A Comprehensive Numerical Study of Obstacle-integrated Flow Field Header Design for Proton Exchange Membrane Fuel Cells

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Proton exchange membrane fuel Cells (PEMFCs) efficiently convert hydrogen and oxygen into electricity, presenting a highly promising solution for clean energy generation. Among all the mechanical components, metallic bipolar plates remain a critical limitation for PEMFC power density, because 30-40% of its total area is the inert header region that cannot contribute to power generation. Therefore, a smaller header region is expected to improve the PEMFC power density. Recent efforts to reduce header size are still facing challenges. Small headers deteriorate the flow distribution in PEMFCs, leading to the loss of energy efficiency due to reduced reactant utilization. Although the flow distribution can be improved by integrating obstacles in the header regions, the flow separation and recirculation around the obstacles increases the pressure loss, which increases pumping power. Therefore, it is necessary to investigate the comprehensive effects of obstacle-integrated header design on net power density, including the power loss due to flow maldistribution and pressure loss.

This study employs numerical simulations to investigate the comprehensive effects of header design parameters on flow distribution, pressure drop and their subsequent impact on power density. The simulation encompasses header size, inlet angle, obstacle size, porosity of headers, and obstacle arrangement to select the most influential factors. Then, a cross-over parametric design further identifies the comprehensive interactions between the parameters. Finally, the influence of flow distribution and pressure drop on power density is analyzed with an analytical approach. Results revealed that the header size, obstacle size and porosity are most influential for flow uniformity and pressure loss. Based on these three factors, the cross-over study indicates that obstacle size is the most significant tuning factor for the high-power density design by balancing the pressure drop and flow distribution. The result also gives an optimal design within the tested range for the highest power density. This comprehensive study provides valuable insights into the design and optimization of obstacle-integrated headers for PEMFCs, advancing the understanding of flow distribution and contributing to the development of more efficient fuel cell systems.

Key words; Proton exchange membrane fuel cell, bipolar plate, header design, flow field, numerical simulation