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Structural effects of expanded metal mesh used as a flow field for a passive direct methanol fuel cell

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HIGHLIGHTS

- Stainless-steel expanded meshes are used as flow fields in a passive DMFC.
- The meshes with different strand widths and assembly patterns are evaluated.
- Visualization methods are used to investigate the two-phase flow characteristics.
- Optimal setup of the meshes helps improve the reactant and product managements.

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ABSTRACT

The metal expanded mesh is an attractive alternative to be flow field plate of the direct methanol fuel cell (DMFC) for practical applications. This work investigates the structural effects of the stainless-steel expanded mesh used as a flow field in a passive DMFC. Three expanded meshes with different strand widths are tested at various methanol concentrations. Effects of its assembly diversity, in terms of two different mesh surfaces and orientations of the opening mesh, are also explored at both the anode and cathode. The influential mechanisms in the light of reactants and products management are analyzed by use of a visualization method. The mesh with a smaller strand width yields a better cell performance at a lower methanol concentration, which performs worse at a higher methanol concentration. Compared with the traditional perforated flow fields, the expanded mesh is preferred at lower methanol concentrations. The assembly mode combining BU at the anode and BL at the cathode is recommended. The visualization tests at both sides reveal the positive effects of above optimal configuration on the reactants and products management in a passive DMFC.

1. Introduction

Passive direct methanol fuel cell (DMFC) has emerged as one of the most promising candidates to be a next-generation power source for portable electronic applications. It relies on diffusion, natural convection and capillary action for reactants and products transport with no need for any energy-consuming auxiliary devices so as to alleviate parasitic power losses [1,2]. Furthermore, a passive DMFC has many advantages such as high energy density, compact structure, safe fuel storage, easy refueling and convenient operation [1–5]. A passive DMFC is generally composed of the anode and cathode end plates, flow field plates, current collectors, membrane electrode assembly (MEA) and gaskets. As a mass transfer regulating component, the flow field plate plays a critical role in reactants (methanol and water at the anode and oxygen at the cathode) and products (carbon dioxide at the anode and water at the cathode) management of a DMFC. Therefore, it must have high electrical conductivity, high corrosion resistance, low thermal conductivity, good mechanical strength, light weight and low cost [1,2,6]. For this reason, many studies have been dedicated to design, manufacture and optimization of the flow field plate, including its materials, patterns and geometries [7–9].

A common method to make the flow field plate is to use metal sheets with an array of machined holes or non-blind channels (known as perforated plate) [8–26]. In this regard, many studies related to the pattern and geometric design of flow field plates have been reported since such issues are of great importance to the cell performance [12–24]. Besides, the porous metals, such as metallic foams, sinters and meshes, can be also used as alternative materials to replace traditional bulky solid materials for flow field fabrication. Metal foams used as the component of a DMFC can enhance stiffness and reduce weight with

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Table 1
Advantages and disadvantages of perforated plate and metal mesh used as the flow field.

Flow field		Advantages	Disadvantages	Refs.
Perforated pattern	Serpentine	Help remove products and enhance mass transfer	High pressure drop between the inlet and outlet	[12–14,18,20–22]
	Parallel	Low pressure drop	Difficult CO_2 removal and non-uniform reactants distribution	[13–15,17–19,21]
	Circular hole	Low contact resistance	Difficult water removal and uneven reactants distribution	[10,11,15–17,19,25]
Metal mesh	Wire mesh	Lightweight, low-cost, high open ratio and uniform fuel distribution	Flexible and high electrical resistance	[36–42]
	Expanded mesh	Lightweight, low-cost, high open ratio and good mechanical strength	High contact resistance	[46,47,55–59]

additional benefits of the controllable porosity and high electrical conductivity [27–29]. Planar sintered metal fibers applied for the fuel cell also exhibit a series of advantages, including good ductility, controllable permeability and high specific surface area [30–34]. However, it is undeniable that both the metal foams and metallic sintered fibers are subject to complex and high-cost manufacturing processes, which is against the fuel cell commercialization. Unlike this, the metal-based wire mesh and expanded mesh have shown great potential to be used for DMFCs [35–61]. Compared with the widely-used perforated metal sheets, the meshes are lightweight, easy-to-make, low-cost, and have higher open ratios. Table 1 shows a comprehensive comparison about the pros and cons between the perforated plates and metal meshes.

The wire mesh consists of thin wires, each of which passes alternately over and under the successive wires. Many previous studies used this material as a flow field medium for a passive DMFC [36–45]. Shrivastava et al. [36] reported on the structural effects of five different wire meshes as flow field plates by designing and fabricating a novel single cell fixture. Results revealed that the mesh made of relatively thick wires yielded a better cell performance. Falcão et al. [37] tested five different wire meshes used as a flow field between the MEA and current collector in a passive DMFC. They claimed that the use of a mesh helped enhance current collection and reduce methanol crossover (MCO), leading to a better pattern of CO_2 bubble distribution. Their results also indicated that the mesh with a larger open ratio and strand width improved the cell performance. Zhang et al. [38,39] investigated the mesh structures, operating conditions and dynamic characteristics of an active DMFC, and concluded that the mesh could inhibit MCO, reduce internal resistance and accelerate CO_2 removal. Contrarily, they found that the mesh with a smaller open ratio and opening was conducive to improve the cell performance and dynamic responses. Zheng et al. [40] devised a new structure of the passive DMFC with a stainless-steel mesh directly welded onto the polymer electrolyte membrane (PEM) coated with catalyst ink.

The expanded metal mesh is produced by simultaneously slitting and stretching a metal plate. For this material, the cuts are expanded into diamond-shaped holes with no material loss, which dramatically reduces the waste of material. Besides, this pattern of mesh is quite light due to the use of thinner raw metal plate and higher open ratio. It has good mechanical strength so that it is capable of well supporting the MEA. Therefore, the expanded metal mesh can be considered as an attractive material to be used as the flow field plate in a passive DMFC [46–54]. Scott et al. [46] firstly verified the feasibility of using a mesh as the flow bed for an active DMFC and investigated the structural effects and CO_2 bubble behaviors. They declared that the use of a mesh exhibited a higher performance in CO_2 gas removal than the parallel flow channels. The mesh with a smaller open ratio and a larger strand width could significantly improve the cell performance. Guo et al. [47] compared the performances of the cells equipped with gold-coated stainless-steel mesh and platinum-coated niobium mesh used as flow field plates. The meshes were directly put or hot-pressed onto the diffusion layer. They announced that the latter mesh hot-pressed with a diffusion layer yielded the highest performance. Besides, some other researchers designed novel electrodes based on the expanded mesh which had a more competitive performance than the conventional carbon-papers or -cloths [55–61]. They claimed that using a mesh was in favor of two-phase transport and promoted higher catalyst utilization. More details can be found in Table 2 that summarizes the current literatures involving the use of mesh-type materials for DMFCs.

In the field of reactants and products management, visualization methods are often adopted to observe the two-phase flow phenomena [13,21,46,62–66]. Yuan et al. [13] investigated the two-phase flow characteristics in the serpentine, parallel and porous flow fields at both the anode and cathode. Their results showed that the use of a serpentine pattern and a higher fuel feed rate was helpful to remove the CO_2 bubbles and water droplets. Yang and Zhao [21] compared the two-phase flow behaviors between the serpentine and parallel flow fields. Results showed that gas blockage never happened to the former pattern, whereas in the latter case gas bubbles tended to block the channels under the condition of a lower methanol feed rate and a higher current density. Yang et al. [62] and Liao et al. [63] explored the effects of the operational parameters on the gas bubble behaviors in the serpentine and parallel channels, respectively. They both concluded that using a higher methanol feed rate favored in reducing the quantity and length of gas slugs but resulted in more serious MCO.

In view of the current literatures, as listed in Tables 2 and 3, there have been studies concerning the use of expanded metal mesh for practical applications. However, there is barely research activity dedicated to the structural optimization and two-phase flow characteristics of mesh-based flow field in a passive DMFC. In particular, less information can be found regarding the bubble behaviors at the anode and water behaviors at the cathode. With this background, the present work aims to investigate the effects of structural factors and assembly modes of the expanded stainless-steel mesh used as the flow field in a passive DMFC, as well as to analyze the relevant influence mechanisms. In addition, we also visually looked into the two-phase flow at both the anode and cathode to disclose how the expanded mesh affects the gas and water managements. We believe this contribution will provide more evidenced information that can be referenced to optimize the structural design and reactants/products management for a passive DMFC based on mesh-based flow fields for practical applications.

2. Experimental

2.1. Fabrication of the membrane electrode assembly (MEA)

The MEA with an active area of 3 cm × 3 cm was fabricated in our laboratory by hot-pressing a Nafion 117 membrane (Dupont, Inc.) between the anode and cathode diffusion electrodes at 10 MPa, 120 °C for 2 min. Before put into practical use, the membrane was pretreated to remove the organic and inorganic contaminants, which was boiled in 3 wt% H_2O_2 aqueous solution for 1 h, followed by in deionised (DI) water for 1 h, then in 0.5 M H_2SO_4 solution for 1 h and finally in DI water for 1 h. The catalyst ink was mixed uniformly and then sprayed on the gas diffusion layer to form a gas diffusion electrode. The anode