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Regulation of biocathode microbial fuel cell performance with respect to azo dye degradation and electricity generation via the selection of anodic inoculum

Jian Sun [a,*], Bihai Cai [a], Yaping Zhang [a], Yenping Peng [b], Kenlin Chang [a], Xunan Ning [a], Guoguang Liu [a], Kun Yao [a], Yujie Wang [a], Zuoyi Yang [a], Jingyong Liu [a]

[a] School of Environmental Science and Engineering, Guangdong University of Technology, Guangzhou 510006, PR China

[b] Department of Environmental Science and Engineering, Tunghai University, Taichung, Taiwan

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ABSTRACT

Biocathode microbial fuel cell performances with respect to azo dye decolorization and electricity generation were examined using two anodic inoculums, textile dyeing sludge (MFC-I) and municipal sludge (MFC-M), to determine the potential performance regulation of the MFC via the selection of anodic inoculum. The results showed that the MFC-I exhibited excellent performance in Congo red decolorization, whereas the MFC-M performed well in electricity generation. The MFC-I achieved fast Congo red decolorization with a first-order rate constant $k = 0.0501$, which was 34% higher than that obtained by MFC-M ($k = 0.0375$). The MFC-M exhibited 3.22 times higher power output (29 mW/m^2 vs. 9 mW/m^2) and 38.0% lower anode impedance (749 Ω vs. 1208 Ω) compared to MFC-I. The functional stains isolated from the anodic biofilm of MFC-I were identified as *Pseudomonas* sp. and *Aquamicrobium* sp., while isolates from MFC-M belonged to *Pseudomonas* sp. and *Bacillus* sp. Four selected isolates were proved to be exoelectrogens and bacterial decolorizer simultaneously but exhibited different bioelectrocatalytic activities and dye decolorizing capabilities, which could partly explain the performance difference between the two MFCs with different anodic inocula.

Introduction

Microbial fuel cells (MFC) explore the novel characteristics of microorganisms as a biocatalyst and converts chemical energy in pure organic compounds even composite organic wastewater into electricity [1]. More renewable energy can be recovered from organic wastes by combining MFC with dark fermentation in term of hydrogen [2]. Nevertheless, the application of MFC for environmental remediation,

* *Corresponding author*. Tel.: +86 13480273800; fax: +86 02 39322547.
E-mail address: sunjian472@163.com (J. Sun).

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particularly for recalcitrant environmental pollutant removal with concomitant bioelectricity generation, has emerged as active areas of MFC research in recent years [3]. The anode chamber of the MFC resembles the anaerobic treatment unit in which pollutants are degraded via redox reactions and enzymatic activities but demonstrates a higher pollutant degradation rate due to the presence of an anode, which can serve as an inexhaustible electron acceptor [4].

Microorganisms grown as biofilm on the anode surface are crucial for anode performance because they directly correlate with substrate metabolism (or pollutant degradation) and electricity harvesting from the substrate using the anode as an electron acceptor. The mixed electrogenic communities in the bioanode can be enriched using inocula from various natural environments, such as aquatic sediment [5], soil [6], municipal sludge and wastewater [7], among other areas. Depending on the inoculum, the microbial community established in a mixed culture bioanode may vary and can thus affect the corresponding performance of the MFCs. Li et al. [8] have compared the use of domestic wastewater, activated sludge, and anaerobic sludge in the characterization of a two-chamber MFC treatment of acidic food waste leachate. It was determined that the MFC inoculated with anaerobic sludge exhibited the highest power among the three MFCs based on similar removal efficiency of the COD due to an enrichment of both fermentative and electrogenic bacteria. In another study, the performance of the air-cathode single-chamber MFC with confectionery wastewater as a substrate was investigated using multiple aerobic sludge, anaerobic sludge, and wetland sediment as anodic inocula [9]. Wetland sediment has been determined to be a good source of inoculum for the MFC due to its higher power output and more rapid COD removal compared to aerobic and anaerobic sludge. The relative enrichment of iron-reducing bacteria in sediment was responsible for its good performance in electricity generation. Furthermore, Va'zquez-Larios et al. [10] reported the performance of cylinder-shaped single chamber MFCs fed with simulated hydrogenogenic fermentation liquid of organic solid wastes, which are dependent on the inoculum type (sulfate-reducing, methanogenic, and aerobic inocula). These researchers observed that the highest powers and coulombic efficiency were achieved with MFC loaded with sulfate-reducing consortia. Baranitharan et al. [11] used a dual chamber MFC to treat palm oil mill effluent with predominant microorganisms isolated from palm oil anaerobic sludge as inoculum. The maximum power density produced by the MFC was two times higher than that of MFC operated using usual anaerobic sludge as inoculum due to the substantial improvement in electron transfer between the microorganisms and anode. However, these studies primarily examined the harvesting of electricity from readily biodegradable organic matter in wastewater on the basis of the activity of electrochemical active microorganisms enriched in the anode using different inoculum. However, it remains unclear whether the inoculum from the waste disposal site correlates with the performance of the MFC designed for specific recalcitrant environmental pollutant removal. Moreover, less is known regarding the possibility of manipulating the anode microbial community via the selection of inoculum to increase MFC performance with respect to pollutant degradation and bioelectricity generation.

Several recent studies have demonstrated that azo dye-a recalcitrant pollutant present in textile industry wastewater can be effectively removed in the bioanode of the MFC [12–14]. In such a system, azo dye-degrading bacteria and electrochemically active bacteria interact with each other and together contribute to the simultaneous azo dye degradation and electricity generation [13].

The purpose of this work was to investigate the effect of an inoculum source on the performance of a biocathode MFC designed to treat textile industry wastewater and to determine whether the performance of the MFC with respect to azo dye decolorization and electricity generation can be regulated by selecting the inoculum source. The sludge from the textile dyeing wastewater treatment plant, which enriches indigenous azo dye degraders and the anaerobic sludge from the municipal sewage treatment plant, which contains abundant electrogenic bacteria, were used for anode inoculation. The performance of the MFCs were comprehensively assessed using Congo red decolorization rates, power output and anode polarization. Characterization of the degradation intermediates of Congo red, electrocatalytic activity of the bioanode and dominant functional bacteria within the anodic biofilm was performed to determine the essence of the observed results.

Materials and methods

Dye

Congo red (Sigma–Aldrich) was selected as the model azo dye and used to evaluate the decolorization performance of the MFC. The Congo red is a representative di azo dye and it's chemical structure is shown in Fig. 1.

MFC configuration

The aerobic biocathode two-chamber MFCs were constructed by assembling two equivalent plastic cubic chambers and inserting two carbon-based electrodes into the chambers, as previously described [15]. Each chamber had an approximately 400 mL liquid volume. The anode and cathode chambers were separated by an cation exchange membrane (CEM, Zhejiang Qianqiu Group Co., Ltd., China, 4 × 4 cm in diameter). Porous carbon papers (without water-proofing) with a projected surface area of 3 × 3 cm^2 on each side were used as the electrode and placed in parallel on opposite sides of the chamber with a spacing of 2 cm. The external circuit of the MFC was connected with a titanium wire and was placed

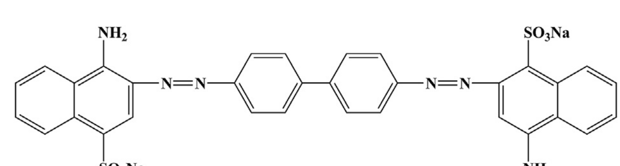

Fig. 1 – Chemical structure of Congo red.