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Modeling of high temperature proton exchange membrane fuel cell start-up processes

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ABSTRACT

In this study, a three-dimensional dynamic multi-phase model is developed for the high temperature proton exchange membrane fuel cell (HT-PEMFC) to study its start-up processes. Two different kinds of start-up methods which are constant voltage and constant current density are investigated and compared with each other under the same conditions. It is found that the constant voltage mode can make HT-PEMFC reach its normal operating temperature faster than the constant current density. During both the constant voltage and constant current density conditions, there is liquid water produced in the catalyst layer of the cathode zone because the cell temperature is under 100 °C. The effects of surrounding environment are also analyzed and investigated. It is found that the heat convection coefficient has an important influence on the HT-PEMFC start-up process. The final cell temperatures under different conditions are obtained and the start-up durations are compared. To shorten the start-up time, a new non-heating method, variable voltage start-up strategy, is proposed and compared with the traditional assisting heating method. It is shown that the HT-PEMFC start-up performance is improved significantly by using this new variable voltage start-up strategy.

Introduction

H_2/O_2 (or air) proton exchange membrane fuel cells have many advantages, such as, high power density, fast start-up speed and high thermal efficiency. They are becoming a leading candidate of energy solution for the future life. There are great advances during the proton exchange membrane fuel cell (PEMFC) development history [1]. However, there are still some disadvantages which limit the further commercialization of traditional PEMFC (operating temperature is usually about 80 °C). Firstly, the water and

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Nomenclature

a, b	pre-exponential factors to calculate membrane proton conductivity
A	cell geometric area, m^2
c	mole concentration, mol m^{-3}
C_p	specific heat, J kg^{-1} K^{-1}
D	mass diffusivity, m^2 s^{-1}
DL	phosphoric acid doping level for PBI membrane
E_a	activation energy, J $kmol^{-1}$
F	Faraday's constant, 96,487 C mol^{-1}
h	surrounding heat transfer coefficient, W m^{-2} K^{-1}
I	current density, A cm^{-2}
j	reaction rate, 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 mol^{-1}
p	pressure, Pa
q	heat flux, W m^{-2}
$\dot{Q}$	heat transfer rate, W
RH	relative humidity
s	volume fraction
S	source terms
t	time, s
T	temperature, K or °C
$\vec{u}$	velocity, m s^{-1}
X	mole fraction
Y	mass fraction

Greek letters

α	transfer coefficient
ε	porosity
η	over potential, V
ι	interfacial drag coefficient
κ	electrical conductivity, S m^{-1}
μ	dynamic viscosity, kg m^{-1} s^{-1}
ξ	stoichiometry ratio
ρ	density, kg m^{-3}
φ	electrical potential, V
ω	volume fraction of ionomer in catalyst layer

Subscripts and superscripts

a	anode
act	activation
BP	bipolar plate
c	cathode
cell	cell
CL	catalyst layer
cond	condensation
eff	effective
ele	electronic
evap	evaporation
fl	fluid phase
g	gaseous phase
GDL	gas diffusion layer
H_2	hydrogen
H_2O	water
in	inlet
init	initial condition
ion	ionic
lq	liquid water
m	mass (for source term)
mem	membrane
ohmic	ohmic
others	other gas
out	outlet
O_2	oxygen
pc	phase change
ref	reference state
sat	saturation
sl	solid phase
surr	surrounding
T	energy (for source term)
u	momentum (for source term)
vp	water vapor
v–l	vapor to liquid

heat management system of PEMFC is complicated. Secondly, the tolerance to fuel impurities (e.g. CO and sulphide) is poor which results in high requirement of the hydrogen purity. What is more, the electrochemical kinetics, especially in cathode, is slow due to the low operating temperature. So increasing PEMFC operating temperature is promising.

High temperature proton exchange fuel cell (HT-PEMFC) usually means those fuel cell which works above 100 °C. Because of its relatively higher operating temperature, it shows several technological and commercial advantages compared with traditional PEMFC, including faster electrochemical kinetics, simpler water management and cooling (water is generally in vapor state), easier useful waste heat recovery (high operating temperature), and higher tolerance to CO poisoning. However, with higher operating temperature, there will be a longer start-up process. During the start-up process, when the temperature of cell is lower than 100 °C, there may be liquid water generated in the catalyst layer of cathode zone. If there is too much liquid water, the flow channel and gas diffusion layer will be blocked and the performance of HT-PEMFC will be impaired. So the start-up process is significant to HT-PEMFC working cycle.

By now, the research on HT-PEMFC has been concentrated on the following aspects: Firstly, improving membrane's proton exchange ability in high temperature to elevate HT-PEMFC performance [2–4]; secondly, further simplifying the water and thermal management system of HT-PEMFC to reduce its cost and enhancing the CO tolerance ability [5–8]; thirdly, understanding the influence of working condition on HT-PEMFC by changing operating temperature, pressure, intake stoichiometric, relative humidity and so on [9–12]; and fourthly, long term testing of HT-PEMFC working