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Modifying membrane anode in a microbial fuel cell to improve removal of gaseous ethyl acetate without reducing generation of electricity

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ABSTRACT

An S-type flow-field pipe-microbial fuel cell (SFP-MFC) was developed to remove ethyl acetate (EA) from an air stream. Features of the SFP-MFC included the use of polyvinyl alcohol and a membrane electrode assembly (PVA-MEA) as the gas diffusion membrane and proton exchange membrane (PEM), which separated the anode from the cathode. The performance of the SFP-MFC system was evaluated with an empty bed residence time (EBRT) of 14.35 s and an organic loading rate of 63–3700 g/m^3/h, with or without the modification of the PVA-MEA electrode using conductive carbon black (CCB). Experimental results revealed that the maximum elimination capacity (EC) and voltage were 2288 g/m^3/h and 330 mV, respectively, which were obtained when the PVA-MEA was modified using CCB. The PVA-MEA that was modified with CCB exhibited a 90% higher EA elimination capacity than the PVA-MEA without CCB modification. Moreover, the SFP-MFC system exhibited buffering at high organic loading, reducing the microbial inhibition by toxic pollutants. The maximum EC and EBRT of the modified SFP-MFC were 3–10 times higher and 2–12 times shorter, respectively, than those of biotrickling filters.

1. Introduction

Volatile organic compounds (VOCs) such as alcohols, acids, ethers, esters, ketones, aldehydes and petroleum hydrocarbon, are present at low concentrations in many gaseous industrial waste emissions. Ethyl acetate (EA), a VOC, is an organic solvent that is highly volatile, has a sweet smell, and is damaging to the respiratory system [1]. It is commonly used as a solvent in paint, varnish, adhesives, and organic syntheses, especially in the food and pharmaceutical industries [2]. Exhaust emissions of VOCs from various industrial processes cause environmental damage and are a human health hazard [3]. Purifying waste gases that contain VOCs is important to many firms that seek to conform to environmental regulations. The many techniques for controlling VOCs include physical, chemical and biological techniques, which may involve activated carbon adsorption, the use of an absorption tower, incineration, catalytic oxidation and biotrickling filters [4]. Biological treatment has been shown in recent years to be low-cost and to cause no secondary pollution, and it has therefore become a focus of interest in the field of air pollution control.

Microbial fuel cells (MFC) can be utilized to generate electricity directly by the oxidation of dissolved organic matter. Studies have established that fuels that are used in MFCs can be used with many substrates, such as acetate, glucose, sucrose, and other organic substances. However, MFCs have been made much more valuable in recent years by combining them with wastewater, including swine wastewater [5], paper-recycling wastewater [6], food wastewater [7], and domestic wastewater. The use of MFC for eliminating toxic contaminants such as phenol [8], benzene [9], and toluene, has recently been investigated [10].

Polyvinyl alcohol (PVA) is a water-soluble synthetic polymer that is often used in paper, textiles, and many coatings. PVA is most commonly used as a physical cryogel in the formation of cross-linked polymeric macro porous systems [11]. Porous polymeric hydrogels have been prepared by freeze-drying after they swelled in water [12]. Their porous structure offers several advantages, such as a higher specific surface area, high permeability, high osmotic stability, and the effective transmission of nutrients from solution to growing cells in the biofilm [13]. Chen et al. [14] has reported that PVA membranes are suitable for use as three-dimensional electrode materials, because they exhibit high Columbic efficiency with minimal power loss.

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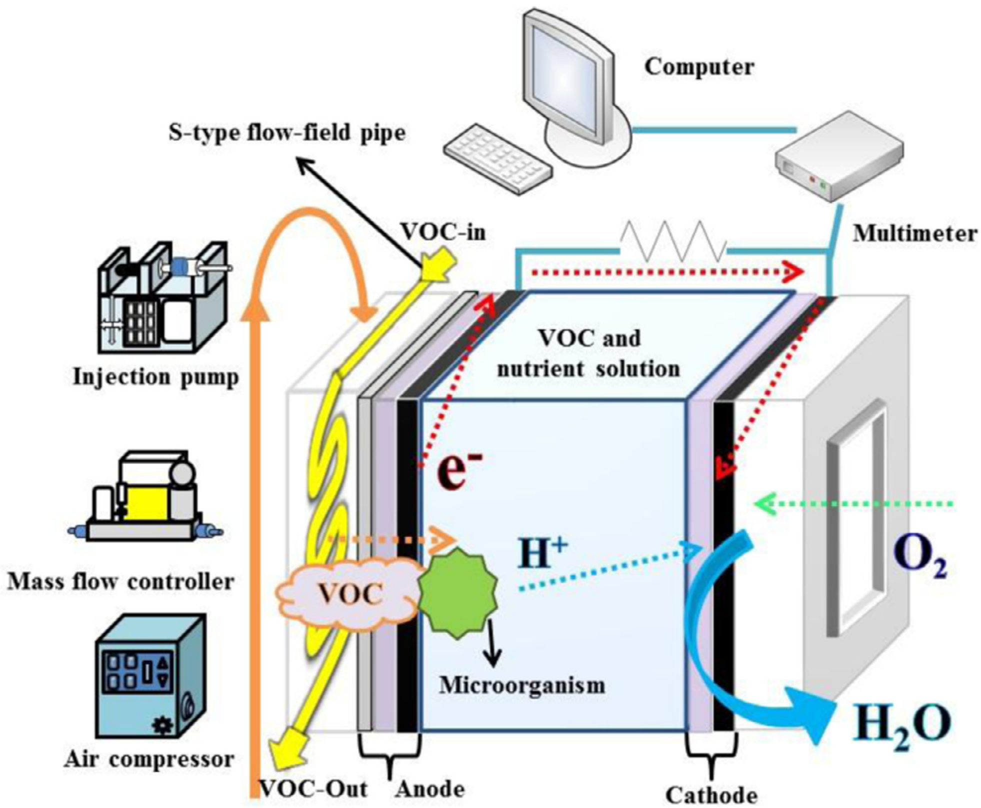

Fig. 1. Conceptual framework of SFP-MFC.

In most relevant studies, the substrates that have been used in MFCs have been liquids. Few investigations have used gaseous pollutants as substrates, or investigated the removal of gaseous pollutants using MFCs [15]. This work develops an S-type flow-field pipe-microbial fuel cell (SFP-MFC) system. The SFP-MFC is characterized by a serpentine-shaped gas conveying pipe that can increase the gas empty bed residence time (EBRT); increase the effective contact area between microorganisms and pollutants, and enable electrons to be transferred from microorganisms to the anode [16].

Effective mass transfer must occur in solution through a gas diffusion membrane for a gaseous substrate, because microorganisms do not directly degrade gaseous substrates. In this work, EA, a highly volatile VOC, was used as a substrate in an MFC. However, limited mass transfer of EA from gas to liquid, followed by poor biodegradation, are expected if gaseous EA is introduced directly to the MFC. To overcome this limitation on EA transfer, a new anode that allows gaseous EA to be directly transported to the biofilm, is designed. The innovative features of the novel anode include a polyvinyl alcohol and membrane electrode assembly (PVA-MEA); it is doped with conductive carbon black (CCB) to form a PVA-CCB-MEA. CCB is well known to exhibit high porosity and electrical conductivity (low resistance) [17]. The addition of CCB to form PVA-CCB-MEA is believed to provide two main functions – which are improving the diffusion of gas and improving the transport of protons.

Both the EA degradation and electricity generation performance of the SFP-MFCs herein were studied and the affecting factors were examined. The performances of the currently used MFC and the modified MFC were evaluated with respect to organic loading, elimination capacity, and maximum power production.

2. Material and methods

2.1. SFP-MFC configuration and operation

An S-type flow-field pipe-microbial fuel cell (SFP-MFC) system was constructed by modifying a conventional MFC system by installing an additional gas pipe, called an S-type flow-field pipe, to convey inlet gas, as presented in Fig. 1. Fig. 2 displays a conceptual model of contaminant transport through the PVA-CCB-MEA. One of the features of CCB is its porous structure, which provides powerful adsorption of contaminants and favors the following attachment of growing biofilms. As shown in Fig. 2, first, gaseous VOCs in the S-type pipe were quickly diffused to the CCB layer, concentrating them; the VOCs were then transferred to the PVA and the carbon cloth by diffusion. Finally, the VOCs were delivered to liquid phase and biodegraded by microbes. VOC adsorption and degradation in the SFP-MFC system caused the difference between VOC concentrations, which provides a concentration gradient; therefore, VOCs were continuously transferred from high concentration region to low concentration region by diffusion.

Fig. 3 presents the assembly diagram of an SFP-MFC. The MFC was a single-chamber air-cathode cubic reactor that was constructed from acrylic glass. A nutrient reservoir was constructed from an acrylic sheet with dimensions of 50 mm wide × 50 mm high × 20 mm deep for use as a reactor. To prevent water leakage, support plates and an O-ring were sandwiched between the anode and the cathode. The anode and cathode were located either side of the nutrient reservoir. All of the components of the SFP-MFC, including the membrane electrode assembly, the nutrient reservoir and each plate, were sealed within an O-ring and bolted together. Compressed air was pumped into the SFP-MFC using an air compressor at a flow rate of 0.13 L/min. Concentrated EA