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Examination of optimal separator shape of polymer electrolyte fuel cell with numerical analysis including the effect of gas flow through gas diffusion layer

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Abstract

This work concentrates on the effects of channel depth and separator shape on cell output performance, current density distribution and gas flow condition in various conditions with PEFC numerical analysis model including gas flow through GDL. When GDL effective porosity was small, the effect of gas flow through GDL which was changed by channel depth on cell output performance became large. However, current density distribution was ununiform. As GDL permeability became larger, cell output density increased, but current density and gas flow rate distribution were ununiform. From the results of changing the gas flow rate, it was found that the ratio of the minimum gas flow rate to the inlet flow rate depended on channel depth. Furthermore, the optimal separator, which increased output density and made the current density distribution and gas flow rate distribution uniform, was examined. It was also found that cell performance had possible to be developed by improving the turning point of the serpentine separator.

Keywords: PEFC; Numerical analysis; Current density distribution; Gas diffusion layer; Pressure drop

1. Introduction

In recent years, humankind has been facing global serious problems of energy and environment. For example, the exhaustion of fossil energy resource, the global warming caused by the green house gas like carbon dioxide, the atmospheric pollution caused by nitrogen oxide, sulfur oxide and particle matter and so on. For the clean and comfortable future, these problems need to be solved immediately. To solve these problems, new energy technologies, which are more efficient, more convenient and cleaner than the current technologies, has been developed. Fuel cell has high power efficiency and enables to reduce the emission of carbon dioxide, because it is different from a thermal power generation or an internal-combustion engine, and converts chemical energy into electric energy directly. And fuel cell can contribute to promote the alternative energy because it can use various fuels, such as a natural gas and methanol. Moreover, it has been effective to conserve the atmosphere because it hardly discharges nitrogen oxide and sulfur oxide. Polymer electrolyte fuel cell (PEFC) is expected as the driving power of vehicles and stationary power supply, because it has low operation temperature and high power density. The development of the components and optimization of the system lead the PEFC performance to improve greatly. However, in order to come it into general use, PEFC greatly needs to be improved the cell performance and durability, and to be reduced the costs. And it is necessary to examine the factor and the mechanism of cell performance and durability by studies in many different fields.

In the internal PEFC, the multi-dimensional phenomena of mass transfer, heat transfer, catalysis, electrochemical reaction and fluid dynamics are caused complexly, and these are strongly related to each other. There are various kinds of studies which examine the internal phenomena of PEFC by

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Nomenclature

b_c condensation rate constant (s^{-1})
C_j molar concentration of species j ($mol\,m^{-3}$)
$C_{j(n)}$ molar concentration of species j in next channel of n direction ($mol\,m^{-3}$)
$C^e_{O_2}$ oxygen concentration at catalyst layer ($mol\,m^{-3}$)
$C^{ref}_{O_2}$ reference oxygen concentration ($mol\,m^{-3}$)
C_p specific heat at constant pressure ($J\,kg^{-1}\,K^{-1}$)
D_j diffusion coefficient of species j ($m^2\,s^{-1}$)
D^{eff}_j effective diffusion coefficient of species j ($m^2\,s^{-1}$)
E electromotive force (V)
$E_{\Delta H}$ the value of reduction change of water enthalpy to voltage (V)
F Faraday's constant (96485 $C\,mol^{-1}$)
h heat transfer coefficient of gas ($J\,m^{-2}\,s^{-1}\,K^{-1}$)
H_{GDL} length of GDL gas flow area (m)
ΔH_{H_2O} change of water enthalpy between vapor and liquid ($J\,mol^{-1}$)
i current density ($A\,m^{-2}$)
i_{O_2} oxygen exchange current density ($A\,m^{-2}$)
k thermal conductivity of solid phase ($J\,m^{-1}\,s^{-1}\,K^{-1}$)
k_p permeability of GDL (m^2)
k^{sep} thermal conductivity of separator ($J\,m^{-1}\,s^{-1}\,K^{-1}$)
$l_{d,g}$ gas channel depth (m)
l_{GDL} GDL thickness (m)
l^{sep} separator thickness between back plate and gas phase (m)
l^S thickness of solid phase (m)
M_j molecular weight of species j ($kg\,mol^{-1}$)
p pressure (Pa)
p_n pressure in next channel of n direction (Pa)
$P_{H_2O,\,sat}$ saturated vapor pressure in stream (Pa)
q_1 heat flux from solid phase to gas phase ($J\,m^{-2}\,s^{-1}$)
q_2 heat flux from back plate to gas phase ($J\,m^{-2}\,s^{-1}$)
q_3 heat value generated by reaction ($J\,m^{-2}\,s^{-1}$)
q_4 heat flux from gas phase to solid phase ($J\,m^{-2}\,s^{-1}$)
q_5 heat flux from back plate to solid phase ($J\,m^{-2}\,s^{-1}$)
q_6 latent heat value of condensation ($J\,m^{-2}\,s^{-1}$)
Q_b all gas flow rate through GDL per unit volume to next channel (s^{-1})
$Q_{b(n)}$ flow rate through GDL per unit volume to next channel of n direction (s^{-1})
$Q_{b(n,in)}$ inflow rate through GDL per unit volume from next channel of n direction (s^{-1})
$Q_{b(n,out)}$ outflow rate through GDL per unit volume to next channel of n direction (s^{-1})
r_j molar flux of species j ($mol\,m^{-2}\,s^{-1}$)
R gas constant (8.314 $J\,mol^{-1}\,K^{-1}$)
Re Reynolds number
R_{ohm} resistance of proton transfer through electrolyte membrane ($\Omega\,m^2$)
R_{rea} all reaction rate (s^{-1})
Sc Schmitt number
Sh Sherwood number
t time (s)
T gas phase temperature (K)
T_n gas temperature in next channel of n direction (K)
T^b back plate temperature (K)
T^s solid phase temperature (K)
U average gas velocity in GDL of x direction ($m\,s^{-1}$)
U_T overall heat transfer coefficient between gas and back plate ($J\,m^{-2}\,s^{-1}\,K^{-1}$)
U^s_T overall heat transfer coefficient between back plate and solid phase ($J\,m^{-2}\,s^{-1}\,K^{-1}$)
v flow velocity ($m\,s^{-1}$)
V operation voltage (V)
w_C channel width (m)
w_L land width (m)
x distance in x direction (m)
y distance in y direction (m)

Greek letters
α net water transfer coefficient
α_t transfer coefficient
β parameter in oxygen mass transfer model shown in Table 1
ε effective porosity of GDL
γ variable for calculation of overvoltage ($A\,m\,mol^{-1}$)
λ parameter in oxygen mass transfer model
μ viscosity of mixture gas (Pa s)
ρ density of mixture gas ($kg\,m^{-3}$)
ω parameter in oxygen mass transfer model shown in Table 1

Subscripts
ave average
H_2O water
$H_2O(l)$ liquid water
$H_2O(v)$ vapor water
j species j
N_2 nitrogen
O_2 oxygen
x x-direction
y y-direction

Superscripts
a anode
c cathode