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Influences of bipolar plate channel blockages on PEM fuel cell performances

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ABSTRACT

In this paper, the effect of partial- or full-block placement along the flow channels of PEM fuel cells is numerically studied. Blockage in the channel of flow-field diverts the flow into the gas diffusion layer (GDL) and enhances the mass transport from the channel core part to the catalyst layer, which in turn improves the cell performance. By partial blockage, only a part of the channel flow is shut off. While in full blockage, in which the flow channel cross sections are fully blocked, the only avenue left for the continuation of the gas is to travel over the blocks via the porous zone (GDL). In this study, a 3D numerical model consisting of a 9-layer PEM fuel cell is performed. A wide spectrum of numerical studies is performed to study the influences of the number of blocks, blocks height, and anode/cathode-side flow channel blockage. The results show that the case of full blockage enhances the net electrical power more than that of the partial blockage, in spite of higher pressure drop. Performed studies show that full blockage of the cathode-side flow channels with five blocks along the 5 cm channel enhances the net power by 30%. The present work provides helpful guidelines to bipolar plate manufacturers.

1. Introduction

With the limitations of fossil fuel resources and crises in environmental pollution, recent attention to alternative power sources for various applications has been very serious. Proton Exchange Membrane Fuel cells (PEMFCs) with high efficiency and high environmental compatibility have attracted considerable interest within academic and industrial area as a potential power source for transportation and other mobile applications [1,2].

Bipolar plates (BPP) employ various patterns of grooves or flow-field channels to feed reactant gases to the electrode of PEM fuel cells. Several numerical and experimental investigations have attempted to visualize and quantify the characteristics of different flow-field designs [3–8]. For example, Spernjak et al. [8] compared water content and dynamics by simultaneous neutron and optical imaging for three PEM fuel cell flow-fields: parallel, serpentine, and interdigitated. They concluded that the serpentine flow-field showed stable output across the current range and the highest limiting current in comparison to parallel and interdigitated flow-fields which exhibited substantially higher water contents. However, the serpentine flow-field also experienced the highest pressure drop. Li and Sabir [9] presented a review of the flow-field layouts developed by different companies and research groups and their associated pros and cons. Manso et al. [10] also reviewed recent works related to the influence of geometric parameters of flow channels on overall PEMFC performance. Based on this work, homogeneous gas distribution in the gas flow channel can provide a uniform current density throughout the active area and, hence, a uniform temperature distribution, causing less mechanical stresses in MEA and increasing the PEMFC lifetime.

In this paper, a method to improve fuel cell performance is introduced by inserting blockages into the BPP flow-field channels. This method draws its inspiration from heat transfer enhancement techniques employing blockages. Blockages can be considered as passive control devices to enhance forced convection heat transfer. According to Guo et al. [11] and He and Tao [12], blocks make synergy between convection and conduction terms in heat transfer, and increase the heat transfer between the wall and the core flow. This is explained as follows. Consider the energy equation and its advection term, $\vec{V}\cdot\nabla T \equiv (u\partial T/\partial x + v\partial T/\partial y)$,

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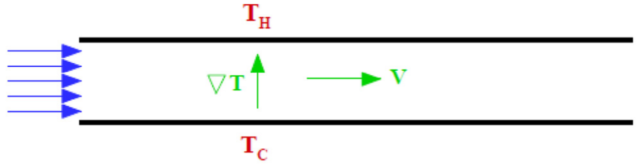
$$\text{Heat-Transfer}: \quad \underbrace{u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}}_{=\vec{V}\cdot\nabla T}=\alpha\nabla^2 T \tag{1}$$

where $\vec{V}=(u\hat{i}+v\hat{j})$ is the local velocity vector, ∇T is the temperature gradient and α is thermal diffusivity respectively. In the case of no blocks (Fig. 1a), ∇T is almost in transverse direction, and $\vec{V}$ is along the channel. Hence the intersection angle between $\vec{V}$ and ∇T is almost 90° and $\vec{V}\cdot\nabla T$ is at its minimal value (≈ 0). Placement of blocks within the channel (Fig. 1b), induces a velocity component in transverse direction. Hence, the intersection angle between $\vec{V}$ and ∇T will reduce and $\vec{V}\cdot\nabla T$ can, therefore, begin to move away from almost zero value. As a result, convection between the wall and the core flow should also start to increase by the channel blockage.

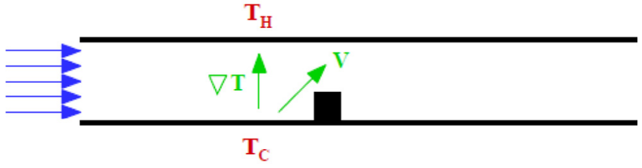
Several papers have investigated the effect of blockages on the improvement of forced convection heat transfer [13–15]. For example, Heidary and Kermani [14] computed the hydrodynamics and heat transfer enhancement in a channel containing one or more rectangular blocks that partially filled the channel cross-section, and reported a 60% improvement in convective heat transfer. Similarly, Huang et al. [15] computed the heat transfer enhancement due to the installation of multiple heated blocks in channels filled with porous media and showed that flow modification via the blocks can significantly enhance convective heat transfer.

From the analogy between heat and mass transfer phenomena in dynamically similar problems, in a mass transfer problem, it is expected that channel blockage enhances the mass exchange between the channel core part and, say a catalyst layer at the top boundary of Fig. 1c. Considering the mass concentration equation as:

(a) convective heat transfer in a straight channel (with no block)



(b) Enhanced convective heat transfer in a straight channel with block



(c) Enhanced mass transfer in a straight channel with block

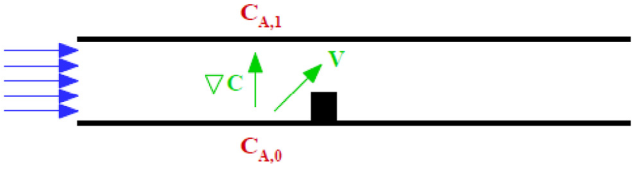


Fig. 1. Schematic figures showing synergy between convection and diffusion mechanisms of heat and mass transfer; (a) heat transfer in a straight channel with no block, (b) heat transfer in a straight channel with block, (c) mass transfer in a straight channel with block.

$$\text{Mass-Transfer}: \quad \underbrace{u\frac{\partial C_A}{\partial x}+v\frac{\partial C_A}{\partial y}}_{=\vec{V}\cdot\nabla C_A}=D_{A,eff}\nabla^2 C_A \tag{2}$$

Here ∇C_A is the concentration gradient and $D_{A,eff}$ is effective binary diffusivity of the reacting species. It is noted that by the blockage of the channels, the intersection angle between $\vec{V}$ and ∇C_A will reduce from 90° and $\vec{V}\cdot\nabla C_A$ similar to $\vec{V}\cdot\nabla T$ will start to move from almost zero value. Indeed, such a placement of blocks in PEMFC flow channels can facilitate over-block convection, thereby driving reactant gas convectively into the gas diffusion layer and delivering reactant species directly to the catalyst sites. Over-block convection also aids the removal of reaction products from the gas diffusion layer into the channel which can further improve performance [16].

The literature contains only a few studies that have investigated the effect of blockages in PEM fuel cell flow-field channels. Heidary and Kermani [17,18] numerically investigated the effect on heat transfer of partial blockages and the corrugated wall in the flow-field channels of a fuel cell and showed that the heat exchange between the channel walls and the core flow strongly depends on the number of blocks along the bottom wall and shape of corrugation. Kuo et al. [19] performed numerical simulations to investigate the performance characteristics of PEMFCs with wave-like gas channels. Perng and Wu [20] also numerically investigated the installation of transverse trapezoidal baffles in the flow channel of PEMFCs and found that the fuel cell performance was enhanced. Wu and Kuo [21] developed a three-dimensional model to analyze PEMFC performance using multiple transversely-inserted rectangular cylinders along the channel axis, and found higher performance with a reasonable pressure drop. Tiss et al. [22] have presented a numerical model investigating the mass transport in a PEM fuel cell with partial blocks inserted in the gas channel. Bilgili et al. [23] have studied the performance of PEM fuel cells containing baffles in PEMFC flow channels and shown that such baffles enhance gas concentration along the channels and higher cell voltages are obtained at high current densities.

Belchor et al. [24] compared experimentally the PEMFC performance of parallel-serpentine-baffle and parallel-serpentine flow channels. They showed that under low humidity conditions, the parallel-serpentine-baffle configuration exhibited better performance due to improved water retention in the flow-field channels. Han et al. [25] studied the effect of wall waviness of the flow channel on PEMFC performance and concluded that concentration loss induced by unstable mass transfer was delayed, and the fuel cell's performance was improved by 5.76% in their experiment, and by 5.17% in their computational study. Ku and Wu [26] investigated a novel design consisting of rectangular parallelepiped within an interdigitated flow-field by simulation and experiment, and reported that the presence of baffles increased the rate of electrochemical reaction and net power by up to 26%. Ghanbarian and Kermani [27] have studied the effect of the partial blockage of flow channels in a parallel flow field and shown that blockage provides performance enhancements over 25% at some specific cases. Heidary et al. [28] have investigated experimentally the effect of two types of full blockage configurations within a parallel flow-field and resulted that the staggered configuration enhances cell performance by up to 28% over the baseline case, and by 18% when compared to the in-line case.

In published papers, blocks were installed in anode and cathode side flow channels simultaneously. Therefore individual effect of blockages in each side has not been discussed. In this paper, we have investigated the blockage effect in anode/cathode side individually. Alongside the investigation of blockage on cell performance, the effect of two types of blockage is also investigated in this study: partial and full blockage. In partial blockage, a part of