Numerical simulation and experimental validation of PEMFC

Keerasut Suttanarak[1], Jarruwat Charoensuk[1,*], Nirut Naksuk[2]

[1]Department of Mechanical Engineering Faculty of Engineering, King Mongkut's Institute of Technology Lardkrabang, Bangkok, Thailand.
[2]National Metal and Materials Technology Center, Pathumthani, Thailand

Abstract:
This work presents Computational Fluid Dynamic model development with 100 cm^2 active area of multi-serpentine flow channel for Proton Exchange Membrane Fuel Cell (PEMFC). Single Cell PEMFC test station was established in order to validate numerical result. Most input parameters were obtained by experimental measurement and literature survey. However some parameters such as reference exchange current density was fitted to calibrate model result as well as surface volume ratio of catalyst layer had been adjusted. The result of numerical model shows good agreement with experiment in terms of polarization curve. Moreover several reaction transport results have been explored through the simulation. This research aim to develop fundamental understanding of transport phenomena in order to gain insight complex coupled process taking place in PEMFC as well as to aid further optimization in design process.

Keywords: *Fuel Cell; PEMFC; CFD; Numerical Simulation; Experimental measurement*

**Corresponding author. Tel.: +66-2329-8321*
E-mail address: kcjarruw@kmitl.ac.th

1. Introduction
Proton Exchange Membrane Fuel Cell (PEMFC), with its zero emission and numerous future commercial prospects, is a promising future energy technology. To develop an efficient fuel cell system, it is necessary to understand its underline mechanisms such as non-uniform concentration, current density distributions, high ionic resistance due to dry membrane, or high diffusive resistance due to the flooding on the cathode. These phenomena can cause performance loss (Barbir, 2005). Numerical simulation is the interesting tool to be used for this research. However to ensure accuracy of numerical model, its validation against with experiment is necessity. Therefore this work studies numerical simulation and experimental validation of single cell PEMFC.

2. Methodology
2.1 Simulation implementation
Fig. 1 shows schematic diagram of single cell PEMFC considered in this investigation which consisting of both anode and cathode sides, including bipolar plates where contact current collectors, GDL, and Membrane Electrode Assembly (MEA). MEA consists of Polymer electrolyte membrane sandwiched between two catalyst layers, which is where the Triple Phase Boundary (TPB) is located.

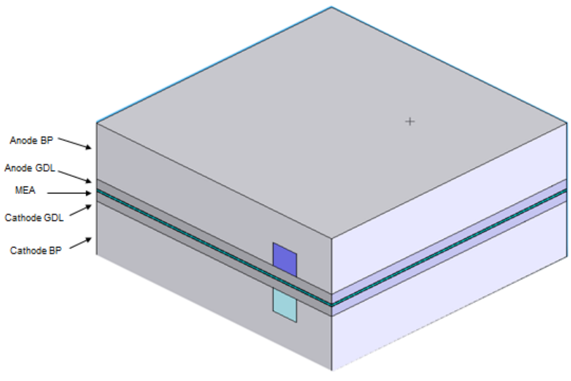


Fig. 1 Schematic diagram of single cell PEMFC (Computational Domain).

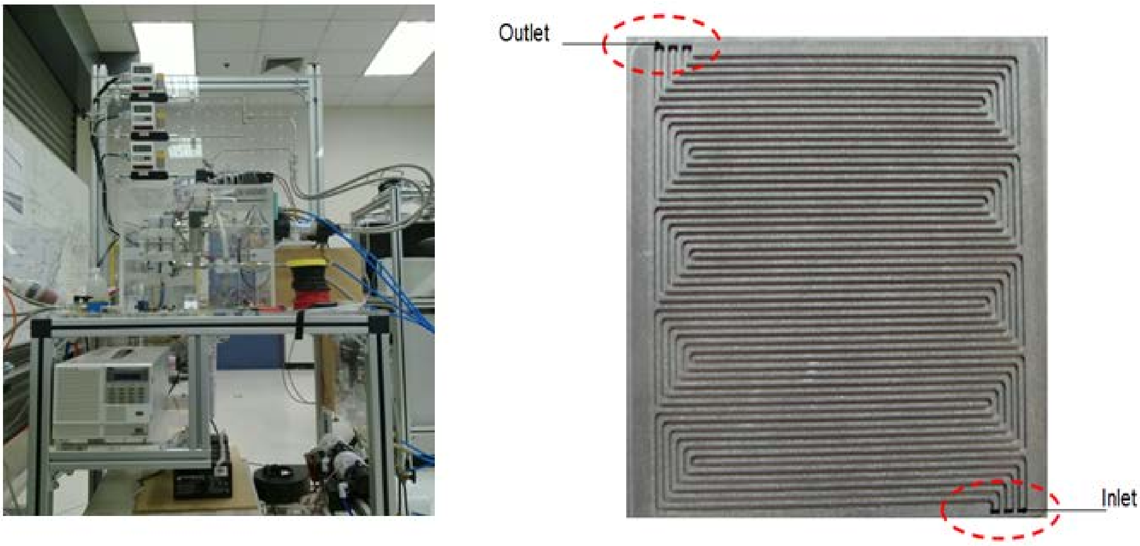
2.1.1 Governing Equation

Physical phenomena occurring within PEMFC can be represented by solution of conservation of mass, momentum, energy, species and charge transfer as well as water transport equation is taken in to account. Detail of PEMFC transport equation can be found (Hyong et al., 2008).

The PEMFC model assumptions (Weng et al., 2005), (Nguyen, 2005) are based on following 1. Fluid flows are laminar; 2. Two phase flow (gas/liquid) is considered. 3. The operating condition is in steady-state; 4. Isothermal (boundary) condition; 5. The porous media including membrane, GDL and Catalyst are considered to be isotropic.

2.2 Experimental implementation

Fig. 2(a) shows single cell PEMFC test station which mainly includes mass flow controller, humidifier, humidity exchanger, purging valve, temperature controller, pressure controller and electronic load. Hydrogen was used as fuel and air as oxidant. Both gases are supplied to single cell with constant flow rate (stoichiometric ratio). In this experiment electrical current between 0-40 A is drawn from single cell as well as the starting procedure is heated up in order to satisfied cell operating temperature (Springer et al., 1993). Fig. 2 (b) shows 100 cm^2 bipolar plates (graphite plates) with conventional multi-serpentine flow channel.



(a) (b)

Fig. 2 (a) Single Cell PEMFC Test Station (b) 100 cm^2 bipolar plate.

3. Result and discussion

Fig. 3 shows IV polarization curve between simulation and experiment, it is observed that at the low and medium current density, the simulation result is reasonable agreed well with experiment. However there is some error in terms of high current density (mass transport loss) region caused by current implemented model cannot be served in liquid water blockage effect. Fig. 4 shows temperature distribution at both anode and cathode TPBs. The results show that temperature is increased gradually from inlet to outlet and because of electrochemical reaction (exothermic reaction) (Larminie and Dick, 2000), average temperature of cathode side is higher than anode side. Obviously heat is generated during water formation.

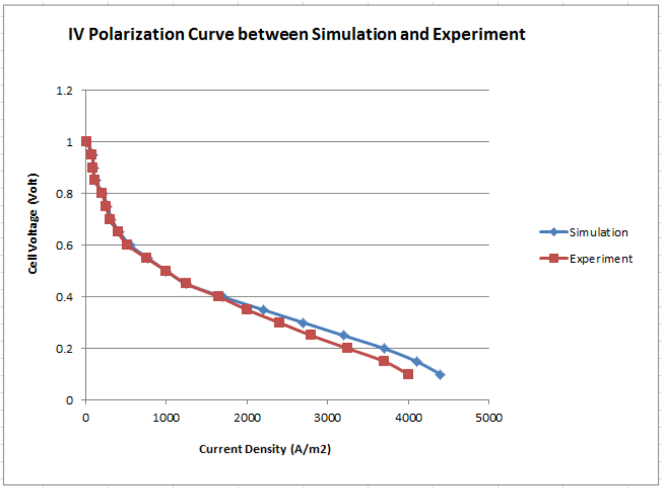
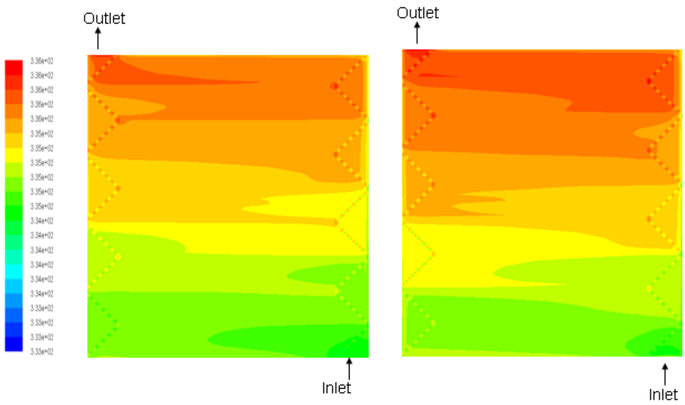


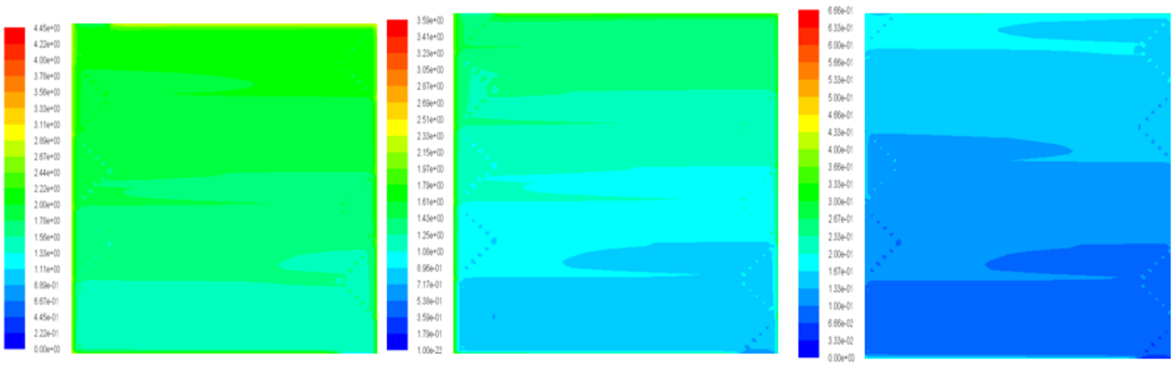
Fig. 3 IV Polarization curve between simulation and experiment.



(a) (b)

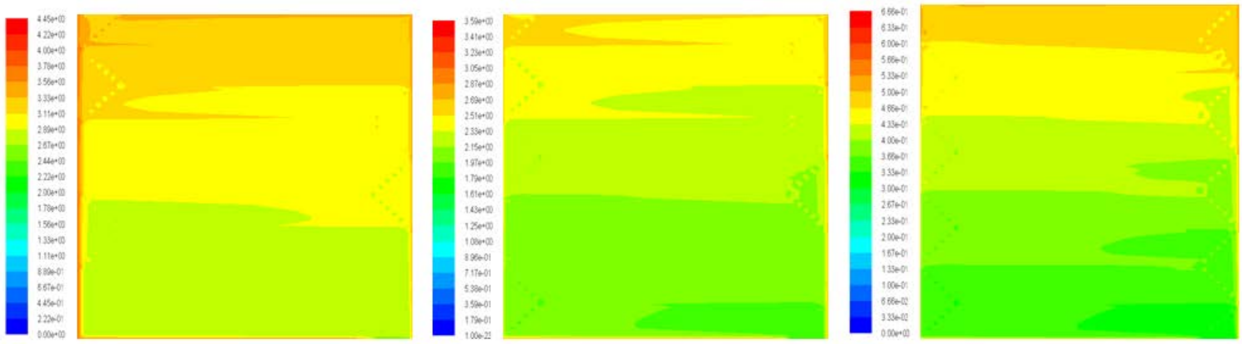
Fig. 4 Temperature distribution at (a) Anode TPB and (b) Cathode TPB.

Furthermore the simulation result reveals that the amount of water content could directly affect the protonic conductivity as well as water activity at both anode and cathode TPBs as shown in Fig. 5 and Fig. 6. Indeed the average of transport values of cathode side are higher than anode side due to effect of water formation from electrochemical reaction and electro-osmotic drag in which water molecules are pulled from anode to cathode side by proton transport mechanism.



(a) (b) (c)

Fig. 5 Transport results at Anode TPB (a) Water content (b) Protonic conductivity (c) Water activity.



(a) (b) (c)

Fig. 6 Transport results at Cathode TPB (a) Water content (b) Protonic conductivity (c) Water activity.

4. Conclusion

This paper presents numerical simulation using CFD tool and its validation against with experiment. Reference exchange density was adjusted to fit test result as well as surface volume ratio of catalyst layer. The simulation result shows good agreement with experimental measurement. Furthermore layer cuts of 3D reaction transport results have been explored in terms of heat, water and protonic conductivity which are important in transport mechanism that effect directly to cell performance. This information would be useful for engineer or researcher dealing with optimization in design process.

5. Acknowledgement

The author would like to thank Electrochemical Materials and Systems Laboratory, National Metal and Materials Technology Center for the software package used in this research.

6. References

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