to middle frequency region could be attributed to the charge transfer resistance while the left-side incomplete semicircle could be related to other processes in the cathode.

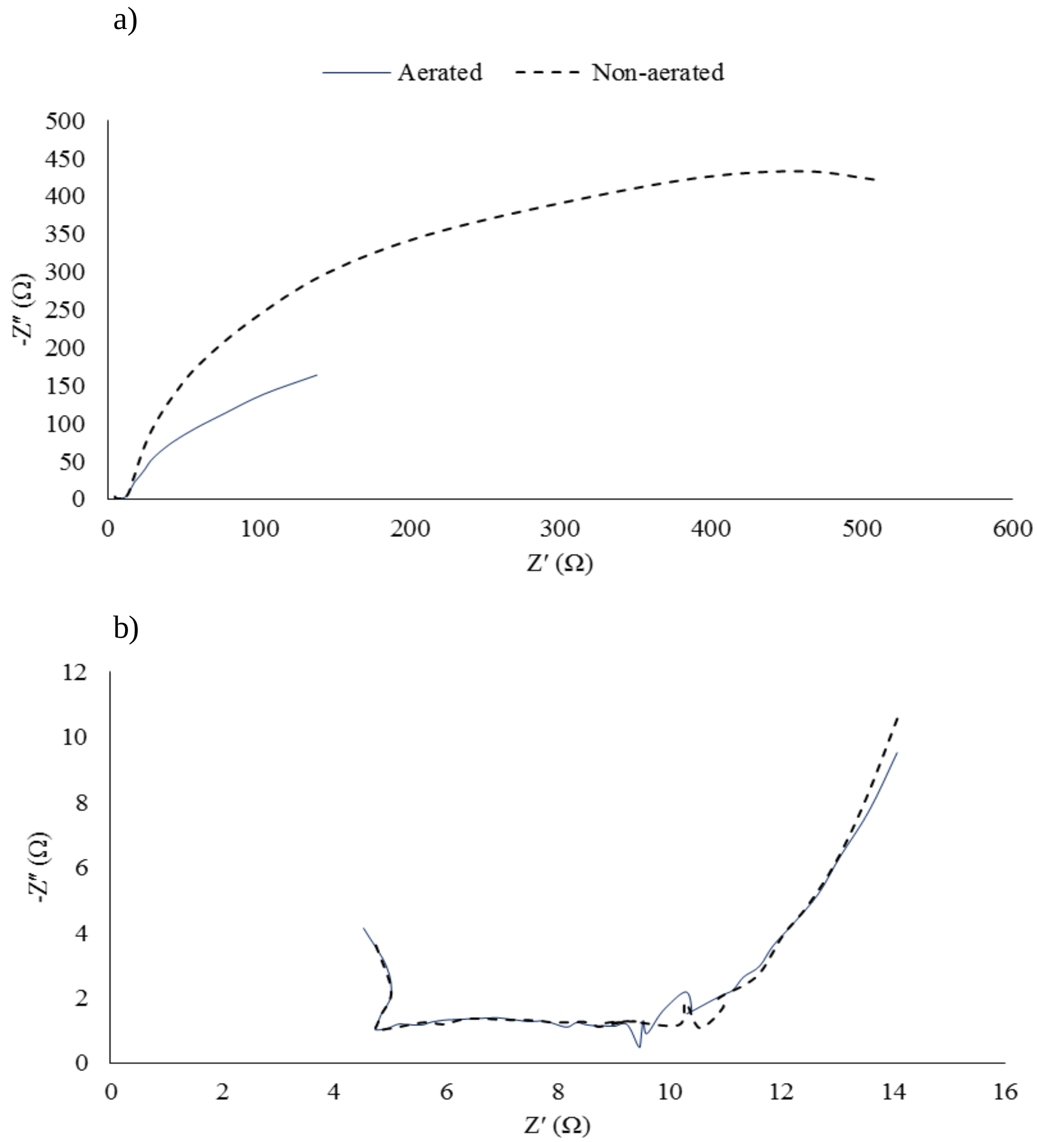

Fig. 2. a) Nyquist plot of SMFC catholyte without aeration and aerated [6] b) The expanded view of high frequency region

Comparing the data shown in Fig. 2(b), the high frequency and middle frequency semicircles completely overlap. This was expected since the same cathode electrode and electrolyte was employed in the two cases, thereby resulting in a similar charge transfer resistance as well as resistances for other processes occuring in the cathode. On the other hand, the mass transfer resistance (Fig. 2 (a)) appears to be considerably different for aerated and non-aertaed conditions. Mass transfer resistance of 451 Ω was obtained for the aerated cathode [6] while this was 953 Ω when aeration was stopped for 1 hr in the present study, leading to total resistance of 984.1 Ω. Aeration leads to the increase in availability of oxygen in catholyte, facilitating oxygen mass transfer to the cathode. When aeration stopped, however, oxygen concentration was reduced in catholyte so that mass transfer resistance increased due to the lack of presence of oxygen. This clearly suggests that the presence of electron acceptor have a significant role in decreased mass transfer resistance in cathode and improved performance of SMFC is avhieved by sufficient amount of oxygen concentration as the electron acceptor in catholyte.

Conclusions

In the present study, resistances of an SMFC without aeration in cathode was studied. EIS results demonstrated that mass transfer resistance and consequently the total resistance was remarkably increased when cathode aeration was stopped, suggesting that the lack of oxygen as electron acceptor in cathode enhnaced resistance against oxygen mass transfer to cathode. Findings of this study showed the importance of the presence of sufficient electron acceptor in cathode of SMFCs to decrease mass transfer resistance and improve SMFC performance.

Acknowledgements

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