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Numerical investigation on impacts on fuel velocity distribution nonuniformity among solid oxide fuel cell unit channels

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ABSTRACT

In this paper, fuel velocity distribution nonuniformity among channels in planar SOFC units under different working conditions is numerically investigated. A comprehensive three-dimensional electrochemical model is validated and then adopted in a cell unit model with structure of a real cell unit. The model couples interdependent process of species transport, heat transport, chemical reaction, electrochemical reaction, ionic conduction and electronic conduction. A nonuniformity index is proposed to quantitatively evaluate nonuniform degree of fuel velocity distribution among channels in the planar SOFC unit. The effect of the fuel velocity distribution nonuniformity on cell performance and the effects of working voltage, flow rate, flow pattern and fuel type on fuel velocity distribution nonuniformity among channels are investigated. The result shows that an increase in fuel velocity distribution nonunifomtiy can lead to a cell performance drop and fuel velocity distribution is less uniform under lower cell voltage, lower flow rate, using co-flow configuration instead of counter-flow or using syngas as fuel instead of hydrogen. In addition, the CO oxidation should be considered when studying the fuel velocity distribution nonuniformity among channels.

Introduction

Fuel cells are electrochemical devices which can directly convert chemical energy of fuel into electricity with high efficiency and low pollutant emission [1]. Among different types of fuels cells, planar solid oxide fuel cells (SOFCs) show distinct features of fuel flexibility and potential high power density and thus have been recognized as a promising technology for future medium-sized power generation industry [2]. However, challenges in material, cell geometry design and sealing still remain to be solved before planar SOFC commercialization [3]. One of the major challenges is the geometry design of planar interconnects. Interconnects act

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Nomenclature

c	gas concentration, mol m^{-3}
c_p	molar heat capacity under constant pressure, J mol^{-1} K^{-1}
c^*	concentration at equilibrium conditions, mol m^{-3}
D	gas diffusivity, m^2 s^{-1}
ΔG	electrochemical reaction activation energy
i	current density, A m^{-2}
i_0	exchange current density, A m^{-2}
I	total current, A
j_i	molecular mass flux of species i, kg m^{-2} s^{-2}
k	coefficient of thermal conductivity, W m^{-1} K^{-1}
K	reaction equilibrium constant
M_i	molecular weight of species i
p	gas pressure, Pa
Q	source term of charge balance equations, A m^{-3}
r	reaction rate, mol m^{-2} s^{-2} or radius, m
R	gas constant, 8.314 J mol^{-1} K^{-1}
R_i	source term of mass balance equations, kg m^{-3} s^{-2}
S	entropy, J K^{-1}
S_{TPB}	TPB active area per unit volume, m^2 m^{-3}
T	temperature, K
v	velocity, m s^{-1}
V	voltage, V
AVG	average
CV	coefficient of variation
PEN	positive electrode-electrolyte-negative electrode
SOFC	solid oxide fuel cell
STD	standard deviation
TPB	triple phase boundary
OCV	open circuit voltage

Greek letters

α	transfer coefficient
β	adjustable parameter
ε	porosity
τ	tortuosity factor
η	overpotential, V
μ	fluid viscosity, kg m^{-1} s^{-1}
ρ	density, kg m^{-3}
σ	electrical conductivity, S m^{-1}
ω_i	mass fraction of species i
χ_i	mole fraction of species i

Superscript

0	standard state
eff	effective

Subscript

an	anode
ca	cathode
chem	chemistry
el	electrolyte
elec	electronic
eq	equilibrium
ion	ionic
inter	interconnect
prod	product
react	reactant
ref	reference
shift	water gas shift reaction
trans	transfer

both as gas distributor and current collector in a planar SOFC. One aim of the interconnect optimal design is to provide a uniform fuel velocity distribution among channels on anode side to improve cell performance [4].

Many efforts have been devoted to studying the fuel velocity distribution nonuniformity among channels in planar SOFC and its influence on cell performance. Bi et al. [5] investigated numerically the effects of design parameters such as the channel height and manifold width on fuel velocity distribution nonuniformity among channels. Huang et al. [6] found experimentally that by adding small guide vines in an interconnect, the fuel velocity distribution uniformity among channels could be improved and the power density of the cell could be increased by 10%. Moreover, geometry modifications to improve fuel distribution uniformity among channels have also been proposed by researchers. Dey et al. [3] attached square type distributors on the manifolds to obtain a uniform reactant velocity distribution among channels below the active area. Liu et al. [7] adopted a symmetric bifurcation design of flow channel to gain a uniform flow field. Fuel velocity distribution nonuniformity among channels in planar SOFC unit is recognized as one crucial challenge in SOFC development.

Numerical method is essential to study fuel velocity distribution among channels inside SOFC, since SOFC is tightly sealed and it is hard to experimentally get information inside the cell such as flow velocity, temperature and gas composition. It can be time-saving and cost-effective if the numerical model can predict detailed electrode behavior and help researchers to gain a better understanding of the complex multi-physical process inside the cell. For this purpose, a reliable electrochemical model is required. However, the previous modeling studies on the fuel velocity distribution nonuniformity among channels usually focus on the transport behavior, such as fluid flow and heat transfer, while the very important electrochemical reaction kinetics are treated in a very simple manner, or even neglected.

In this paper, a comprehensive three-dimensional mechanistic model of an anode-supported SOFC unit is developed. Different from the existing models in the literature, the present model fully considers the intricate process of mass transfer, heat transfer, momentum transfer, chemical reaction, electrochemical reaction, ionic conduction and electronic conduction to predict nonuniform flow velocity distribution among channels in a SOFC unit. A validated electrochemical model is coupled with heat and momentum transfer for simulating a cell unit with real geometry. A quantitative index of nonuniformity is proposed to compare fuel velocity distribution nonuniformity among channels in different working conditions. Influence of fuel velocity