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# Humidity of reactant fuel on the cell performance of PEM fuel cell with baffle-blocked flow field designs

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**Abstract**

The objective of this work is to examine the effects of humidity of reactant fuel at the inlet on the detailed gas transport and cell performance of the PEM fuel cell with baffle-blocked flow field designs. It is expected that, due to the water management problem, the effects of inlet humidity of reactant fuel gases on both anode and cathode sides on the cell performance are considerable. In addition, the effects of baffle numbers on the detailed transport phenomena of the PEM fuel cell with baffle-blocked flow field are examined. Due to the blockage effects in the presence of the baffles, more fuel gas in the flow channel can be forced into the gas diffuser layer (GDL) and catalyst layer (CL) to enhance the chemical reactions and then augment the performance of the PEMFC systems. Effect of liquid water formation on the reactant gas transport is taken into account in the numerical modeling. Predictions show that the local transport of the reactant gas, the local current density generation and the cell performance can be enhanced by the presence of the baffles. Physical interpretation for the difference in the inlet relative humidity (RH) effects at high and low operating voltages is presented. Results reveal that, at low voltage conditions, the liquid water effect is especially significant and should be considered in the modeling. The cell performance can be enhanced at a higher inlet relative humidity, by which the occurrence of the mass transport loss can be delayed with the limiting current density raised considerably.


*Keywords:* Modeling; Flow field design; PEM fuel cell

## 1. Introduction

It has been a period of time that the attention on the modeling of fuel cell has been drawn since the early 1990s. One of the most promising types of fuel cells, the proton exchange membrane fuel cell (PEMFC), is currently being aggressively researched due to its significant advantages in portable electronic applications over conventional battery systems. It also meets more stringent emissions standards because far fewer pollutants produced than that of internal combustion engines. In previous studies, many pioneers have contributed to the modeling of fuel cells. Most early studying is one-dimensional (ID) or two-dimensional (2D) flows [1–4]. Bernadi and Verbruge [1] developed a ID hydraulic model assuming that the membrane is fully saturated with water and that most of the water is transported through the electrodes in the liquid phase. Springer et al. [2] proposed an isothermal, one-dimensional model for the proton exchange membrane fuel cells. In their model, water diffusion coefficient, electro-osmotic drag coefficient, water sorption isotherms and the membrane conductivities were assumed to be functions of membrane water content. The first quasi-2D, along-the-channel model of a PEM fuel cell was established by Fuller and Newman [3] with the assumption of constant diffusivity of water in membrane to study water and thermal management issues. Nguyen and White [4] proposed a model of the water and heat management of the PEMFC systems, which includes the effect of electro-osmosis, diffusion of water, heat transfer from solid phase to gas phase and latent heat as water evaporation and condensation.

The stability of the membrane is determined by its water content. Proper hydration of the membrane is critical for maintaining membrane conductivity and mechanical stability [5,6]. Various humidification designs such as internal humidification, external humidification and direct injection methods are used in the

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**Nomenclature**

| | |
|---|---|
| $a$ | chemical activity of water vapor in cathode |
| $Aj_0$ | reference exchange current density ($A\,m^{-2}$) |
| $C_F$ | quadratic drag factor |
| $C$ | concentration |
| $D$ | diffusivity ($m^2\,s^{-1}$) |
| $i$ | current density due to potential difference ($A\,m^{-2}$) |
| $j$ | current density due to chemical reaction ($A\,m^{-3}$) |
| $k$ | permeability ($m^2$) |
| $M$ | molecular weight |
| $P$ | pressure (atm) |
| $P$ | partial pressure for $i$ species (atm) |
| $R$ | universal gas constant ($8.314\,mol^{-1}\,K^{-1}$) |
| $s$ | the ratio of the volume of pore occupied by liquid water to the volume of pore in the porous medium |
| $S$ | source term in momentum equation |
| $S_c$ | source term of chemical reaction in the species concentration equation |
| $S_j$ | source term in phase potential equation |
| $S_L$ | source term with consideration of liquid water in the species concentration equation |
| $T$ | temperature (K) |
| $U$, $V$ | velocities in the $X$- and $Y$-direction ($m\,s^{-1}$) |
| $X$, $Y$ | rectangular coordinate system (m) |
| $Z$ | number of electrons transferred |
| $Z_f$ | charge transfer coefficient |

*Greek letters*

| | |
|---|---|
| $\alpha$ | charge transfer rate |
| $\varepsilon$ | porosity |
| $\eta$ | overpotential |
| $\nu$ | kinematic viscosity ($m^2\,s^{-1}$) |
| $\Phi$ | membrane potential |
| $\rho$ | density ($kg\,m^{-3}$) |
| $\sigma$ | electric conductivity ($Q^{-1}\,m^{-1}$) |
| $\tau$ | tortuosity of the pore in the porous medium |

*Superscripts and subscripts*

| | |
|---|---|
| a | quantity in anode |
| c | quantity in cathode |
| eff | effective value |
| g | of gas diffuser layer |
| $H^+$ | for proton |
| $H_2$ | for hydrogen |
| $H_2O$ | for water |
| I | for $i$ species |
| m | of membrane |
| $O_2$ | for oxygen |
| ref | reference value |
| sat | saturation pressure for water vapor |
| total | for total value |
| $x$ | in the $X$-direction |
| $y$ | in the $Y$-direction |

PEMFC to maintain hydration level of the polymer membrane. Therefore, humidities of fuel and oxidant gases influence on the cell voltage performance and stability [7]. There are studies examined various aspects of PEMFC performance as a function of humidity [8,9]. However, the humidity is applied with external humidifiers. Water management is another important issue in the study of fuel cell. Yi and Nguyen [10] developed an along-the-channel model for evaluating the effects of various design and operating parameters on the performance of PEMFCs. They discovered that humidification of the anode gas is required to enhance the conductivity of the membrane, and the liquid injection and higher humidification temperature can improve the cell performance by introducing more water into the anode. Also applying a higher cathode gas pressure helps to replenish the water loss by electro-osmosis, thereby making the membrane more conductive and thus resulting in higher cell performance. A two-dimensional model was developed by Ge and Yi [11] to investigate the effects of operation conditions and membrane thickness on the water transport. In their study, the liquid water effect on the effective porosity for gas transport was considered to simplify the model of the two-phase flows in porous layers. The results revealed that the cell performance can be enhanced by increasing the cell temperature. However, the cell performance could not be obtained for higher humidity or saturation conditions. Baschuk and Li [12] established a mathematical model with variable degrees of water flooding in the PEMFC. Physical and electrochemical processes occurring in the membrane electrolyte, the cathode catalyst layer (CL), the electrode backing layer and the flow channel were considered. Compared with experimental results, they found that when air was used as the cathode fuel, the flooding phenomena are similar at different operating conditions of the pressures and temperatures. When cell pressure is increased significantly, the water flooding in the electrode becomes serious and leads to a noticeable reduction in the power output. Hsing and Futerko [13] developed a 2D model coupling fluid flow, mass transport and electrochemistry of a PEMFC taking into account the dependence of diffusion coefficient of liquid water in membrane. They found that the molar fractions of water are higher at the exit of flow channel. Furthermore, the molar fractions of water on the interface of flow channel and gas diffusion layer (GDL) decrease as the flow rate of hydrogen gas increases.

Designing flow field in bipolar plates of PEMFCs is one of the crucial factors to the cell performance. In order to augment the liquid water transport out of the GDL, a new flow channel design was developed by Nguyen [14]. This design works by converting the transport of reactant/product gases to/from the CL from diffusion mechanism to a convection mechanism. Um and Wang [15,16] constructed a multidimensional model to investigate the electrochemical kinetics, current distribution, fuel and oxidant flow and multicomponent transport in a PEMFC with the interdigitated flow field. He et al. [17] studied the effects of electrode and flow field design on the performance of a PEMFC with a half-cell model. It was found that the electrode performance would be increased with higher differential pressure between inlet and outlet channels. Increasing the electrode thickness is equivalent to increasing the diameter of a pipe in a fluid flow