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Influence of porous carbon inserts on scaling up studies for performance enhancement on PEMFC

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ABSTRACT

In order to reduce the effect of water flooding on larger active area of Proton Exchange Membrane Fuel cell (PEMFC), an enhanced flow distribution on the flow channel is mandatory. In this paper to mitigate the water flooding problem, experimental studies have been carried out on 25 cm^2 and 70 cm^2 active area of PEMFCs with various flow channel designs on the cathode flow plate namely serpentine, uniform and zigzag pin type; and flow channel with 2 mm cubical porous inserts on the uniform and zigzag pin types. The results show that the cathode flow field plate with zigzag positioned porous carbon inserts having 80–90% porosity has improved the current and power densities by 7% and 11.5% respectively, when compared to the conventional serpentine flow field plate for 25 cm^2 PEMFC. The above procedure has been followed for scaling up studies from 25 cm^2 to 70 cm^2 PEMFCs for effective water management. It is concluded that the 70 cm^2 PEMFC with zigzag positioned porous carbon inserts on the cathode flow field has increased the current and power densities by 8.7% and 20.6% respectively compared to the conventional serpentine flow field. The porous carbon inserts on the rib surface of the cathode flow field removes the accumulated liquid water from the rib surface through the capillarity of its porous structure, due to this the performance of PEMFC is enhanced in scaling-up studies with better water transport characteristics.

Introduction

With increase in number of fossil fuel based power generation systems, environmental pollution and depletion of fossil fuel resources are unavoidable at present. Automakers and industrial developers are investigating many possible solutions to bring out new methods for reducing environmental pollutants that come from the power sources of both stationary and transportation applications. In the last decade, fuel cells appear to be one of the most suitable alternatives for the generation of clean and green energy, and PEMFC seems to be one of the most reliable ones. Compared with other types of fuel cells, PEMFC has high power density and efficiency, easy implementation, longer lifetime, lower operating parameters such as temperature and pressure, fast start-up and soundness of the system.

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Water generated as a by-product of electrochemical oxidation and reduction reactions, has to be precisely balanced to prevent the problem of flooding and dehydration of membrane. Excess amount of water in liquid phase would result in blocking of the pores in the catalyst layer and Gas Diffusion Layers (GDL) whereas an insufficient amount of water would result in membrane dehydration thereby leading to poor performance of the PEMFC by significant ohmic loss.

Various methods have been adopted for addressing the water management issues, out of which the flow field design is the most significant factor [1,2]. Manso et al. [3] studied the performance of the PEMFC by various geometric parameters of the flow fields such as pins, straight and serpentine channels, integrated and interdigitated channels. Nattawut Jaruwasupant et al. [4] numerically studied the effect of PEMFC performance with respect to length, width and channel curve on the serpentine flow field and concluded that serpentine flow channel produced a higher pressure drop during the reactant flow. A three dimensional model with various flow field design on the performance of PEMFC has been studied by Yuh Ming Ferng et al. [5]. They confirmed that, the performance of PEMFC has been significantly enhanced with the parallel flow channel with the step-wise depth design. Birgersson et al. [6] studied the effect of four flow-distributor geometries (interdigitated, co-flow and counter-flow channels and foam) on the cathode of PEMFC, and concluded that the interdigitated flow channels were capable of sustaining higher current densities, when compared to other flow-distributor geometries. Rahimi et al. studied the performance of a 25 cm^2 PEMFC by having wire coils inserted in the cathode flow channels [7]. They concluded that by the insertion of wire coils, the power density had increased about 41% due to the circumferential flow of oxidant closer to the GDL. Shiang-Wuu Perng et al. [8] numerically studied and effectively enhanced the performance of PEMFC by installing a rectangular cylinder along the flow channel in transverse manner. Atul Kumar et al. [9] carried out simulation studies with respect to various flow channel shapes and various dimensions of channel width, land width and channel depth. They reported that the cell efficiency can be improved by the use of triangular and hemispherical shaped cross-sections of the flow channels, due to more consumption of hydrogen on anode region. Shimpalee et al. [10] investigated the performance of the PEMFC with different gas path lengths on serpentine flow field design and they concluded that the performance and durability of PEMFC were affected by the path length of the flow field. Kap-Seung Choi et al. [11] compared the serpentine flow field with different widths and heights of channels and found that, the increase in channel width enhanced the water removal and influenced the performance and life period of the PEMFC. Natthawoot Bunmark et al. [12] analyzed the effects of slanted channels on PEMFC performance. In order to improve water management in PEMFCs, a slanted channel with an angle of 20° was used to collect water from the GDL. Water removed from the GDL on the anode region has induced the back diffusion of water from cathode to anode, thus improving proton conductivity. The use of down-slanted channels on anode has improved the performance of PEMFC, whereas on the cathode there has not been any improvement in the performance.

The scaling up of the fuel cell must be addressed to match the requirements of the power sources for the larger scale applications. Experimental investigation on scaling up and stacking up studies by Karthikeyan et al. [13], concluded that in case of the larger cell area, more amount of water was produced and the risk of flooding was also more which resulted in 40% of reduction on PEMFC performance. In order to overcome this effect of flooding, the flow field with an enhanced flow distribution is suggested. Ay Su et al. [14] from their experimental results on 25 cm^2 and 100 cm^2 active areas of PEMFC with serpentine, parallel, interdigitated and serpentine-interdigitated flow fields, concluded that the parallel and interdigitated flow channels are much prone to flooding problem easily. Ryo Koresawa et al. [15] fabricated a new gas channel with microgrooves and found that the microgrooves inside the channel walls make a pathway for the water removal, due to capillarity effect and shear forces from air flow. This has resulted in the enhancement of the current density of PEMFC around 16%. Yanzhou Qin et al. [16] investigated the effect of hydrophilic plate in the middle of the flow channels. This hydrophilic plate facilitated the effective removal of liquid water droplets from membrane electrode assembly by means of a larger contact angle with the bottom surface of the channel, but less than the MEA surface. J.M. Sierra et al. [17] numerically studied the PEMFC model with tubular plates. They showed that the cylindrical channel configurations facilitated the removal of water from GDL due to the twist of the channel and gradual reduction of the flow path angle. A single fuel cell having an active area of 200 cm^2 of PEMFC with the installation of six humidity sensors on the serpentine flow field design on anode and cathode sides, showed that the moisture content had decreased along the anode flow field and had increased along the cathode flow field for better water management on the PEMFC [18]. Preeyaphat Wawdee et al. [19] designed a new flow field with up and down slanted flow channels on anode and cathode sides of 150 cm^2 PEMFC for effective water management. They found that the down-slanted channel on anode side improved the cell performance compared to the rectangular channel, because of improved conductivity and membrane hydration. They also found that the up-slanted channels on anode or cathode sides have reduced the cell performance due to flooding.

Whenever the requirement of power is more, the active area considered should be well more than 25 cm^2. This requires scaling up of the fuel cells, i.e. increasing the active area of the cell. Usually a scaled up fuel cell requires appropriate flow channel geometry and provision for effective removal of water from flow field channel for better water management. Improper water management results in flooding which significantly influences the steady and transient performance of PEMFC. In this concern, a strategy has been developed and investigated experimentally by Karthikeyan et al. [20] to mitigate the flooding problem in PEMFC. They studied the effects of various flow fields with the adoption of 2 mm porous carbon inserts on the cathode rib surface with various porosity ranges for performance enhancement of 25 cm^2 PEMFC for better water transport characteristics. The novelty of this paper lies in preventing water flooding in scaling up studies of active area of 70 cm^2 PEMFC. The various flow field

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