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Gas diffusion layer deformation and its effect on the transport characteristics and performance of proton exchange membrane fuel cell

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ABSTRACT

Cell/stack assembly force can strongly affect the transport characteristics and performance of a proton exchange membrane fuel cell (PEMFC) through causing the structural deformation. In this study, a mathematical model has been developed to investigate the effect of the assembly force for different gas diffusion layers (GDL) and membranes. The results indicate that the predominant deformation of the cell structure occurs in the porous GDL due to its weak mechanical strength. Thicker GDLs result into lower water content in the GDL structure, and can sustain a larger assembly force without the risk of "electrode flooding"; while thinner GDLs have higher water content, can maintain the hydration required for the membrane, and yield a better cell performance with less sensitivity to the variations in the assembly force. Thinner membranes yield better cell performance, but the cell performance is more sensitive to the changes in the assembly force. A combination of thin GDL and membrane is beneficial for better cell performance with reasonable sensitivity to the assembly force. For thinner GDLs, an optimal assembly force exists beyond which the cell performance is reduced; and practical cell assembly force will limit the GDL thickness.

1. Introduction

Proton exchange membrane fuel cell (PEMFC) has been widely considered as one of the most promising clean power sources because of its capability for zero-emission operation with high efficiency and power density. Over the past several decades, significant progress has been made in the drive towards commercialization [1]. Gas diffusion layer (GDL), a key component of PEMFC required for reactant supply to the catalyst layer (CL), product water removal and collection/transport of electron, experiences significant deformation under the cell/stack assembly force. GDL deformation changes its structural characteristics, including its thickness and porosity, which in turns change the transport properties such as permeability, effective diffusivity and electrical conductivity, negatively impacting the transport process for reactant, water and charged species, consequently the efficiency and power density.

The effect of the cell/stack assembly force on the GDL in PEMFC has been investigated with various degrees of complexities. Experimental studies have been performed, for example, Lee et al. [2] showed that each type of GDL has a

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Nomenclature

a	water activity
A	cell geometric area, m^2
c	molar concentration, mol m^{-3}
C_p	specific heat, J kg^{-1} K^{-1}
d	pore diameter, m
D	mass diffusivity, m^2 s^{-1}
E	young's modulus, Pa
EW	equivalent weight of membrane, kg $kmol^{-1}$
F	interfacial drag coefficient
F	faraday's constant, C mol^{-1}
G	shear elastic modulus, Pa
H	latent heat, J kg^{-1}, surrounding heat transfer coefficient, W m^{-2} K^{-1}
I	current density, A cm^{-2}
J	reaction rate, A m^{-3}
j_0	volumetric exchange current density, A m^{-3}
k	thermal conductivity, W m^{-1} K^{-1}
K	permeability, m^2
$\dot{m}$	mass flow rate, kg s^{-1}
M	molecular weight, kg $kmol^{-1}$
n_d	electro-osmotic drag coefficient (H_2O per H^+)
p	pressure, Pa
$\dot{Q}$	heat transfer rate, W
R	universal gas constant, J mol^{-1} K^{-1}
RH	relative humidity
s	volume fraction
S	source terms or entropy, J $kmol^{-1}$ K^{-1}
T	temperature, K
T_0	volume averaged cell temperature, K
$\vec{u}$	velocity, m s^{-1}
V	electrical potential, V
X	mole fraction
Y	mass fraction

Greek letters

α	transfer coefficient
γ	water phase change rate, s^{-1}
ε	porosity or strain tensor
ζ	water transfer rate, s^{-1}
η	over potential, V
θ	contact angle, o
κ	electrical conductivity, S m^{-1}
λ	water content in ionomer or lame constant
μ	poisson ration or dynamic viscosity, kg m^{-1} s^{-1}
ξ	stoichiometry ratio
ρ	density, kg m^{-3}
σ	surface tension, N m^{-1}
σ_0	Assembly force, uniformly distributed, MPa
φ	electrical potential, V
ω	volume fraction of ionomer in catalyst layer
τ	shear stress, Pa
δ	thickness, m
ϕ	electronic potential or volume fraction

Subscripts and superscripts

a	anode
BP	bipolar plate
c	cathode
cell	cell characteristic
CL	catalyst layer
Cond	condensation
d	dissolved water
eff	effective
ele	electronic
EOD	electro-osmotic drag
equil	equilibrium
evap	evaporation
fl	fluid phase
g	gas phase
GDL	gas diffusion layer
H_2	hydrogen
i, j	the ith and jth components
in	inlet
ion	ionic
l	liquid water
m	mass (for source term)
mem	membrane
O_2	oxygen
out	outlet
ref	reference state
rev	reversible
Sat	saturation
sl	solid phase
surr	surroundings
T	energy (for source term)
u	momentum (for source term)
v	water vapour
d-v	dissolved water to vapour
v-l	vapour to water liquid (vice versa)

unique mechanical structure and property, hence a different optimal compression or assembly force. Ge et al. [3] designed a special test fixture to directly measure a range of compression ratio and studied the effect of the GDL compression and deformation on the PEMFC performance.

However, it is difficult to measure experimentally the changes in the physical properties caused by the assembly force. Therefore, numerical method has been frequently used to investigate the compression effect. In a half-cell model by Chu et al. [4], four different functions of position were chosen to describe the porosity variations in the in-plane direction of the GDL. A sine wave porosity distribution was considered by Roshandel et al. [5] when assembly force was applied, although a constant permeability was still used in their study. Some studies have focused on the effect of assembly force on the temperature distribution and the contact resistance [6–11], while some others investigated the transport properties and performance of PEMFC under the assembly force [12,13]. Su et al. [14] focused on the impact on the gas transport in the GDL material for three different configurations. Lai et al. [15] studied the effect of GDL intrusion into the flow channel on the transport properties of PEMFC by using 2-dimensional finite element method. Xing et al. [16] used the simultaneous perturbation stochastic algorithm method to