Energy Conversion and Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Flow field bipolar plates in a proton exchange membrane fuel cell: Analysis & modeling

Huseyin Kahraman [a,1], Mehmet F. Orhan [b,*]

[a] Department of Mechanical Engineering, Technology Faculty, Sakarya University, P.O. Box 54187, Sakarya, Turkey
[b] Department of Mechanical Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates

ARTICLE INFO

Article history:
Received 28 March 2016
Received in revised form 6 October 2016
Accepted 21 October 2016
Available online xxxx

Keywords:
Fuel cells
Proton exchange membrane
Bipolar plates
Flow field

ABSTRACT

This study investigates flow fields and flow field plates (bipolar plates) in proton exchange membrane fuel cells. In this regard, the main design considerations and limitations for a flow field network have been examined, along with a comprehensive review of currently available flow field channel configurations. Also, the common materials and material properties used for flow field plates have been explored. Furthermore, a case study of step-by-step modeling for an optimum flow field design has been presented in-details. Finally, a parametric study has been conducted with respect to many design and performance parameters in a flow field plate.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Hydrogen and fuel cell systems are the most important candidates to meet the energy demand in the near future [1]. In the proton exchange membrane (PEM) fuel cells, uniformity of reactants distribution *to* and *inside* each individual unit cell is indispensable to obtain optimum performance from the fuel cell stack. The design of the reactants manifold guarantees delivery of reactants to each individual cell, while the flow fields distribute the reactant gasses received from the manifold evenly over the active area of each individual unit cell. Thus, the main function of flow fields is to evenly distribute the reactants to the gas diffusion layer (GDL) and then to the active catalyst layer in the membrane electrode assembly (MEA) through the porous electrode while maintaining a minimum pressure drop [2–7].

Delivery of reactants and removal of products from a PEMFC is crucial for optimum performance and durability. Flow-field design of bipolar plates is the main actor for these processes. Power capacity value of a PEMFC can be affected by the flow field design excessively. Homogeneous current and temperature distribution along with effective water removal are crucial tasks, and require a careful flow field design in a PEMFC.

Fig. 1 illustrates this concept. Bipolar plates, also called flow field plates, constitute more than 60% of the weight and 30% of the total cost in a fuel cell stack [9]. Table 1 lists the main functions a bipolar plate performs in a PEMFC and the corresponding properties.

The main task of designing a flow field network is to achieve the maximum possible homogeneity over the cell's active area, which means using the hydrogen effectively [10], with respect to temperature, gas concentration, and humidity. The stoichiometry and composition of the reactants and the stack's operating conditions have to be accurately accounted for [11,12]. However, this is not an easy task due to many conflicting design parameters that have opposing effect on the overall fuel cell efficiency. Therefore, the main constraint to an optimum design of a flow field is the complex balance between these parameters [13].

Bipolar plates are counted for around 60% of the total cost of the stack. Also, an optimal design of the bipolar plate can improve the overall stack performance considerably, as high as 50%. Due to these significant importance and their critical roles, in this manuscript bipolar plates have been studied in detail presenting design considerations and constraints, bipolar plate materials, channel configurations, channel-land dimensions and shape, flow directions, pressure drop, heat and mass transfer, as well as electrical conductivity and resistivity.

2. Bipolar plate materials

In order for a bipolar plate to perform the functions listed in Table 1, it must be manufactured from materials with properties that satisfy the necessary requirements.

* Corresponding author.
E-mail addresses: huseyink@sakarya.edu.tr (H. Kahraman), morhan@aus.edu (M. F. Orhan).
[1] Visiting scholar at American University of Sharjah during 2015–2016.

http://dx.doi.org/10.1016/j.enconman.2016.10.053
0196-8904/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Kahraman H, Orhan MF. Flow field bipolar plates in a proton exchange membrane fuel cell: Analysis & modeling. Energy Convers Manage (2016), http://dx.doi.org/10.1016/j.enconman.2016.10.053

Nomenclature

$\mathbf{LtoC} = \frac{w_L}{w_C}$	land-to-channel ratio
$\mathbf{w_L}$	land width (m)
$\mathbf{w_C}$	channel width (m)
$\mathbf{d_C}$	channel depth (m)
$\mathbf{d_{BP}}$	bipolar plate depth (m)
$\mathbf{d_{GDL}}$	GDL depth (m)
$\boldsymbol{\rho_{BP,z}}$	resistivity of the bipolar plate in the z-direction (Ω cm)
$\boldsymbol{\rho_{BP,xy}}$	resistivity of the bipolar plate in the xy-plane (Ω cm)
$\boldsymbol{\rho_{GDL,z}}$	resistivity of the GDL in the z-direction (Ω cm)
$\boldsymbol{\rho_{GDL,xy}}$	resistivity of the GDL in the xy-plane (Ω cm)
$\mathbf{R_{CR}}$	contact resistance between the GDL and the bipolar plate (Ω cm^2)
$\mathbf{I_{density,GDL-CL}}$	current density at the GDL-catalyst layer interface (A/cm^2)
$\boldsymbol{\nu}$	Poisson's ratio
P	pressure (kPa)
E	Young's modulus (kPa)
t	thickness of the MEA (mm)
b	unsupported channel width (mm)
L	channel length (mm)
$(\Delta \mathbf{P})_{\mathbf{parallel}}$	pressure drop across a parallel-channel flow field (Pa)
f	friction factor
L	channel length (m)
$\mathbf{D_H}$	hydraulic diameter (m)
ρ	fluid density (kg/m^3)
$\mathbf{v_{avg}}$	average velocity (m/s)
$\mathbf{K_L}$	local resistance found experimentally
$\mathbf{A_{active}}$	cell active area (m^2)
$\mathbf{N_{channels}}$	number of parallel channels
$\mathbf{A_{CS}}$	cross-sectional area of the channel (m^2)
p	wetted perimeter of the channel, (m)
$\mathbf{N_{cells}}$	number of cells
I	stack current (A)
$\mathbf{S_{O_2}}$	oxygen stoichiometric ratio
$\mathbf{S_{H_2}}$	hydrogen stoichiometric ratio
R	universal gas constant, equal to 8.314 (J/mol K)
$\mathbf{T_{in}}$	stack's inlet temperature (K)
F	Faraday's constant, equal to 96,485 (C/mol)
$\mathbf{P_{in}}$	stack inlet pressure (Pa)
φ	relative humidity
$\mathbf{P_{sat@T_{in}}}$	saturation pressure at the given inlet temperature (Pa)
$\mathbf{r_{H_2}}$	hydrogen volume fraction in the fuel mixture
$\mathbf{r_{O_2}}$	oxygen volume fraction in the air mixture
$\mathbf{Q_{stack,in}}$	stack's inlet volumetric flow rate (m^3/s)
Re	Reynolds's number
μ	fluid viscosity, (kg/m s)
$\frac{\varepsilon}{D}$	relative roughness (absolute roughness divided by the channel's inner diameter)
$\mathbf{I_{density}}$	current density (A/m^2)
$(\Delta \mathbf{P})_{\mathbf{porous}}$	pressure drop across a porous flow field (Pa)
$\mathbf{Q_{cell}}$	volumetric flow rate through a cell (m^3/s)
K	permeability of the porous flow field (m^2)
$\mathbf{A_{CS}}$	cross-sectional area of the flow field (m^2)
L	length of the flow field (m)
$\dot{\mathbf{N}}_{\mathbf{gas}}$	molar flow rate of the oxidant or fuel
$\mathbf{P_{vap}}$	partial pressure of the water vapor in the gas stream
$\mathbf{P_T}$	total gas pressure (Pa)
$\mathbf{u_m}$	mean velocity (m/s)
H	height of the channel (m)
$\mathbf{y_i}$	central location of each node (m)
Δy	distance between adjacent nodes (m)
N	number of nodes
c i	specific heat capacity (J/kg K)
W	depth of the channel (m)
T	temperature (K)
k	conductivity (W/m k)
$\mathbf{T_s}$	plate surface temperature (k)
$\mathbf{A_{electrode}}$	electrode's surface area.
$\mathbf{h_m}$	mass transfer coefficient.
$\mathbf{\Delta C_{lm}}$	logarithmic concentration difference
Sh	Sherwood number
$\mathbf{D_{i,j}}$	binary diffusion coefficient for species i and j
$\mathbf{T_{ref}}$	temperature at which the binary diffusion coefficient is known
T	temperature of the reactant
$\mathbf{C_{m,in}}$	mean concentration at the flow channel inlet
$\mathbf{C_{m,out}}$	mean concentration at the flow channel outlet
$\mathbf{A_a}$	apparent contact area between the GDL and the bipolar plate,(m^2)
K	geometric constant
G	topothesy of a surface profile.
D	fractal dimension of a surface profile
$\mathbf{P^*}$	ratio of the actual clamping pressure and comprehensive modulus of GDL
κ	effective electrical conductivity of the two surfaces (S/m)
ρ	contact resistivity (Ω cm^2)
P	contact clamping pressure (MPa)
A, B, and C	experimental constants
L	distance between the bypass location to the bypass emergence point
V	channel bulk flow velocity
$\mathbf{U_{avg}}$	bulk average velocity through the GDL
ΔS	porous GDL thickness in the flow direction (equivalent to the land width, w_L)
$\mathbf{d_h}$	channel's hydraulic diameter, found (in general and for a rectangular channel, respectively)
$\mathbf{A_{CS}}$	cross-sectional area of the channel
p	wetted perimeter of the channel
ε	porosity of the porous medium
$\mathbf{d_s}$	diameter of the theoretical spherical particles the medium is modeled to consist of (pore diameter)

In general, there are two main families of materials that are commonly used for the production of bipolar plates; graphite and metals. Despite its high cost, solid graphite is commonly used due to its corrosion resistance, chemical inertness and good conductivity. However, their favorableness is decreasing due to the fact that they cannot be mass produced since flow channels need to be machined or electrochemically etched on the graphite bipolar plate surface. In contrast to graphite, metallic plates are suitable for mass production in very thin layers for lightweight and portable stacks. Some of the main material properties of graphite/composite and metallic bipolar plates have been listed in Table 2, respectively.

Metals can dissolve and diffuse into the electrolyte, which is usual in the corrosive environment of the bipolar plates. This process lowers ionic conductivity, and fuel cell's overall efficiency and life. Some materials such as graphite, gold, silver, palladium, platinum, carbon and conductive polymer are used to coat the bipolar plate, and prevent corrosion while promoting conductivity. Common coating concerns are corrosion resistance, micro-pores/cracks and more importantly difference in the thermal expansion coefficient compared to the plate itself.

Table 3 includes common materials used for coatings. These materials are selected based on their conductivity, corrosion resistance, thermal expansion, and the absence of micro-pores/cracks.

Please cite this article in press as: Kahraman H, Orhan MF. Flow field bipolar plates in a proton exchange membrane fuel cell: Analysis & modeling. Energy Convers Manage (2016), http://dx.doi.org/10.1016/j.enconman.2016.10.053

Download English Version:

https://daneshyari.com/en/article/5012988

Download Persian Version:

https://daneshyari.com/article/5012988

Daneshyari.com