Study of Thermal Management in PEM Fuel Cells with Numerical Modeling and in-situ Diagnosis Approaches

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Extended Abstract

Introduction

Proton exchange membrane fuel cell (PEMFC) is a very promising type of fuel cell regarding energy efficiency, power density and specific power, yet it is still facing major technical challenges to the commercialization, including water management, thermal management, R&D of new materials with lower cost and better performance, etc.

Thermal management is a challenging issue due to the facts that PEM fuel cells must be operated in a narrow suitable temperature range, that it is difficult to remove generated heat which is no less than the electric energy produced and that the heat generation is usually non-uniform. It is critical to clearly understand the mechanism of heat and mass transfer issues in PEM fuel cells to realize better thermal management, including heat generation, heat transfer mechanism, temperature distribution, mass distribution, etc.

Numerical modelling is a very useful tool in studying mechanism of heat generation, heat and mass transfer as well as other issues in PEM fuel cells [1-4]. And in-situ diagnosis is a crucial approach to the understanding of such issues and validation of modeling study.

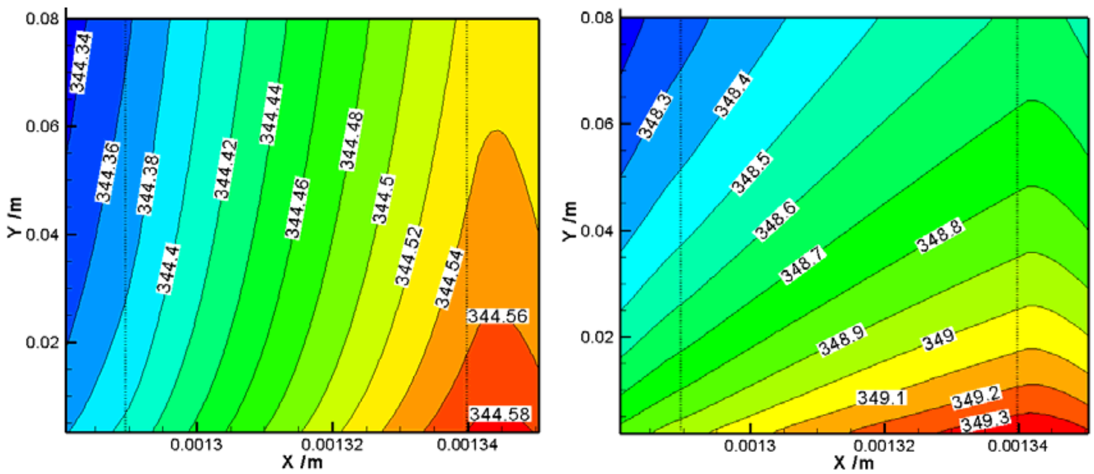
Numerical Modeling

As a very useful tool, numerical modeling is used to study the mechanism of heat generation, heat and mass transfer and other issues in PEM fuel cells. Two models with special features have been developed in our laboratory.

One is a single-domain, two-dimensional, two-phase flow mathematical model based on the multiphase mixture flow model and the unified approach is used [2, 3]. With this model, the two-phase flow phenomena not only in the cathode but also in the anode were found existing. The effects of phase change were taken into consideration in both the momentum and energy equations.

The other is a two-dimensional, mixed-domain, two-phase flow, non-isothermal one fully coupling momentum transfer, species transfer, heat transfer, charge transfer and electrochemical reactions [4]. Different phases of water existing, i.e. water in gas phase, liquid phase and water in the membrane, are considered in this model. Different from the single-domain method using fictitious water concentration treatment, a more reasonable mixed-domain method is used to describe water transfer. This model also accounts for the mutual influences and dependence among different transport phenomena. The work of extending this model from two-dimensional to three-dimensional is also in process.

Fig. 1 is a sample result simulated with the mixed-domain model. It shows the temperature distribution in membrane electrode assembly (MEA) operated at 0.7 V (a) and 0.4 V (b) under some specific operating conditions. It can be seen that the highest temperature occurs in the cathode catalyst layer in the through-plane direction where the heat from electrochemical reaction is generated. The temperatures decrease along the flow direction, suggesting the influence of decreased reactant concentration. Comparison between Fig. 1 (a) and Fig. 1 (b) shows that the local temperatures are significantly increased with lower operating voltage (higher current density) and the temperature gradient is also much larger.



(a) (b)

Fig. 1. Sample modeling results of temperature distribution in MEA (Anode at left side and cathode at right; H_2: 60 sccm, Air: 160 sccm, $T_{H2,humi}=T_{Air,humi}=T_{Cell}=70$ °C) operated at 0.7 V (a) and 0.4 V (b)

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Analysis of the results presented in Fig. 1 demonstrates that valuable information such as how the temperature distribution varies in space and how the heat is transferred can be obtained from modeling. With reliable and comprehensive modeling, various aspects of heat and mass transfer issues in PEM fuel cells can be studied and the results can be helpful in developing effective thermal management measures.

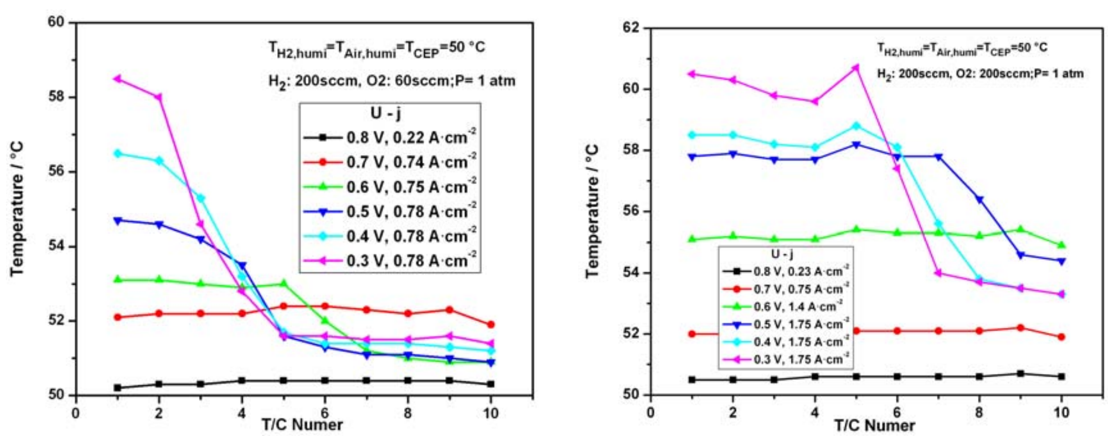
In-situ Measurement of Temperature and Current Distributions

In-situ diagnosis such as in-situ measurement of temperature distribution, current distribution, water distribution, species distribution, etc., is as valuable as modeling in understanding the mechanism of heat generation, heat and mass transfer and other issues in PEM fuel cells. It is also crucial in the validation and improvement of modeling.

Temperature distribution and current distribution are the major interests regarding in-situ diagnosis in our laboratory. In-situ measurement of temperature distribution is realized with a technique using very thin thermocouples placed between GDL and catalyst layer (CL) in the cathode. And a novel and simple current distribution measurement gasket technique was invented to measure current distribution in-situ [5-8]. Both of the two in-situ diagnostic techniques have special advantages that there is no need of special design or modification of fuel cell components and that they can be used in PEM fuel cell stack.

With the two kinds of techniques developed, temperature distribution and current distribution under various operating conditions have been measured and studied. Simultaneous measurement of temperature distribution and current distributions in an experimental PEM fuel cell were also carried out.

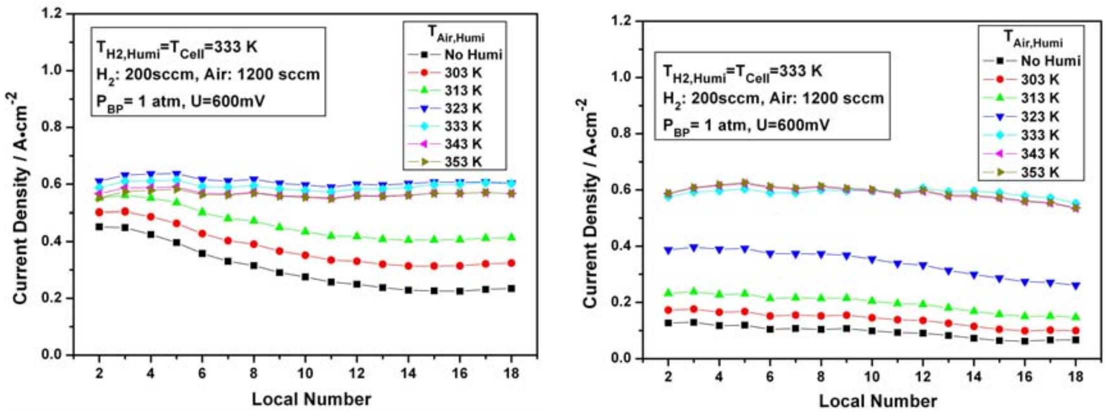
Fig. 2 shows the sample results of in-situ measurement temperature distribution in experimental PEM fuel cell operated with oxygen flowrate of 60 sccm (a) and 200 sccm (b). The PEM fuel cell is externally cooled with air from a fan. It can be seen from Fig. 2 that there exists great difference between the temperature at GDL/CL interface and that of cathode endplate (CEP), which is almost 10 ºC at high current density, and that significant temperature non-uniformity exists in the PEM fuel cell, especially at low operating voltage with insufficient oxygen supply (a). It indicates that effective cooling measures must be taken to remove the heat generated to avoid too high temperature rise inside PEM fuel cell, and that special attention should be paid to the non-uniformity of temperature distribution.



(a) (b)

Fig. 2. Sample results of in-situ measurement of temperature distribution in PEMFC with oxygen flowrate of 60 sccm (a) and 200 sccm (b)

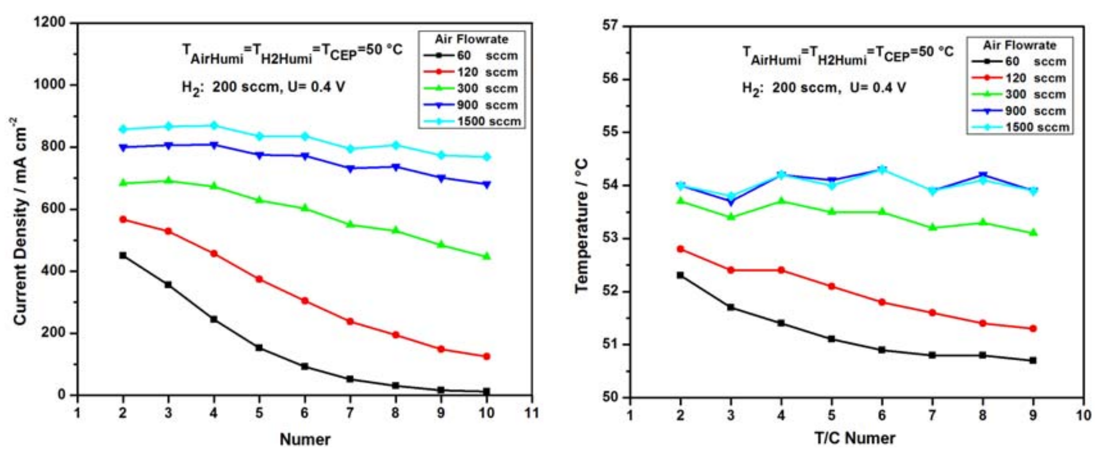
Fig. 3 is the sample result of in-situ measurement of current distributions. It shows the comparison of current distributions with serpentine and interdigitated flow fields under various air humidification temperatures [8]. Current distribution with interdigitated flow fields is more uniform than that with serpentine flow fields, indicating the more uniform distribution of mass concentration. The interdigitated flow fields present much better performance than that of serpentine flow fields in the cases of excessive air humidification while it presents much worse performance with insufficient air humidification. This great difference suggests the much stronger water removal ability of forced convection in PEM fuel cell with interdigitated flow fields than that with serpentine flow fields. Since heat generation in PEM fuel cells is closely related to electrochemical reactions, the rate of which is indicated by the local current density, it can be expected that temperature distribution in PEM fuel cell with different flow fields will also be very different. Therefore, the difference in fuel cell regarding structure and other aspects should be carefully concerned in developing thermal management measures.



(a) (b)

Fig. 3. Comparison of current distributions in PEMFC with serpentine (a) and interdigitated (b) flow fields under various air humidification temperatures

Both in-situ temperature distribution and in-situ current distribution are useful, yet measuring temperature distribution and current distribution simultaneously will help to reveal more information that measuring only one item cannot do. Fig. 4 is a sample simultaneous measurement result in the experimental PEM fuel cell under different air flowrates. It can be seen that temperature distribution agree quite well with current distribution, especially at low air flow rate, indicating that temperature distribution in PEM fuel cell with external air cooling is mainly influenced by current distribution. Note that while local current densities increase significantly when air flow rate is increased from 900 sccm to 1500 sccm, the local temperatures increase little, suggesting the cooling effect of large air flow rate.



(a) (b)

Fig. 4. Simultaneous measurements of current distribution (a) and temperature distribution (b) in PEMFC under different air flowrates

Conclusions

Thermal management is one of the major technical challenges to the commercialization of PEM fuel cells. Modeling and in-situ diagnostic techniques are used to study thermal management issues as well as other transport issues in PEM fuel cells.

Two improved models have been developed. With these models, the mechanism of heat generation, heat and mass transfer as well as other issues are investigated and comprehensive information including temperature distribution, mass distribution, water distribution are obtained.

Two kinds of in-situ diagnostic techniques for PEM fuel cells have been developed and proved to be effective, one is in-situ measurement of temperature distribution and the other is of current distribution. Both of the two techniques have advantages of no need to modify fuel cell components and applicability in fuel cell stack. With the two in-situ diagnostic techniques, temperature distribution and current distribution in a PEM fuel cell under various operating conditions were investigated and discussed. Valuable information about heat generation, heat and mass transfer and other issues are obtained and discussed. It is found that temperature distribution agrees well with current distribution in PEM fuel cells, suggesting that local temperature is mainly dependent on local current density. It is also found that large air flow rate has cooling effects on the local temperatures.

The modeling and experimental results show that numerical modeling and in-situ diagnosis are useful approaches to the understanding of thermal management as well as other transport issues in PEM fuel cells. And there is still plenty of work in this field that needs further efforts:

(1) Realize in-situ measurement of temperature distributions in both in-plane direction and through-plane direction without modification of fuel cell component or structure to obtain comprehensive three-dimensional information of temperature distributions;

(2) Validate and improve the modeling results with the experimental results of temperature distribution and current distribution;

(3) Extend the modeling and in-situ diagnosis work into stack level from single fuel cell level or even single channel level;

(4) Evaluate various fuel cell cooling techniques with modeling and in-situ diagnosis to develop better thermal management techniques.

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