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Short Communication

A novel microbial fuel cell sensor with a gas diffusion biocathode sensing element for water and air quality monitoring

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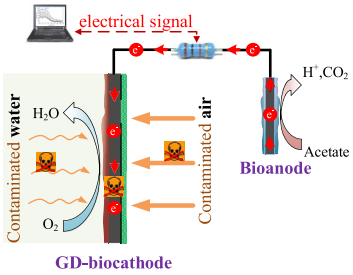
HIGHLIGHTS

- Gas diffusion biocathode sensing element was fabricated in uncomplicated method.
- MFC sensor was directly used in monitoring of aerobic and anaerobic water bodies.
- MFC sensor was for the first time used for air pollution monitoring.

GRAPHICAL ABSTRACT



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ABSTRACT

Toxicity monitoring is essential for the protection of public health and ecological safety. Microbial fuel cell (MFC) sensors demonstrated good potential in toxicity monitoring, but current MFC sensors can only be used for anaerobic water monitoring. In this study, a novel gas diffusion (GD)-biocathode sensing element was fabricated using a simple method. The GD-biocathode MFC sensor can directly be used for formaldehyde detection (from 0.0005% to 0.005%) in both aerobic and anaerobic water bodies. Electrochemical analysis indicated that the response by the sensor was caused by the toxic inhibition to the microbial activity for the oxygen reduction reaction (ORR). This study for the first time demonstrated that the GD-biocathode MFC sensor has a detection limit of 20 ppm for formaldehyde and can be used to monitor air pollution. Selective sensitivity to formaldehyde was not achieved as the result of using a mixed-culture, which confirms that it can serve as a generic biosensor for monitoring gaseous pollutants. This study expands the realm of knowledge for MFC sensor applications.

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1. Introduction

Environmental toxicity monitoring is important for the protection of public health and ecological safety. There has been a growing interest in developing microbial fuel cell (MFC) based sensors, as they self-generate electric signals with biodegradable substrates, provide real-time data, and are at low cost (Sun et al., 2015; Wang et al., 2015; Jiang et al., 2018). The traditional MFC sensor has a bioanode sensing element and has been used successfully for toxicity monitoring in anaerobic water. When using the bioanode sensing element, microorganisms conduct the outward extracellular electron transfer (EET) process by transferring electrons obtained from substrates to the anode (Pandey et al.,

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2016; Kumar et al., 2017; Saratale et al., 2017; Zhao et al., 2018). The electric signal is obtained as the electrons further flow throughout an external circuit to the cathode. The presence of toxic compounds causes a decrease in microbial activity which causes the electric signal to change (Alaraj et al., 2014; Grattieri and Minteer, 2018). However, the bioanode sensing element can only be used for anaerobic water monitoring. In addition, its performance for toxicity monitoring is negatively affected by the variation in the concentration of organic matter (Jiang et al., 2016a, 2017c; Jin et al., 2016; ElMekawy et al., 2018). Our pervious study has proven that the use of a biocathode sensing element solved the problem of false negative due to the combined signals mixed with organic degradation and toxicity, and it achieved increased sensitivity (Jiang et al., 2017b). It is also known that microorganisms can conduct inward EET process by transferring electrons obtained from the cathode for oxygen reduction reaction (ORR) (Li et al., 2017). The working principle of the biocathode sensing element is that the presence of toxic compounds is expected to decrease the activity of microorganisms on the biocathode. The biocathode sensing element requires a sufficient supply of oxidants, such as oxygen, whereas the bioanode sensing element requires a sufficient supply of reductants, such as hydrocarbons.

External aeration (EA) is commonly used to supply oxygen for a biocathode via air sparging (Wu et al., 2016). However, the EA-biocathode MFC sensor was potentially restricted by the loss of volatile pollutants. Moreover, the method is energy intensive so is not suitable to achieve energy self-sustainability (Grattieri and Minteer, 2018). Although not designed for environmental monitoring, it shows that a MFC with a gas diffusion (GD) biocathode could produce a power density comparable to that of platinum (Xia et al., 2013; Lu et al., 2016).

In this study, a novel structure of GD-biocathode sensing element sensitive to the analyte was constructed. Bioanode separated by a piece of membrane was used as the counter electrode, which maintained the advantage of MFC sensor as a typical type of self-powered biosensor (Jiang et al., 2015; Grattieri and Minteer, 2018). Moreover, the performance of the GD-biocathode MFC sensor for gaseous pollution monitoring was further evaluated.

2. Materials and methods

2.1. MFC sensor construction and startup

The GD-biocathode sensing element was fabricated by the polarity reversion of the bioanode (Fig. 1a) to abstain sufficient biomass loading to catalyze the ORR (Cheng et al., 2009). Briefly, the cultivated bioanodes were assembled with commercial waterproof breathable membrane (WBM) (Ningbo Shanquan Building Material Co., Ltd., CHN) as the GD-biocathode sensing element (Xing et al., 2015). A pair of bioanode and GD-biocathode was installed into the two-chamber MFC sensor (7 mL for each chamber with a cross sectional area of 7 cm^2) (Fig. 1b). The EA-biocathode MFC sensor (Fig. 1c) was constructed as the control test by just replacing the WBM with a blind plate and using an air pump to supply oxygen into the catholyte.

For water monitoring, the MFC sensors were running with anolyte and catholyte with a feeding rate of 6 mL min^{-1} controlled by a peristaltic pump. The anolyte was prepared by dissolving 1 g sodium acetate, 0.13 g KCl, 0.125 g NH_4Cl, 12.5 mL trace minerals solution, and 5 mL vitamin solution in 1 L of 50 mM PBS solution (Lovley and Phillips, 1988; Jiang et al., 2016b). The catholyte was modified from the anolyte by replacing the sodium acetate with 1 g $NaHCO_3$. The anode and cathode were connected with an external resistor of 300 Ω with a data acquisition system. The 300 Ω of the external resistance was the optimized value, as the MFC sensor could only achieve a stable operation when the value of the external resistor was higher than this value (Huggins et al., 2015). A bottle contained 500 mL of anolyte was circulating with the anode chamber to keep a constant concentration of acetate.

For air monitoring, the GD-biocathode MFC sensor was further

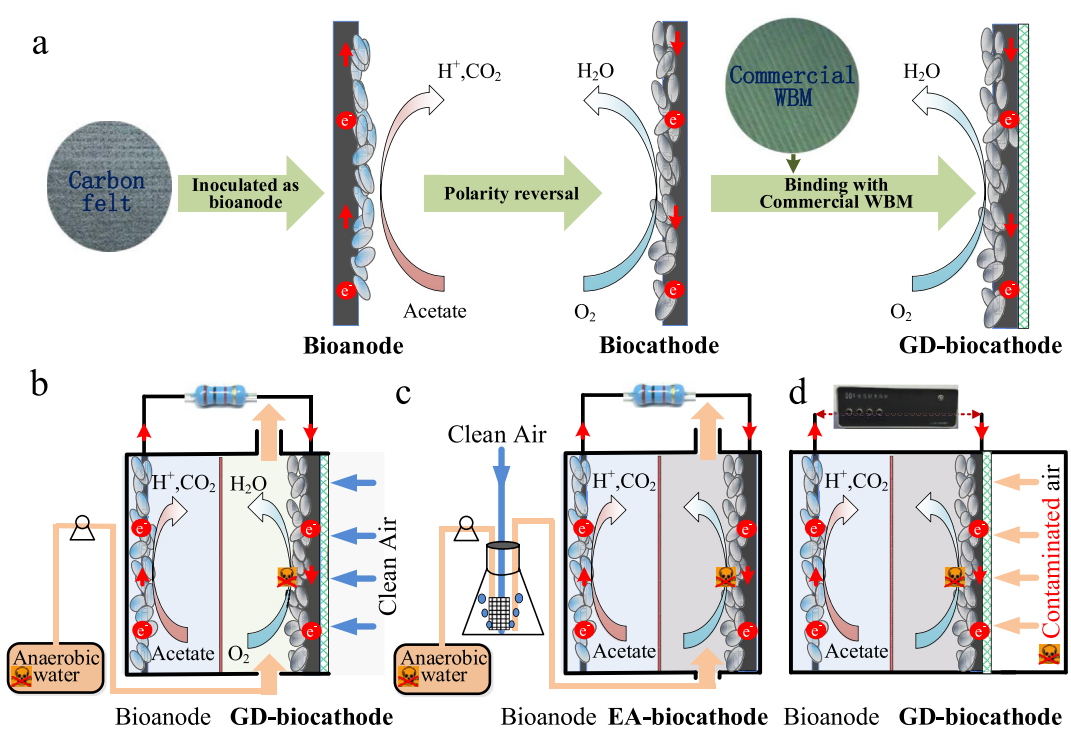

Fig. 1. The schematic illustration for the fabrication process of GD-biocathode (a). Water monitoring achieved by the GD-biocathode MFC sensor (b), and EA-biocathode MFC sensor (c). Air monitoring achieved by the GD-biocathode MFC sensor (d).

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