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Thermal and electrical energy management in a PEMFC stack – An analytical approach

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Abstract

An analytical method has been developed to differentiate the electrical and thermal resistance of the PEM fuel cell assembly in the fuel cell operating conditions. The usefulness of this method lies in the determination of the electrical resistance based on the polarization curve and the thermal resistance from the mass balance. This method also paves way for the evaluation of cogeneration from a PEMFC power plant. Based on this approach, the increase in current and resistance due to unit change in temperature at a particular current density has been evaluated. It was observed that the internal resistance of the cell is dependent on the electrode fabrication process, which also play a major role in the thermal management of the fuel cell stack.

Keywords: Fuel cell; PEMFC; Electrode; Thermal resistance

1. Introduction

Thermal management of PEMFC is a key to ensure high cell performance and efficiency. Heat and water are the sole byproducts of the electrochemical reactions in fuel cells. The irreversibility of electrochemical reactions and joule heating are the most important factors causing heat generation inside PEM fuel cells. In addition, the kinetics of electrochemical reactions directly depends on the operating temperature. The temperature distribution in the cell has a strong impact on the cell performance. It influences the water distribution by means of condensation and affects the multi component gas diffusion transport characteristics through thermo capillary forces and thermal buoyancy. Excessive local cell temperature due to insufficient or non-effective cell cooling may cause membrane dehydration, shrinking or even rupture. Hence, thermal and water management issues are strongly coupled and they have a direct impact on cell performance.

Thermal management includes the removal of the generated heat from inside the cell to the outside or to the surroundings. Further, a temporally and spatially uniform temperature distribution must be provided, in order to avoid hot spots in the membrane. The pumping power required for the coolant circulation has to be minimized for system optimization in order to ensure high overall cell efficiency. Therefore, pressure drop must be minimized while maximizing the heat transfer capability at the same time. The method employed to remove heat from the fuel cell stack depends on its size. Daugherty et al. [1] studied fuel cells of less than 100 W of capacity and used air convection to cool the cells and provide sufficient air flow to evaporate the water without using any fan. However, higher capacity fuel cell stacks requires cooling circuit that could be incorporated in the stack for thermal management. Computer simulations have been carried out to study the thermal management in a fuel cell by many groups along with the water management studies. Dumercy et al., [2] have developed a 3D steady state thermal

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modeling for a fuel cell stack which is helpful in defining the geometry of the fluids ducts. While a number of models assume a constant temperature of the fuel cell stack, Shan and Choe [3] have carried out dynamic analysis especially the temperature response to the dynamic load.

The thermal load can be managed simply by using fans without any water cooling system like the air-cooled PEMFC, which is widely used in sub kW and around 1 kW systems. Many systems have been reported wherein a single air blower is used to feed the reactant gas as well supply the air to cool the stack. The performance of an air-cooled system is highly dependent on ambient temperature and humidity. Air-cooled systems are expensive to build as each cell has to have channels for the anode and cathode plates for the cooling air to flow. In order to reduce the cost, novel methods are being developed and one such method is reported by Ruge and Hoekel [4] who have used a edge air cooling integrated with a fan. However, in case of tropical and sub tropical countries, air cooling concept has to be thought very seriously as the average temperature is about 35 °C. In such applications, liquid cooling is preferred and also design of the cooling plate play a major role for heat dissipation uniformly from the cells. Serpentine or meander cooling patterns have been used. These circumstances call for a flow geometry with minimum flow resistance between a volume subjected to two constraints: fixed total volume and fixed channel volume.

Although there have been a number of studies on heat and mass transfer in the reactant gas channels, there have been very limited studies on optimizing the cooling process of a fuel cell. Musser and Wang [5] employed a two-dimensional code to predict the temperature variation in the fuel cell. However, the two-dimensional analysis could not reflect on the real cooling arrangement which includes complicated configurations such as serpentine type structures. Chen et al. [6] have used a three-dimensional CFD code to investigate the coupled cooling process involved in fluid flow and heat transfer between the solid plate and the coolant flow. They investigated six different cooling modes in their analysis and have arrived at the conclusion that serpentine type flow mode is better than the parallel type mode.

Operating conditions of a fuel cell widely depend on the thermal management. It is used to control the cooling system, to maintain a good hygrometry level in the fuel cell and to optimize the efficiency of the system. If the gradients of temperature through the layers (MEA) are not taken into account, then the heat transfer can only be estimated along the channels. These studies are realized with water circulation on the external faces by forced convection.

Recently Faghri and Guo [7], reviewed the numerous technical challenges that exist in fuel cell technology development with respect to thermal management from single cells to system level for both low and high temperature fuel cells. A chaotic heat-exchanger for PEMFC cooling applications has been studied by Lasbet, et al. [8] in which they proposed a three-dimensional flow inside cooling channels using a novel channel geometry that generates chaotic flow and developed heat exchangers that can be easily reduced in size while preserving high thermal performance. A model has been developed by Yu et al. [9] for the water and thermal management for Ballard PEM fuel cell stack to investigate its performance. A general calculation methodology was developed to implement this model by knowing a set of gas feeding conditions like pressure, temperature, flow rate and stack physical conditions like channel geometry, heat transfer coefficients, operating current, etc. The model could provide information regarding the reaction products water and heat, stack power, stack temperature, and system efficiency, thereby assisting the designer in achieving the best thermal and water management. Furthermore, if the stack undergoes a perturbation, such as the initial start-up, quick change in current, or a shutdown, the model could predict the dynamic information regarding stack temperature, cell voltage, and power as a function of time. In another model for thermal coupling in fuel cell stacks, developed by Promislowa et al. [10], the steady state thermal transfer in polymer electrolyte membrane fuel cell stacks using straight coolant channel was considered, ignoring the impact of the gas and coolant channel geometries. The model provides estimates on two important quantities: the local temperature difference between coolant and membrane, and the spread of heat from an anomalously hot cell to its neighbours in a stack environment.

However, none of these models address the heat generation due to electrodes and their fabrication process. Hence, in the present paper, the thermal heat evaluation from a fuel cell stack has been reported. The study is aimed to know the ability of the heat fluxes to cross through the various layers of the cells and to quantify the heat by taking in to consideration of the operating current, pressure, flow rate, channel dimensions, coefficient of heat transfer coolant volume, etc. The distribution of temperatures is obtained for different current densities. An analytical method has been developed to find out the change in current and resistance due to unit change in temperature at a particular current density, without changing the coolant flow rate. This approach will be helpful in identifying the thermal and electrical output for a PEM based fuel cell power plant of large capacity for cogeneration.

2. Experimental

Four membrane electrode assemblies of 153 cm^2 electrode area were made by a proprietary process in use at Centre for Fuel cell technology [11–13]. The MEA's were kept in between two graphite bipolar plates with grooved flow fields for fuel and oxidant supply. The 4 cells assembly is made with 2 cell repeat units consisting of monopolar plate for fuel/oxidant, bipolar plate for fuel and oxidant and another bipolar plate for oxidant and coolant, as shown in Fig. 1. The gas feed plate made of acrylic and current collection plate made of copper is kept on the ends and