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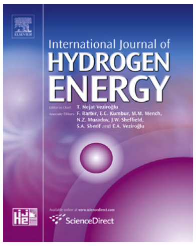

Types of simplified flow channels without flow obstacles in microbial fuel cells

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ABSTRACT

Microbial fuel cells (MFCs) use microorganisms to convert organic matter into electricity. In order to enhance the mass transfer of MFCs, four types of simplified flow channels, without flow obstacles (square, circular, divergent and convergent), were designed and applied to the anode/cathode channels of MFCs. The simulation analysis showed that the four types of simplified flow channels without flow obstacles obtained a better flow mixing efficiency with an Aspect Ratio (AR) of 1 at a Reynolds number (Re) of 60. A maximum power density of 617.8 mW/m^2 and a COD (chemical oxygen demand) degradation ratio = 9.9% were obtained by the MFCs with the convergent types of flow channels without flow obstacles. This is because the flow mechanism (convection and vortex flow) generated by convergent types of flow channels decrease the mass transfer and ohmic losses. Therefore, this concept of the simplified flow channel without flow obstacles will be useful to the application of MFCs in the future.

Introduction

Microbial fuel cells (MFCs) are bioreactors which can convert organic matter from wastewater into electricity by using microorganisms [1]. On application, the macro-scale MFCs have the potential for use in wastewater treatment [2]. Micro-scale MFCs can be applied to portable electronic devices and sensors [3]. However, more importantly than that, it may be possible for MFCs to help to solve the environmental concerns for the next 50 years because MFCs are the one form of clean energy that can reduce environmental pollution problems [4].

However, reducing the internal resistance of MFCs is the primary objective as it causes a serious low power density of MFCs [3,5]. In recent years most studies have focused on reducing activation losses in MFCs [6–8] as the main electricity generation is the electron transfer process from microorganisms through the electrode [9]. But the mass transfer impact might be larger than expected because it not only affects the mass transfer losses, such as substrate flux [10,11] and waste removal [12] in MFCs, but also affects the activation losses [13–15] and ohmic losses such as the proton transfer [16]. Therefore, the flow control in MFCs is significantly important because the performance of flow mixing and

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mass flow transfer in MFC channels can be controlled to improve the power performance of MFCs [17].

Nowadays, the main flow control method to enhance the mass transfer is by using a magnetic stirrer bar [18–20], which needs external energy and is difficult to fabricate on micro-scale MFCs. But the flow channel design of MFCs in this study is easy to fabricate and does not need external energy, which is of benefit to commercial applications. According to previous studies, different types of flow channels can generate different flow fields to enhance the performance of MFCs. The convergent flow channel generates a two-flow mechanism (convection and vortex formed), which enhances the mixing of anolytes and the transfer of protons/electrons, and thus increases the power performance of MFCs [21]. A biometric flow channel can distribute the flow field of the anolytes to make the reactant more uniform on the electrode surface and enhance the proton transfer, which reduces the mass transfer losses of MFCs [22]. In addition, the MFCs with a biometric mixer added makes reactant mixing uniform and the power density reaches 118.34 mW/m^3, which is higher than MFCs without an external mixer added by 28.9% [23]. However, for commercial applications, the structure of the flow channel needs to be simplified, thus, in this study, the effects of four types of simplified flow channels (square, circular, divergent and convergent) without flow obstacles were applied to continuous types of MFCs for power performance investigation. In order to decrease the ohmic losses, the structure of the flow channels were designed into a flat configuration, which kept the two electrodes close [24].

Materials and method

Numerical model

The geometrical dimensions of the four types of simplified flow channels (square, circular, divergent and convergent) without flow obstacles are shown in Fig. 1. The bottom area was constructed to 903 mm^2 for all types of flow channel in accordance with the standard working area of the electrode, and was placed at the bottom of the flow channel. Before the experiment, the optimization of the four types of simplified flow channels was based on a numerical simulation to analyze the effects of aspect ratio (AR) and Reynolds number (Re) on the flow mixing performance. In addition, the simulation discusses only the flow regimes of the four types of simplified flow channels, so the placing of the electrodes was ignored.

Numerical simulation

The flow mixing performance of four types of simplified flow channels (square, circular, divergent and convergent) without flow obstacles was based on the Finite Volume Method and analysis by CFD-ACE+ (2013, CFDRC Research Corp., U.S.). The program was run on a 2.4 GHz Pentium IV processor with a RAM memory of 1 GB. A multi-block unstructured grid number of the simulation model selected was 6 × 10^4 for a two-dimensional numerical simulation after the mesh-independent tests; in addition, the convergent value was set as 1.0 × 10^4.

In the simulation of the flow mixing process, three governing equations [23], the continuity equation (1), momentum equation (2) and the diffusion equation (3), would be utilized as following:

$$\nabla\cdot\overrightarrow{V}=0 \tag{1}$$

$$\frac{\partial\overrightarrow{V}}{\partial t}+\overrightarrow{V}\cdot\nabla\overrightarrow{V}=-\nabla p+\frac{1}{\mathrm{Re}}\nabla^2\overrightarrow{V} \tag{2}$$

$$\frac{\partial C_i}{\partial t}+\overrightarrow{V}\cdot\nabla C_i=\frac{1}{\mathrm{ReSc}}\nabla^2 C_i \tag{3}$$

where V stands for fluid velocity vector, P is the flow field pressure, Re represents the Reynolds number, C_i denotes mole concentration, and Sc represents the Schmidt Number.

Additionally, the assumption of simulation for simplifying was set as follows [22,23]: (1) Steady state. (2) Incompressible flow. (3) Fluid properties were set as constant. (4) The effects of the gravity and temperature fields were ignored. (5) The effect of chemical reactions on the variation of flow concentration was neglected.

In order to analyze the flow mixing performance of the four types of simplified flow channels without flow obstacles, the mixing efficiency ($\varepsilon_{\mathrm{mixing}}$) is defined in (4) and calculated at the cross section of the outlet channel of MFCs for the mixing index:

$$\varepsilon_{\mathrm{mixing}}=1-\frac{1}{L}\int_0^L\left|\frac{X_{\mathrm{Ax,outlet}}-0.5}{X_{\mathrm{Amax}}-0.5}\right|dx \tag{4}$$

where $\varepsilon_{\mathrm{mixing}}$ is indicated as the mixing efficiency, X_{Amax} is the maximum mole fraction for substance A, $X_{\mathrm{Ax,outlet}}$ indicates the concentration of substance A at the outlet channel, and L represents the width of the outlet channel, set at 5 mm.

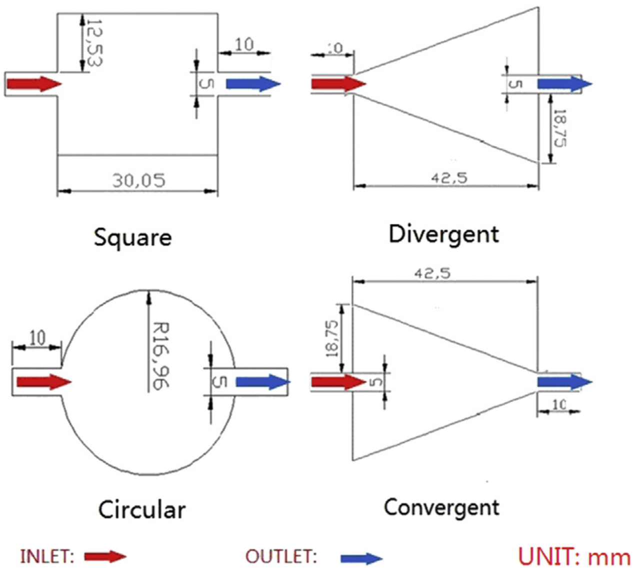

Fig. 1 – The shapes and dimensions of the four types of simplified flow channels without flow obstacles.

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