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Modeling the temperature distribution and performance of a PEM fuel cell with thermal contact resistance

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ABSTRACT

In this paper, a 3-D, nonisothermal numerical model with anisotropic property of gas diffusion layer (GDL) is applied to investigate the effect of thermal contact resistance (TCR) between rib and GDL, channel and rib width, and different heat transfer coefficients on the temperature distribution and performance of a single PEM fuel cell. A proper thermal contact resistance in this model is determined by comparing the predicted temperature variation between plate and cathode electrode to the available experimental results. The numerical results proved that to improve the prediction accuracy of temperature distribution and cell performance, the effect of TCR cannot be neglected. An underestimate of 1.5 K is found when cell output voltage to be 0.6 V of the case without TCR. And it is found that the rib and channel width and the ratio between them have an obvious effect on heat and mass transfer processes occurred in the electrode. The relatively optimum rib to channel width ratio is found to be 1.0 mm/0.8 mm, and the narrower the channel and rib widths the better the performance when their widths equal to each other. By comparing the temperature distribution between different heat transfer coefficients, it is found that when natural air convection is applied to cooling down the PEM fuel cell, the generated heat cannot be removed completely, however, when liquid water is used as the cooling fluid, the heat removed ability greatly exceeds the real demands of single PEM fuel cell, and the temperature of water must be heated to a proper value (larger than 333 K for the cases studied) to prevent over cooling of fuel cell.

1. Introduction

The polymer electrolyte membrane fuel cell (PEMFC) is a clean energy conversion device, which is considered to be a promising alternative power resource for many applications, such as, portable device, backup power, and especially automobile. To meet the requirements of commercialization, the performance and durability of PEMFC still need to be improved, and the cost should be reduced [1]. The heat, mass transport and chemical reaction processes in the PEMFC are very complicated and are affected by many physical and chemical parameters. Temperature is one of the key parameters affecting the performance and lifetime of PEMFCs [2]. This is because that the chemical reaction rates [3], proton conductivity [4], water transport process [5,6] and other transport properties [7] are strongly affected by local temperature, and furthermore, the degradation of membrane [8] and electrode [9] is usually related to the non-uniform temperature distribution and local hot spot due to incorrect thermal management.

Many efforts have been done to investigate the effects of the temperature distribution within a PEMFC in the last decades. In this regard the first important thing is to measure the PEMFC temperature. Many experimental techniques have been used to measure fuel cell temperature of different locations. The measurement methods include: thermocouples [10–14], MEMS sensors [15–18], infrared thermal imaging [19,20], platinum wires [21], magnetically soft material based method [22], and other optical methods [23–26]. Depending on the different methods, the temperature test locations can vary from the outer surface of flow field plate [13,22], the interface between different layers [10–12,17,26], to the center of two membranes [14,18]. The local temperature information obtained from the experimental results indeed facilitate the understanding of the thermal behavior of PEMFCs. Because of the complexity of the process and structure, especially the extremely compact structure and small scale of the membrane electrode assembly (MEA) it is still a big challenge to get the detail temperature distribution within the electrode by experimental method.

Compared with the experiment measurements, numerical methods have the advantage of easy of implementation, and can

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Nomenclature

Abbreviation

ACL	anode catalyst layer
CCL	cathode catalyst layer
GC	gas channel
GDL	gas diffusion layer
HTC	heat transfer coefficient
MEA	membrane electrode assembly
PEMFC	proton exchange membrane fuel cell
TCR	thermal contact resistance

Symbols

a	water activity
A	area, m^2
A_s	specific area of catalyst layer, m^{-1}
D	diffusion coefficient, $m^2\ s^{-1}$
F	Faraday constant, 96485 C mol^{-1}
h	heat transfer coefficient
k	thermal conductivity, $Wm^{-1}K^{-1}$
K	hydraulic permeability, m^2
RH	relative humidity
s	liquid water saturation
T	temperature, K
V	voltage, V
w	width, mm
Y	mass fraction
α	transfer coefficient
ε	porosity
ϕ	potential, V
η	overpotential, V
λ	membrane water content
σ	electric conductivity, S m^{-1}
ζ	stoichiometric flow ratio

Subscript and superscripts

a	anode
c	cathode, capillary
ch	channel
d	dissolved
e	equilibrium state
eff	effective
g	gas phase
h	hydrogen
k	species
l	liquid
mem	membrane
o	oxygen
oc	open circuit
ref	reference
rib	rib
sat	saturation

get the detail temperature field distribution of every components. Many numerical models were developed to analyze the heat transfer mechanism and temperature field of a PEMFC. For example, Shimpalee and Dutta [27] applied a three-dimensional model to simulate the temperature distributions inside a straight channel PEMFC with constant temperature and insulated boundary conditions; Ju et al. [28–30] investigated the water and heat transport phenomena by a non-isothermal model; Birgersson et al. [31] analyzed the temperature distribution under three different thermal conditions by using a two-dimensional PEMFC model; Wang and Wang [32] developed a two-phase, non-isothermal model to investigate the liquid water distribution and flooding issues; Sui et al. [33,34] developed a comprehensive three-dimensional computational model and analyzed the basic transport processes of species and heat; Pharoah and Burheim [35] presented a 2D thermal model to elucidate the temperature distribution in PEM fuel cells; Jung et al. [36] simulated the non-isothermal transport phenomenon with a baffle plate in tapered channel and found that the baffle blockage enhanced the convection heat transfer performance; Cao et al. [37] numerically studied the coupled water and thermal problem by a two-phase, non-isothermal model; and, recently, Xing et al. [38] developed a two-dimensional, non-isothermal model to investigate the thermal transport within the electrode and the combined water phase-transfer mechanisms. The accuracy of the predicted temperature field by numerical model mainly depends on the following issues: (1) the proper thermal boundary conditions for the computation domain, (2) the thermal properties of different components, (3) the heat sources located in different regions, and (4) the contact resistances between different layers. In the above mentioned numerical models, most of them applied a uniform temperature as the temperature boundary condition, however, several works [13,22] have showed that the temperature outside the flow plate is non-uniform; In addition, the aforementioned numerical models usually assumed an isotropic transport property of the gas diffusion layer (GDL), which cannot represent the actual anisotropic nature of the GDL; Most importantly, the thermal contact resistance (TCR) between GDL and collector rib is often neglected in most of the previous works. However, some works have shown that the contact resistance cannot be neglected. Bapat and Thynell [39] studied the effects of thermal contact conductance and anisotropic thermal conductivity on the temperature distribution inside a PEMFC by a two-dimensional single phase model, and the results showed that the temperature distribution is strongly affected by the thermal contact conductance. Nitta et al. [40] studied the thermal contact resistance between GDL and graphite under different compress pressure, and it is found that the bulk resistance of GDL is comparable to the contact resistance between GDL and graphite collector. Recently, Sadeghi et al. [41] also experimentally investigate the thermal contact resistance of GDL with different compressive load, and the results confirmed that the thermal contact resistance is the dominant resistance of the total thermal resistance.

In this work, a three-dimensional non-isothermal numerical model, which considered the fully anisotropic property of gas diffusion layer, e.g. permeability, mass diffusion coefficient, thermal and electrical conductivity, is applied to analyze the temperature distribution and heat transfer process inside a PEMFC. The effect of the TCR between gas diffusion layer and current collector rib on temperature distribution of a PEMFC is simulated and the proper value of the TCR is determined by comparing the numerical predicted temperature variation between cathode plate and electrode to the experimental value; then, to analyze the effect of channel geometry on heat transfer process and cell performance, simulations with different rib and channel widths are conducted; and finally, temperature distribution under different thermal boundary conditions is simulated to evaluate the heat dissipation potential of various thermal management methods.

2. Numerical model descriptions

In this section, the numerical model used in this study is briefly introduced. This model is based on a two-phase model developed in our own group [42,43] with the ability to deal with anisotropic transport process occurred in gas diffusion layers. It is assumed