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Thermal management strategies for a 1 kWe stack of a high temperature proton exchange membrane fuel cell

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ABSTRACT

A proper thermal management strategy is needed to maintain uniform temperature distribution and derive optimal performance in high temperature proton exchange membrane fuel cells (HT-PEMFC). In HT-PEMFCs, more than half of the chemical energy is converted into thermal energy during the electrochemical generation of electrical power. We investigate the viability of three heat removal strategies: (a) using cooling plates through which cathode air is passed in excess of stoichiometric requirement for the purpose of heat removal, (b) using forced convection partly in conjunction with cooling plates, and (c) using forced convection alone for heat removal. Calculations, partly done using computational fluid dynamics simulations, for a 1 kWe HT-PEMFC stack, which is suitable for scooter type of transport applications, show that a combination of excess stoichiometric factor and forced draft appears to provide the optimal strategy for thermal management of high temperature PEM fuel cells. With proper cooling strategy, the temperature variations within the cell may be reduced to about 20 K over most of the cell and to about 50 K in isolated spots.

1. Introduction

Proton exchange membrane fuel cells (PEMFC) are one of the most promising energy technologies for portable applications such as for transportation and for stand-alone or for distributed small power generation at high energy efficiencies. Conventional PEMFCs use Nafion® and other polymer membranes which are restricted in their operation to the rather low temperature range of between 60 and 80 °C. Their performance is sensitive to the hydration state of the polymer membrane: too little humidification will lead to reduced proton conductivity and too much humidification will lead to flooding, resulting again in severe loss of performance [1]. In recent years, a number of alternative polymer membranes have been developed which enable operation in the higher temperature range of 120–200 °C [2–7]. Higher temperature operation brings in certain advantages: higher tolerance to carbon monoxide (CO) of up to 3–5% by volume enabling a wider choice of fuel; less sensitivity of protonic conductivity to humidification leading to simplification of the water management system; enhanced kinetics; and the possibility of using the exhaust gases for on-board fuel reforming or for other thermal systems [8].

An important consideration in the operation of HT-PEMFCs is their thermal management which is needed to prevent the formation of hotspots and to maintain nearly uniform temperature throughout. Despite the advantages of working at high temperatures, the performance of HT-PEMFCs is currently well below that of normal PEMFCs operating at about 80 °C as shown in Fig. 1. Thus, during the operation of HT-PEMFCs, say, at a cell voltage of 0.6 V, more than half of the chemical energy of the reactants is converted to thermal energy. The heat energy from the fuel cell is the sum of the irreversible heat, entropic heat (reversible heat) and ohmic heat which account for 55%, 35%, and 10% of the total heat, respectively [10]. This heat is continuously generated as long as the cell is in operation and needs to be removed for the fuel cell to operate at a steady temperature. It is also necessary that, in the process of heat removal (which is primarily by conduction through the media involved), high temperature zones are not created within the cell. Non-uniform temperature distribution leads to variations in the rates of electrochemical reaction. In addition, it may lead to the creation of local hotspots which may lead to damage of the structural components. Although the thermal resistance of PBI membrane, which is studied extensively as a candidate for an HT-PEMFC, is high, temperatures higher than 473 K are not advisable because the proton conductivity of PBI depends on the doping level of the phosphoric acid. At high temperature, the membrane may get dried of because of phosphoric acid evaporation. High temperatures

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