International Journal of Heat and Mass Transfer 117 (2018) 1099–1106

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

A novel, net-shape polymer electrolyte fuel cell: Higher power density, smaller stack size and less bipolar plate required

Hamidreza Sadeghifar [a,b,c,d,*], Ashkan Torkavannejad [e], Nader Pourmahmoud [e]

[a] Department of Chemical and Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver, BC V6T 1Z3, Canada
[b] Laboratory for Alternative Energy Conversion (LAEC), School of Mechatronic Systems Engineering, Simon Fraser University, Surrey V3T 0A3, BC, Canada
[c] Institute for Integrated Energy Systems (IESVic) and Energy Systems and Transport Phenomena Lab (ESTP), University of Victoria, Victoria V8W 3P6, BC, Canada
[d] Vancouver International CleanTech Research Institute Inc., 4475 Wayburne Dr. Suite 310, Burnaby, BC V5G 4X4, Canada
[e] Department of Mechanical Engineering, Urmia University, Urmia 57561-15311, Iran

ARTICLE INFO

Article history:
Received 29 August 2017
Received in revised form 14 October 2017
Accepted 16 October 2017

Keywords:
Polymer electrolyte membrane fuel cell
Netlike fuel cell
Stack size
Bipolar plate cost
Performance
Three-dimensional non-isothermal simulation

ABSTRACT

Cost, power density and durability are still major challenges to the large-scale commercialization of polymer electrolyte membrane fuel cells (PEMFCs). Most of these issues could be addressed by changing the conventional architecture of PEMFCs. The present work introduces a novel, net-shape flat architecture with unique capabilities. This netlike design increases the active area dramatically by bringing each channel in contact with three different electrodes. These capabilities are further investigated through a well-validated three-dimensional non-isothermal model in ANSYS Fluent.

Comparing the polarization curves shows that, per unit active area, the net-style design has a performance significantly better than that of conventional (classical) PEMFCs. In addition, it shows more uniform distribution of oxygen, water, current and temperature. Moreover, it provides remarkably higher current and power densities. Owing to its netlike shape, the proposed multi-channel PEMFC is also considerably smaller and requires less bipolar plates per unit active area. As a result, the state-of-the-art design introduced in this work can enhance the performance of PEMFCs remarkably while reducing their size and the bipolar plate cost. The net-type stack can therefore be considered one of the promising designs for the next generation of PEMFCs.

1. Introduction

Although polymer electrolyte membrane fuel cells (PEMFCs) have been considered the best replacement to internal combustion engines, the technology is still immature for widespread commercialization. Critical prerequisites for PEMFCs commercialization are improvements in power density, reliability and durability as well as reductions in production costs [1]. Over the past decade, materials characterization [2,3] and interfacial phenomena [4,5] have been the focus of the most of industrial and academic research projects. Less attention has been to date devoted to the *stack architecture* and the component arrangement, which play crucial roles in PEMFC performance, cost and durability [6–8]. The current capability of conventional (classical) PEMFC stacks has to date led to a few major breakthroughs in reducing their cost and size. The breakthrough improvements have to consider well-designed novel architectures, with precisely-controlled domain sizes and patterns. (*i*) The high cost [9] of the brittle graphite bipolar plates, (*ii*) the temperature and current distribution non-uniformity that intensifies degradation, (*iii*) the maldistribution of reactants inside the cells, and (*iv*) the relatively large and heavy PEMFC stacks have still been considered key priorities to be addressed in fuel cell industry. A number of these issues can be resolved by changing the architecture of PEMFC stacks.

Table 1 summarizes the new designs and architectures ever proposed to improve the conventional PEMFC performance, cost and size. Some of these designs, which comprise non-rectangular channels, have shown the capability of producing higher current density in comparison with the conventional (classical) PEMFCs. Specifically, the tubular multi-channel architectures [4] have recently shown promising potential for the reduction of the stack size and the amount of the bipolar plates required. However, the manufacturing of the graphite plates and membrane electrode assemblies (MEAs) in tubular shapes is indeed hard and highly costly. This point highlights the importance of having novel stacks and bipolar plates in a flat shape.

* Corresponding author at: Department of Chemical and Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver, BC V6T 1Z3, Canada.
E-mail addresses: hsf@mail.ubc.ca, hamidreza.sadeghifar@mail.ubc.ca, sadeghif@sfu.ca, h_sadeghifar@alum.sharif.edu (H. Sadeghifar).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.078
0017-9310/

Nomenclature

a	water activity
A	area (m^2)
C	molar concentration ($mol\ m^{-3}$)
CCM	catalyst-coated membrane
Cell	fuel cell
D	diffusion coefficient ($m^2\ s^{-1}$)
F	Faraday constant ($C\ mol^{-1}$)
GDL	gas diffusion layer
H	channel height (mm)
I	local current density ($A\ m^{-2}$)
i	local current density ($A\ m^{-2}$)
J	exchange current density ($A\ m^{-2}$)
K	permeability (m^{-2})
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	channel length (mm)
M	molecular weight ($kg\ mol^{-1}$)
MEA	Membrane Electrode Assembly
n_d	electro-osmotic drag coefficient
P	pressure (Pa or atm)
PEMFC	Polymer Electrolyte Membrane Fuel Cell
R	universal gas constant ($J\ mol^{-1}\ K^{-1}$)
T	temperature (K)
u	velocity ($m\ s^{-1}$)
t	thickness (μm or m)
V	cell voltage (V)
V_{OC}	open-circuit voltage (V)
W	channel width (mm)
X	mole fraction
Y,y	mass fraction

Greek letters

ø	potential (V)
α	water transfer coefficient
β	a modified heat transfer coefficient accounting for both convective heat transfer and the specific surface area of the porous medium
ζ	stoichiometric ratio
η	overpotential (V)
λ	water content in the membrane
μ	viscosity ($kg\ m^{-1}\ s^{-1}$)
ρ	density ($kg\ m^{-3}$)
σ	ionic or electrical conductivity ($ohm^{-1}\ m^{-1}$)
ψ	humidity
ε	effective porosity

Subscripts and Superscripts

a	anode
act	activation
ave	average
c	cathode
ch	channel
eff	effective value
GDL	gas diffusion layer
i	hydrogen at the anode side and oxygen at the cathode side
in	at the channel inlet
j	water
k	chemical species
land	land (rib)
MEA	membrane electrolyte assembly
Mem	membrane
ref	reference value
sat	saturated
w	water

In the present study, an unprecedented, net-shape flat architecture with specific capabilities is proposed for air-cooled (<5 kW [18]) PEMFCs. As shown in Fig. 1a and b, this unique, netlike design brings each channel in contact with *three* MEAs, which leads to a larger active area per unit volume. It also connects each anode to the cathode of different MEAs and vice versa. These special features offer the possible capability of enhancing the current density while reducing the stack size and the bipolar plates required. This may remarkably enhance all of areal, volumetric and gravimetric power densities. The architecture shown in Fig. 1 is the first version of the net-shape PEMFC and can therefore be further improved for its next-generation designs.

Using a well-validated numerical code in ANSYS Fluent, the present study investigates the possible advantages of the new architecture over the conventional or classical PEMFCs currently available in the market (the base model shown in Fig. 1c). The study further explores the capabilities that the new design could offer in terms of higher current and power densities, uniform current, temperature and reactant distributions inside the cell and any possible reduction in the stack size or in the amount of the bipolar plates required.

2. Design description

In the net-form configuration introduced, each channel is innovatively connected to three MEAs. This is one of the best designs ever introduced, especially in terms of its potential for enhancing the active area and the power density as well as its capacity for

Table 1
New stack designs and architectures capable of improving the PEMFC performance.

Authors	Architecture shape	Advantages over the classical PEMFCs
Pourmahmoud and Torkavannejad [10,11]	Elliptical and circular architectures	Slightly better performance
Mohammadi-Ahmar et al. [12]	Cylindrical circle-, triangle- and square-shape architectures	An enhanced power density
Walckzy et al. [13]	Ribbon-shape MEA	More uniform current distribution
Khazaee and Ghazikhani [14]	Multi-connected-duct architectures	Higher current densities
Torkavannejad et al. [4]	Annular circular-duct architectures	Higher current and power densities
Osanloo et al. [15]	Square duct-shaped PEMFCs	Higher current density and more uniform temperature and reactant distributions
Pourmahmoud et al. [16]	Nesting tubular architecture	Higher current density and more uniform temperature and reactant distributions
Liu et al. [17]	Coupled metal hydride containers	Noticeably larger surface-to-volume ratio