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Non-destructive inverse method for determination of irregular internal temperature distribution in PEMFCs

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Abstract

A non-destructive inverse method is developed to determine internal temperature distribution of the PEMFCs. In this study, the attention is focused on global measurement for the irregular temperature distribution at the interface between the carbon plate and the membrane electrode assembly (MEA) based on the measured temperature data on the outer surface of the end plate. A direct problem solver capable of predicting temperature distribution in the solid layers of the PEMFC under various conditions is incorporated in the inverse approach to provide temperature solutions. In this report, a concept of point-by-point temperature prediction is presented. This approach is particularly suitable for determining irregular temperature distribution that is difficult to handle by the existing polynomial-function approach [C.H. Cheng, M.H. Chang, Predictions of internal temperature distribution of PEMFC by undestructive inverse method, J. Power Sources, in press]. A number of test cases are considered in this study. Some irregular temperature functions are specified and regarded as exact temperature distributions to predict. Meanwhile, the influence of uncertainty in the measured temperature data on the outer surface is evaluated.

Keywords: Non-destructive measurement; Temperature prediction; PEMFC; Inverse method

1. Introduction

In the past several years, significant progress in the development of fuel cell technology has been achieved by an increasing number of experimental [1–3] and theoretical [4–7] studies. The experiments can help determine the overall performance of the fuel cell and find out preferable operation conditions. The theoretical studies help understand the physico-chemical process and the transportation phenomena inside the fuel cell and provide detailed information which may not be easily obtainable by the experiments.

On the other hand, the optimization methods are gradually introduced into the fuel cell design phase. For example, a nonlinear-constrained optimization procedure to maximize the performance of the cathode with interdigitated air channels in a PEMFC was presented by Grujicic et al. [8]. In Ref. [8], the optimization was based on a steady-state single-phase electro-chemical model for the cathode. In the study of Mohamed and Jenkins [9], a genetic algorithm is employed to optimize a PEMFC stack design by searching for the best configuration in terms of cell number and the cell surface area. Grujicic and Chittajallu [10] used a two-dimensional electrochemical model to determine the optimal design of the operational and the geometrical parameters for cathode of a fuel cell.

In general, the electrical energy produced is accompanied by an approximately equal amount of thermal energy dissipated. Therefore, thermal management of a fuel cell is of great concerns to the researchers. In order to ensure efficient thermal management for the fuel cell, it is required to monitor the internal temperature distribution of the PEMFC. However, the internal temperature of the fuel cell is usually not easily measured, especially for a global measurement. To have the internal temperature information, one may use destructive methods, in which a number of temperature sensors are inserted into the fuel cell to measure the internal temperature

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Nomenclature

C	heat capacity (kJ kg^{-1} °C^{-1})
h	heat transfer coefficient (W m^{-2} °C^{-1})
H	height (m)
J	objective function
k	thermal conductivity (W m^{-1} °C^{-1})
L	length of fuel cell (m)
NX, NY, NZ	numbers of grid points in x-, y-, and z-direction
q^*	internal heat source (W m^{-3})
t	time
T	temperature (°C)
$\overline{T}$	simulated experimental temperature data (°C)
T_a	ambient temperature (°C)
W	thickness (m)
x, y, z	Cartesian coordinates (m)

Greek symbols

β	step size
γ	conjugate gradient coefficient
θ	exact temperature solution
ρ	density (kg m^{-3})
σ	experimental temperature uncertainty
ω	random number varied −1 and 1

Subscripts

C	carbon plate
Cu	copper plate
e	end plate
ex	exact
g	gasket
i, j, k	grid point indices
ini	initial guess

Superscript

n	iteration step

directly. Unfortunately, the destructive methods may appreciably disturb the original flow and current fields inside the fuel cell, and may also be possible to cause leakage problems of the fuel and oxidant gases.

In order to resolve these problems, Cheng and Chang [11] introduced the concept of an inverse method for obtaining the global temperature distribution at the MEA/carbon plate interface in the PEMFC. This method is capable of predicting internal temperature distribution of a PEMFC efficiently based on the outer surface temperature data without causing any damage to the fuel cell. However, in the study, the temperature distribution of the predicted interface must be approximated by a polynomial function. As a result, if predicted temperature distribution cannot be cast into a form of a polynomial function accurately, there will exists a remarkable error in predictions. Thus, the flexibility of the inverse method is actually limited due to the polynomial-function assumption.

In the present study, the existing polynomial-function approach is modified and extended to the applications for a more flexible form of temperature distribution at the MEA/carbon plate interface. The temperature distribution is predicted by using a point-by-point concept which is not limited by the mathematical assumption with a polynomial-function form for the temperature distribution. Therefore, even an irregular temperature distribution at the MEA/carbon plate interface can be predicted accurately.

The validity of the present method is demonstrated by dealing with two cases of exact temperature function. In addition, the influence of the uncertainty in the measured temperature data on the outer surface of the end plate is evaluated. Relative performance of the present approach is demonstrated by a comparison with the existing method.

Fig. 1 shows the schematic of a typical single-cell PEMFC. The PEMFC shown in this figure is equipped with a polymer electrolyte at the center. The polymer electrolyte is sandwiched between two electrodes and two gas diffusion layers to form a MEA, which is placed between two carbon plates having machined groves that provide flow channels for fuel and oxidant individually. In addition, two copper current collectors are attached to the outer faces of the carbon plates to conduct the current. In general, the outer surfaces of the copper current collectors are insulated by gasket layers. The single cell is then compressed tightly by two end plates.

While the cell is in operation, a certain amount of heat is generated by the electrochemical reaction. The heat generated must be conducted toward the outer surfaces of the

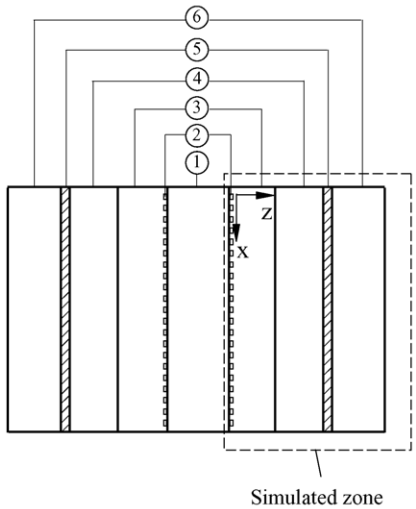

Fig. 1. Schematic of a single-cell PEMFC and the simulated zone.