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A study on using metal foam as coolant fluid distributor in the polymer electrolyte membrane fuel cell

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ABSTRACT

This paper deals with the usage of metal foams in coolant flow field of bipolar or cooling plates in PEMFC stack rather than conventional machined channel designs. A three-dimensional model is employed to simulate the fluid flow and heat transfer in cooling plates and the capabilities of four different coolant flow field designs, include one parallel, two serpentine and one metal foam porous media field, are investigated and compared based on the maximum surface temperature, uniformity of temperature and the pressure drop. The numerical results indicated that a model with the porous flow field made by metal foam is the best choice for reducing the surface temperature difference, maximum surface temperature and average surface temperature, among the studied models. Furthermore, due to its high permeable coefficient, the coolant pressure drop is very low in this model. Consequently, this model can be well-used as a coolant fluid distributor to improve the PEM fuel cell performance.

Introduction

Polymer electrolyte membrane Fuel cells (PEMFCs), which directly convert chemical energy of fuel into electricity, usually generate the heat as much or even more than the electric power [1]. The large amount of heat is generated as the result of ohmic resistance, mass-transport over-potentials, and irreversibility of the electrochemical reactions. During electrochemical generation of electricity, more than half of hydrogen chemical energy in PEMFCs is converted to heat. Heat can influence the temperature, membrane and the reactant gases properties, and hydration of membrane, which is a function of water saturated pressure (and therefore, the water phase change). Thus, thermal management is very important in overall PEMFC performance. In fact, thermal management is defined as the removal of heat generated by the fuel cell stack to the surrounding [2]. The heat of reactions if not exhausted properly, would impair the performance and durability of the cell. Membrane drying is the result of high temperature of the cell. The ionic conductivity can therefore be reduced. In such circumstances, the enhancement of thermal stresses may lead the membrane rupture.

The temperature can also affect the maximum theoretical voltage of a cell [3]. This voltage descends, as the temperature ascends. On the other hand, low temperature reduces the reactions inside the cell and consequently, increases the losses. This indicates that both high and low temperatures are

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restricted, that is, small temperature difference is desirable in a PEM fuel cell [4]. Besides the limitations of the temperature, it may also not be uniform inside a PEM fuel cell, i.e. it may vary from inlet to outlet and from anode to cathode. Non-uniformity of temperature results in differences in the rate of electrochemical reactions at various cell locations. This creates hot spots at special cell locations and consequently, decreases the fuel cell longevity and durability [5].

Therefore, it is very essential that the heat exits the cell to keep it under small temperature changes and optimum performance conditions. In order to run the fuel cell stack at a constant temperature, it is necessary to dissipate the heat at the same rate by which the heat is being produced; therefore cooling system is unavoidable.

In general, large scale PEMFCs are cooled by liquid water which circulates through coolant flow channels. It is a common method in cooling of the PEM fuel cells. In this method, a suitable fluid circulates through the channels formed in bipolar plates or in dedicated cooling plates. The dielectric fluid is the air or a mixture of water and glycol. There are two performance patterns for circulating the cooling fluid: Open and closed loop. The latter pattern is generally employed for a liquid such as water that flows through the channels created inside the polar plate. Hot water out of the cell stack passes within a radiator to lose the heat and then, re-enter the cell. Most commercial fuel cell cooling systems work with one fluid through a closed loop. This method is reliable and can be used for a wide range of cell powers. Although this pattern can also be used for the air cooling fluid, but an open loop is preferred for the air, because of its lower accessories cost. In this model, the ambient air passes through the created channels which are generally parallel with the fan (force-convection flow) and cools the cell [6].

The flow field where the coolant circulates through the channels is formed on the bipolar plates. With respect to the channel geometry, different types of flow fields have been designed by researchers. The most common types are parallel, serpentine, and parallel-serpentine; each has its specific characteristics and outcomes. The flow field should be well designed so that it can simultaneously remove the generated heat at all of the working voltages, minimize the pressure drop across the field and uniform the temperature distribution within the cell active area.

In addition, cooling and bipolar plates are the major parts of PEMFC stack in weight and volume, and accordingly the cost of machining, especially for channels with small dimensions, is also high. Consequently, finding an effective method to increase the rate of heat transfer and obtain the uniform temperature distribution in the cooling plates was always a challenge.

One creative way is to use metal foams as cooling fluid distributor. They are porous media with the porosity up to 98%. Metal foams are employed to increase the heat transfer and reduce weight of stack at the cost of additional pressure drop [7–10]. They also present many other favorable characteristics, such as vibration damper, rigidity, and so on [11]. Since the conductive heat transfer coefficient for metal foam is higher than that of graphite, the heat transferred by the former porous media would be considerably more than graphite made shoulders of the channels in the PEM fuel cells.

A number of studies have been conducted to investigate the heat transfer issues and cooling in PEM fuel cells in the past. Chen et al. [12] conducted a thermal analysis of the coolant flow field configuration to optimize the design of a PEMFC stack. Six coolant flow field configurations, including three serpentine-types and three parallel-types, were analyzed and compared and they found that serpentine configurations have lower index of uniform temperature (more uniform temperature distribution) than the parallel configurations. However, they observed that parallel-type configuration has lower pressure drop than serpentine-type. A numerical study by Choi et al. [13] revealed the effects of coolant flow field configuration on the cooling performance. They designed six cooling plates with different channel configurations and simulated the fluid flow and heat transfer characteristics in the cooling plates by changing the heat flux and flow Reynolds number, and similar results were obtained. The convection - enhanced serpentine flow field design developed by Xu and Zhao [14] was proved to be very effective in improvement of both the cell performance and the operating stability, on the contrary of conventional serpentine flow field design. A multi-pass serpentine flow field (MPSFF) design was proposed by Nam et al. [15]. Initially their design was employed in reactant flow fields in order to improve the under-rib convection and then it was used as the coolant flow fields. Utilizing a numerical modeling, they concluded that in terms of both maximum temperature and temperature uniformity, MPSFF yields better cooling performance than the conventional serpentine cooling flow fields.

In another work, Hashmi [16] investigated numerically different coolant flow field designs with single or multiple channels. Rather than the temperature uniformity and the pressure drop, Hashmi suggested total entropy generation as another criterion for the optimization. He reported that the performance of conventional single-serpentine design is better than the modified single-serpentine design, on the basis of total entropy generation criterion, whereas the latter was found to be better on the basis of temperature uniformity. Sasmito et al. [17] numerically evaluated the performance of different gas and coolant channel designs for high performance liquid-cooled PEMFC stacks, include parallel, serpentine, oblique-fins, coiled, parallel-serpentine and a novel hybrid parallel-serpentine-oblique-fins. Their results indicated that the hybrid channel design yields the best performance as it constitutes lower pumping power and good thermal, water and gas management in comparison with conventional channels. Asghari et al. [5] studied on a parallel serpentine design of cooling flow fields for a 5 kW PEMFC and found that inlet/outlet manifolds of reactant gases influence the temperature distribution in bipolar plates. Therefore they suggested that the uniformity of temperature distribution should be considered in the reactant manifolds design. Modification of channel geometries was proposed by Lasbet et al. [18] to create chaotic regions inside the cooling channels in order to enhance the convective heat transfer between the bipolar plates and the liquid coolant. They evaluated numerically the heat transfer efficiency, the pressure loss and the mixing properties of several chaotic 3D mini-channels, namely C-shaped, V-shaped and B-shaped channels, and compared them with conventional straight channels. Their