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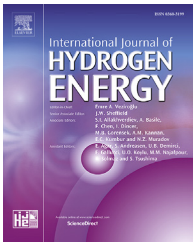

Numerical study on applicability of metal foam as flow distributor in polymer electrolyte fuel cells (PEFCs)

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ABSTRACT

In this paper, the effects of using porous metal foam based bipolar plates (BPs) are investigated under practical automotive fuel cell operations with low humidification reaction gases. Particular emphasis is placed on evaluating water management capabilities of metal foam based BP designs, compared to the traditional serpentine flow field BP designs. A three-dimensional, two-phase fuel cell model developed in a previous study is applied to 25cm^2 real-scale fuel cell geometries with metal foam and serpentine flow modes, and then successfully validated against the experimental data measured under different operating pressures and current densities. The detailed simulation results clearly elucidate advantages of using metal foam as flow distributor through extensive multidimensional contours of flow velocity, species, and current density.

Introduction

For automotive polymer electrolyte fuel cell (PEFC) stacks, metallic bipolar plates (BPs) have been widely used due to several favorable features such as low cost, good mechanical strength, excellent electric and thermal conductivities. Furthermore, using very thin metallic sheets (<1mm) contribute to reducing weight and volume of fuel cell stack, offering good cold-start capability. For reactants supply and product removal, millimeter-scale flow channels are machined on metallic sheets using simple hydroforming and stamping processes. One of drawbacks of the BP design with flow channels is the existence of channels and ribs on the BPs that causes uneven distributions along the cell in-plane direction and results in low performance and degradation problems. In recent years, porous BP designs have received much attention as an alternative to the conventional BP design with flow channels. Employing porous materials as the flow distributor enables to eliminate non-uniform distribution issue between the channel and rib regions and hence better utilize the whole area of membrane electrode assembly (MEA). Baroutaji et al. [1] presented the PEFC using a nickel foam as a flow distributor. They analyzed the influences of air supply and PTFE coating of metal foam on cell performance. Kumar et al. [2] tested the feasibility of using metal foams as flow distributor of PEFCs. As compared to the conventional multi-parallel channel design, the higher performances were achieved by using Ni-Cr and SS-316 metal foams.

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Nomenclature

a	water activity
aL	roughness factor
A	area, m^2
C	molar concentration, mol m^{-3}
D	diffusivity, m^2 s^{-1}
E	effectiveness factor
E_a	activation energy, kJ mol^{-1}
EW	equivalent weight of a dry membrane, kg mol^{-1}
F	faraday constant, 96487 C mol^{-1}
H	Henry's constant
i_0	exchange current density, A m^{-2}
I	operating current density, A m^{-2}
j	transfer current density, A m^{-3}
J	Leverett function
k	thermal conductivity, W m^{-1} K^{-1}
k_r	Relative permeability
K	hydraulic permeability, m^2
m	mass fraction
M_w	molecular weight, kg mol^{-1}
n	number of electrons in the electrochemical reaction or the diffusivity correction factor
n_c	catalyst coverage coefficient∖
n_d	electro-osmotic drag coefficient
P	pressure, Pa
r	radius
r_c	reaction order for electrochemical reaction
R_{we}	water and electrolyte film
RH	relative humidification of the inlet
R_u	universal gas constant, 8.314 J mol^{-1} K^{-1}
s	liquid saturation
S	source term in the transport equation
T	temperature, K
$\vec{u}$	fluid velocity and superficial velocity in a porous medium, m s^{-1}
U_o	thermodynamic equilibrium potential, V
V	volume, m^3
V_{cell}	cell potential, V

Greek symbols

α	transfer coefficient
δ	thickness
ε	volume fraction of the gaseous phase in the porous region
ε_{mc}	volume fraction of the ionomer phase in the CL
γ	advection correction factor
κ	ionic conductivity, S m^{-1}
λ	membrane water content, $mol_{H_2O}/mol_{SO_3^-}$
λ^{α}	relative mobility of phase α
ϕ	phase potential, V
η	overpotential, V
θ	contact angle, ^{o}
μ	viscosity, kg m^{-1} s^{-1}
ρ	density, kg m^{-3}
ρ^{mem}	dry membrane density, kg m^{-3}
ν	kinematic viscosity, m^2 s^{-1}
σ	surface tension, N m^{-1} or electronic conductivity, S m^{-1}
τ	viscous shear stress, N m^{-2}
ξ	stoichiometry flow ratio

Superscripts

e	electrolyte
eff	effective value in the porous region
mem	membrane
g	gas
l	liquid
Pt	platinum
ref	reference value
sat	saturation value

Subscripts

a	anode
agg	agglomerate
avg	average value
c	cathode
CL	catalyst layer
e	electrolyte
GC	gas channel
gra	graphite
GDL	gas diffusion layer
H_2	hydrogen
in	channel inlet
i	species index
k	region index
mem	membrane
$metal$	maetal foam
O_2	oxygen
ref	reference value
s	solid
sat	saturation
T	temperature
u	momentum equation
w	water
ϕ	potential equation
0	standard condition, viz., 298.15 K and 101.3 k Pa (1 atm)

Tang et al. [3] fabricated the porous copper fiber sintered felt for application to PEFCs. The hydrophobic characteristics of the copper felt with the contact angles ranging between 112 and 136° were beneficial for water management but the corrosion resistance should be improved to be successfully applied to PEFCs. Tsai et al. [4] experimentally demonstrated improved cell performance with metal foam flow distributor. They suggested multiple inlets in the metal foam flow designs to facilitate gas distribution and utilization rate. Tseng et al. [5] tested PEFCs loaded with various Ni foams and showed that the hydrophobic treatment of Ni foam using PTFE was essential to obtain stable cell performance. Since metal foams have excellent thermal conductivity and heat removal capability, several groups investigated thermal behaviors of metal foams in fuel cell systems. Odabaee et al. [6] employed metal foams as an air-cooled heat exchanger for fuel cell stacks and experimentally

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