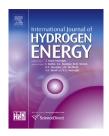


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Modeling of high temperature proton exchange membrane fuel cell start-up processes



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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.

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Introduction

H₂/O₂ (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 $arphi$ electrical potential, V			
Nomenciature		φ	volume fraction of ionomer in catalyst layer
a, b	pre-exponential factors to calculate membrane	ω	volume fraction of lonomer in catalyst layer
	proton conductivity	Subscripts and superscripts	
Α	cell geometric area, m ²	a	anode
С	mole concentration, mol m^{-3}	act	activation
C_p	specific heat, J kg^{-1} K^{-1}	BP	bipolar plate
D	mass diffusivity, $\mathrm{m^2s^{-1}}$	С	cathode
DL	phosphoric acid doping level for PBI membrane	cell	cell
Ea	activation energy, J $$ kmol $^{-1}$	CL	catalyst layer
F	Faraday's constant, 96,487 C $ m mol^{-1}$	cond	condensation
h	surrounding heat transfer coefficient, W $\mathrm{m}^{-2}\mathrm{K}^{-1}$	eff	effective
I	current density, A cm ⁻²	ele	electronic
j	reaction rate, A m ⁻³	evap	evaporation
k	thermal conductivity, W $\mathrm{m}^{-1}\mathrm{K}^{-1}$	fl	fluid phase
K	permeability, m ²	g	gaseous phase
ṁ	mass flow rate, $kg s^{-1}$	GDL	gas diffusion layer
M	molecular weight, kg mol^{-1}	H_2	hydrogen
р	pressure, Pa	H_2O	water
q	heat flux, W m ⁻²	in	inlet
Q	heat transfer rate, W	init	initial condition
RH	relative humidity	ion	ionic
S	volume fraction	lq	liquid water
S	source terms	m	mass (for source term)
t	time, s	mem	membrane
T	temperature, K or °C	ohmic	ohmic
\overrightarrow{u}	velocity, m ${ m s}^{-1}$	others	other gas
X	mole fraction	out	outlet
Y	mass fraction	O_2	oxygen
Greek letters		рс	phase change
α	transfer coefficient	ref	reference state
	porosity	sat	saturation
ε	over potential, V	sl	solid phase
η	interfacial drag coefficient	surr	surrounding
i .	electrical conductivity, S m ⁻¹	T	energy (for source term)
K	dynamic viscosity, kg m ⁻¹ s ⁻¹	u	momentum (for source term)
μ ε	stoichiometry ratio	vp	water vapor
ξ	density, kg m ⁻³	v—l	vapor to liquid
ρ	denoity, kg iii		

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 $^{\circ}$ 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

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