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Research article

Electricity production and benzene removal from groundwater using low-cost mini tubular microbial fuel cells in a monitoring well

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ABSTRACT

A low-cost mini tubular microbial fuel cell (MFC) was developed for treating groundwater that contained benzene in monitoring wells. Experimental results indicate that increasing the length and density, and reducing the size of the char particles in the anode effectively reduced the internal resistance. Additionally, a thinner polyvinyl alcohol (PVA) hydrogel separator and PVA with a higher molecular weight improved electricity generation. The optimal parameters for the MFC were an anode density of 1.22 g cm^{-3}, a coke of 150 μm, an anode length of 6 cm, a PVA of 105,600 g mol^{-1}, and a separator thickness of 1 cm. Results of continuous-flow experiments reveal that the increasing the sets of MFCs and connecting them in parallel markedly improved the degradation of benzene. More than 95% of benzene was removed and electricity of 38 mW m^{-2} was generated. The MFC ran continuously up to 120 days without maintenance.

1. Introduction

Groundwater is frequently contaminated by BTEX (benzene, toluene, ethylbenzene and xylene) because of leaks from gas stations and petroleum tanks (El-Naas et al., 2014). Of the BTEX compounds, benzene is of greatest concern, because of its high toxicity and carcinogenicity. It poses a high risk to human health and the ecosystem (Firmino et al., 2015). Owing to the toxicity of benzene and the low dissolved oxygen concentration in groundwater, microbes have difficulty degrading it (Corseuil et al., 2015; Do et al., 2011). Various techniques for treating benzene-containing groundwater have been developed (An et al., 2016). Bioremediation is a green and popular method for removing pollutants from groundwater (Sharma et al., 2016). However, aerobic bio-remediation requires expensive mechanical aeration to supply dissolved oxygen (Khan et al., 2004; Obiri-Nyarko et al., 2014). Aeration also results in the emission of volatile organic carbons from the groundwater to the atmosphere, causing air pollution (Taylor, 2015).

A microbial fuel cell (MFC) is a bio-electrochemical system that typically contains an anode chamber, a cathode, and a proton exchange membrane (PEM) separator. The microbes in the anode chamber can oxidize organic pollutants to generate CO_2, protons, and electrons (Jang et al., 2004). Microbial fuel cells (MFCs) can simultaneously remove pollutants and recover energy from wastewater (Wang et al., 2016; Yuan et al., 2010). MFCs recently became popular for treating wastewater (Huang et al., 2011; Tao et al., 2015). Many studies have investigated different configuration and materials of MFCs have been assessed, including tubular flat plate, single-chamber, stacked MFC (Cheng and Logan, 2011; Logan et al., 2006). Many MFCs are large such as the traditional baffle stacking MFC (Choi and Ahn, 2013; Lay et al., 2015). They are not suitable for groundwater remediation. Recently, mini MFCs have been designed for different applications (Chouler et al., 2016; Logan et al., 2006; Wang et al., 2011). For example, Chouler et al. (2016) designed air-cathode miniature MFC for electricity generation from urine. Their MFCs electrically linked in parallel to enhance the power generation. Additionally, the expensive PEM separator also limits its use in groundwater bioremediation (Adelaja et al., 2014; Choi et al., 2013).

To increase the power generation and pollutant removal, connecting MFC units in series or parallel can enhance the power generation (Zhuang et al., 2012). Aelterman et al. (2006) reported that connection of MFC units in series and parallel increased the

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power generation. Liu et al. (2016) indicated that the open-circuit voltage of MFCs in series was higher than those in parallel. For example, Chouler et al. (2016) reported that the MFCs electrically linked in parallel can enhance the power generation.

In this study, the mini-tabular-MFC was used to remediate the high concentrations of benzene. The effects of MFCs in series and parallel on benzene removal and power generation were investigated. The effects of design parameters on MFC performance and the long-term performance of the MFC were assessed. Both scanning electron microscopy (SEM) and denaturing gradient gel electrophoresis (DGGE) were carried out to observe the growth the exoelectrogens on the anode surface after the experiment.

2. Materials and methods

2.1. Chemicals

Coke was obtained from China Steel (Taiwan). The coke was washed with distilled water before use. PVA compounds with various molecular weights were obtained from Chang Chun Petro Chemical Co., Ltd (Taiwan). Benzene was purchased from Echo Chemical Co. Ltd (analytic grade, purity 99.5%).

2.2. MFC setup

An MFC reactor comprises three parts the air-cathode, the PVA-coke anode, and the PVA separator (Fig. 1(a)). The anode was prepared as follows; first, the PVA (M.W. 114,400 g mol^{-1}) was dissolved in water to form 10% PVA gel. Then, 60 g of the coke was completely mixed with 10 g of the PVA gel. Coke with various particle sizes (75, 106, 150, 300, 600 μm) and PVAs with various molecular weights (61,600, 105,600, 114,400 g mol^{-1}) were used. The mixture was poured into a mold and compacted with Compact Type Dial Indicator (No.1044s, Mitutoyo Co. Ltd, Taiwan) form the cylindrical anode to achieve the desired density (1.18, 1.20, 1.22 g cm^{-3}). Each cylindrical anode had a diameter of 4 cm and a length of 14 cm. The weight ratio of coke to PVA used was 2:1 (w/w).

The proton exchange layer was prepared by freezing and thawing (Qi et al., 2015). PVAs with various molecular weights (61,600, 105,600, 114,400 g mol^{-1}) were mixed with water to form a 10% of PVA gel, which was poured into a mold (diameter 4 cm);

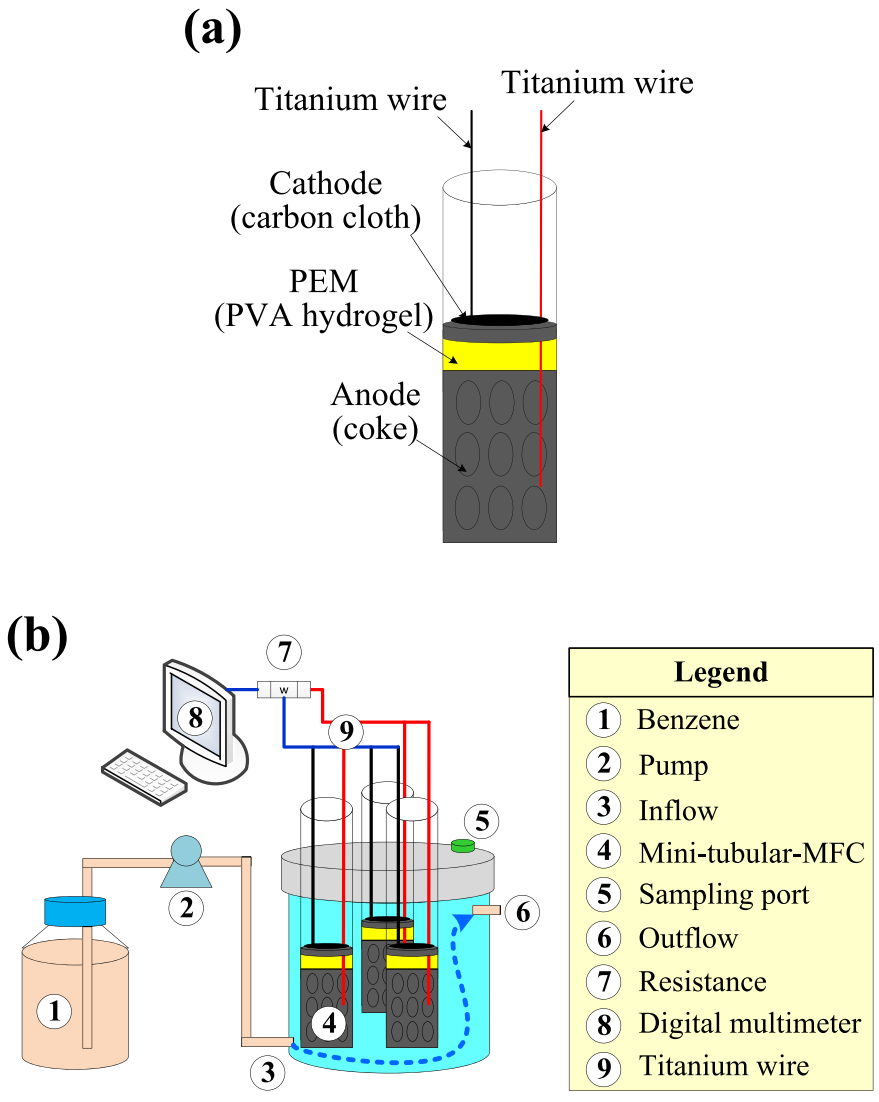

Fig. 1. Setup of well-monitoring MFC (a) PVA-coke anode, (b) schematic diagram of MFC experiment.