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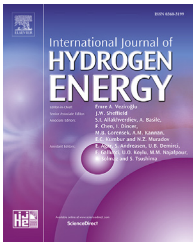

Numerical study of a new cathode flow-field design with a sub-channel for a parallel flow-field polymer electrolyte membrane fuel cell

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ABSTRACT

The cathode flow-field design of a polymer electrolyte membrane (PEM) fuel cell is crucial to its performance, because it determines the distribution of reactants and the removal of liquid water from the fuel cell. In this study, the cathode flow-field of a parallel flow-field PEM fuel cell was optimized using a sub-channel. The main-channel was fed with moist air, whereas the sub-channel was fed with dry air. The influences of the sub-channel flow rate (SFR, the amount of air from the sub-channel inlet as a percentage of the total cathode flow rate) and the inlet positions (SIP, where the sub-channel inlets were placed along the cathode channel) on fuel cell performance were numerically evaluated using a three-dimensional, two-phase fuel cell model. The results indicated that the SFR and SIP had significant impacts on the distribution of the feed air, removal of liquid water, and fuel cell performance. It was found that when the SIP was located at about 30% along the length of the channel from main-channel inlet and the SFR was about 70%, the PEM fuel cell exhibited much better performance than seen with a conventional design.

Introduction

Polymer electrolyte membrane (PEM) fuel cells are highly promising green energy devices because of their high energy conversion efficiencies and low emission levels. They have already been commercialized, however, there are still many challenges to be overcome to further reduce their cost and enhance their performance [1,2], such as achieving effective water management inside the fuel cell [3,4]. During the operation of a PEM fuel cell, sufficient water to humidify the membrane is necessary to ensure effective proton conduction; however, excessive water on the cathode side will partially block the pores of the gas diffusion layer (GDL) and hamper the diffusion of oxygen to the reaction area, degrading the performance of the PEM fuel cell. Therefore, maintaining water balance has become one of the most significant issues for developing PEM fuel cells of high performance [5–7]. Many efforts have been devoted to resolve the problem of water management in PEM fuel cells, with flow-field design being believed to an effective approach to improving the water removal ability and the fuel cell performance [8].

Several flow-field designs have been reported in the literature, including serpentine flow-fields [9–12], parallel

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Nomenclature

Symbol	Description
a	water activity
A	area, m^2
A_s	specific area of catalyst layer, m^{-1}
D	mass diffusivity, m^2 s^{-1}
D_λ	water diffusivity in the membrane, m^2 s^{-1}
EW	equivalent weight of the membrane, kg mol^{-1}
F	Faraday constant, 96,487 C mol^{-1}
i	current density, A m^{-2}
j	volumetric exchange current density, A m^{-3}
j_0^{ref}	reference exchange current density, A m^{-2}
k_c/k_e	Condensation/evaporation rate coefficient
k_{kl}	relative permeability of the liquid water
k_p	permeability, m^{-2}
k_{rg}	relative permeability of the gaseous mixture
M	molecular weight, kg mol^{-1}
c	molar concentration, mol m^{-3}
n_d	electro-osmotic drag coefficient
p_g	gaseous mixture pressure, atm
p_c	capillary pressure, atm
R_u	universal gas constant J mol^{-1} K^{-1}
s	liquid saturation
S_i	source term in the species equation
S_{mass}	source in mass conservation
S_u	source term in momentum equation
S_L	source term for phase change of water
u_g	gaseous-phase velocity, m s^{-1}
T	Cell temperature, K
V_{cell}	operating voltage, V
X	mass fraction of gas species
U_0	Open circuit potential, V

Greek

Symbol	Description
ε	porosity
η	overpotential, V
λ	water content in membrane
ξ	stoichiometry ratio
μ	viscosity, kg m^{-1}s^{-1}
α	exchange transfer coefficient
ρ	density, kg m^{-3}
σ	Surface tension, m N m^{-1}
σ^{eff}	electron conductivity, S m^{-1}
κ^{eff}	proton conductivity, S m^{-1}
Φ_m	ionic phase potential, V
Φ_s	electronic phase potential, V
x_{H2O}	molar fraction of water vapor
θ	contact angle, °

Subscripts

Symbol	Description
a	anode
c	cathode
eff	effective
ref	reference
g	gaseous phase
i	i-th species of the mixture
l	liquid phase
m	membrane
sat	saturation
CL	catalyst layer
GDL	gas diffusion layer
v	vapor

flow-fields [11–19], interdigitated flow-fields [11,12,20,21], pin or mesh flow-fields [22], cascade flow-fields [23] and new types of flow-fields, such as, spiral [24], radial [25], bio-inspired [26] and annular flow-fields [27]. Each configuration has its own advantages and disadvantages, as summarized in Table 1. For example, interdigitated and serpentine flow-fields can reduce flooding in the cathode and improve the fuel cell performance. However, the pressure drops in these designs are large. A parallel flow-field is simple and easy to fabricate and causes the smallest pressure. Nevertheless, the reactants in the parallel flow-field tend to show a non-uniform distribution, and liquid water is prone to accumulate in the downstream of the cathode channel, decreasing utilization of the effective electrode area and lowering the performance. However, an optimized parallel flow-field design could solve the above problem and develop a PEM fuel cell of high performance [9]. For instance, Yan et al. proposed a tapered flow channel and deemed that the new design could enhance gas diffusion and water removal, hence improving the fuel cell performance [13]. Kuo et al. proposed a new wave-like gas channel and

Table 1 – Flow-field designs of present literatures.

Flow-field designs	Description	References
Serpentine flow-fields	High pressure drop. Good ability in liquid water removal, Homogeneous gas distribution	[9–12]
Parallel flow-fields	Small pressure drop, easy fabrication, Inhomogeneous gas distribution.	[11–19]
Interdigitated flow-fields	High pressure drop, Good ability in liquid water removal, Homogeneous gas distribution.	[11,12,20,21]
Pin or mesh flow-fields	Small pressure drop, Inhomogeneous gas distribution, Local flooding.	[22]
Cascade flow-fields	High pressure drop, Good ability in liquid water removal.	[23]
Spiral flow-fields	Small pressure drop, Homogeneous gas distribution, Difficulty in fabrication.	[24]
Radial flow-fields	Small pressure drop, Local flooding.	[25]

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