Energy 94 (2016) 206–217

Contents lists available at ScienceDirect

Energy

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

Influence of cathode flow pulsation on performance of proton exchange membrane fuel cell with interdigitated gas distributors

A. Ramiar [a, *], A.H. Mahmoudi [a], Q. Esmaili [b], M. Abdollahzadeh [c, d]

[a] Babol Noshirvani University of Technology, Faculty of Mechanical Engineering, P.O. Box: 484, Babol, Iran
[b] Amol University of Special Modern Technologies, Faculty of Engineering Technology, Amol, Iran
[c] University of Porto, Laboratory for Process, Environmental and Energy Engineering (LEPABE), Portugal
[d] Universidade da Beira Interior, Departamento de Engenharia Electromecanica, C-MAST – Center for Mechanical and Aerospace Sciences and Technologies, FCT (Portuguese Foundation for Science and Technology) Research Unit No. 151, Covilha, Portugal

ARTICLE INFO

Article history:
Received 6 June 2015
Received in revised form
9 October 2015
Accepted 11 October 2015
Available online 21 November 2015

Keywords:
PEMFC (proton exchange membrane fuel cell)
Interdigitated
Flow pulsation
Water management
Multiphase model

ABSTRACT

In this paper, a numerical study is conducted in order to investigate the effect of pulsation of air flow at the cathode side of Proton Exchange Membrane (PEM) fuel cell with interdigitated flow field. A two dimensional, isothermal, two-phase, unsteady multi-component transport model is used in order to simulate the transport phenomena. The obtained results are discussed in terms of the influence of flow pulsation on water management and cell performance. The results prove the effectiveness of flow pulsation on improving water removal from cell, enhancing reactants transports to the reaction sites, and increasing the cell performance expressed by increment in the cell limiting current density and maximum output power. The effects of pulsation frequency (f), amplitude (Amp), and mean inlet pressure (P_{in}) on the performance and the output power of the cell, are also investigated. The performance of the cell has no dependency on the frequency range considered in this study. However, as the pulsation amplitude increases the increment in the cell performance is more obvious. Moreover, applying flow pulsation at low flow rates leads to higher efficiency in water removal and performance enhancement.

1. Introduction

In recent years, Proton Exchange Membrane Fuel Cells (PEMFCs) have gained increasingly high interests as alternative power source in transportations and stationary power systems, because of their zero pollution, high output power, low operating temperature (below 100 °C), portability and capability to quick start up. Nevertheless, further optimization of PEMFCs is needed in order to be more efficient and economically more viable. Many factors have a strong effect on the performance of PEMFCs such as: operating conditions, geometrical and material parameters. One of parameters which has a very important role in transport phenomena inside the PEMFCs and affects the performance of fuel cell is the flow field design of bipolar plates. Among various flow fields considered in recent years, interdigitated flow filed showed a great capability to improve the cell performance [1]. Fig. 1 shows a cross sectional schematic of interdigitated flow field design. For the first time Nguyen [2], presented interdigitated gas distributor for the cathode of proton exchange membrane fuel cell in order to reduce mass-transport limitations and flooding problem. The results of his study indicate that this new flow field design was able to achieve a higher cell performance.

1.1. Interdigitated flow field

Mathematical modelling provides a tool for evaluation, optimization and further development of fuel cells. Yi and Nguyen [3], developed a two-dimensional, steady-state, multi-component transport model to simulate the transports of gases in the cathode side of PEMFCs with interdigitated gas distributors, and predicted the effects of differential pressure between the inlet and outlet channels of interdigitated gas distributor, and cathode structure parameters like, electrode height and shoulder width on the performance of the cell with interdigitated gas distributor. He et al. [4] also presented a two-dimensional, two-phase, and multi-component transport model to investigate the influence of hydrodynamics of gas and liquid water on the performance of PEMFC

* Corresponding author. Babol Noshirvani University of Technology, Department of Mechanical Engineering, Iran. Tel.: +98 11 323 34205.
E-mail address: aramiar@nit.ac.ir (A. Ramiar).

http://dx.doi.org/10.1016/j.energy.2015.10.110
0360-5442/

Nomenclature

C	Molar concentration (mol/cm^3)
D	Mass diffusivity (cm/s)
P	Pressure (Pa)
P_{ref}	Reference pressure 1.013 × 10^5 Pa
R	Universal gas constant 8.3145 J mol^{-1} K^{-1}
s	Saturation of liquid
T_{ref}	Reference temperature: 25 °C
u	Velocity vector (cm/s)
u	Velocity in x-direction (m/s)
v	Velocity in y-direction (m/s)
T	Time period (s)
Greek symbols	
ρ	Density (kg/m^3)
ε	Porosity
α	Species (O_2, N_2, H_2O)
α_c	Transfer coefficient of oxygen reduction
γ	Advection correction factor
σ	Surface tension (N/m)
η	Over potential (volt)

with interdigitated gas distributors. The model was then employed to determine effect of various electrode parameters on the performance of PEMFC. Abdollahzadeh et al. [5] investigated the performance of PEMFC with parallel and interdigitated flow field designs for the cathode side by employing a two-dimensional, multi-component mixture model. They conducted a wide parametric study on the effect of operating conditions such as pressure difference, operating temperature and geometrical parameters such as diffusion layer thickness and material parameters such as electrode porosity. The results of their simulation were validated and compared with experimental results found in the literature.

A good review of the on-going research in the field of modelling PEMFCs was provided by Sigel [6], Ryan Anderson et al. [7] and Djiali [8]. Wide researches have been done in the literature on improving mathematical modelling of fuel cells for the purpose of optimization and performance evaluation of fuel cell systems (especially PEMFCs) ([9–18]).

Kazim and Liu [19] used a two-dimensional mathematical model for the cathode of proton exchange membrane with interdigitated flow field to study the effects of increasing the porosity of electrode and operating pressure and temperature on PEMFC performance. Tao et al. [20] developed a hybrid single- and two-phase multi-component model for the cathode side of PEMFC with interdigitated flow field to simulate the transport of species and the effects of operating conditions and cathode structural parameters on the cell performance. In the past decade several studies have been done in order to study the effects of some geometrical and operational parameters on the performance of PEFMCs using interdigitated flow fields ([10,12,21–24]).

1.2. Effect of pulsation

Recently, pulsating the air flow at the cathode side of PEMFC was suggested as an alternative mean to increase the overall performance of the fuel cell. Tseng et al. [25] observed that cathode air flow pulsation can improve the transport rate of reactants and help the water removal from the cell. Kim et al. [26] studied the effect of cathode flow pulsation on the performance of PEMFC; they found that by employing a flow pulsation, the maximum output power and limiting current density of cell would increase. They also investigated the influence of change in the pulse amplitude and frequency on the cell performance. Perez [27] introduced the method of applying pulsation to reactants in order to reduce the problem of water accumulation inside the cell. He also investigated the parameters which can affect the power production in fuel cell using pulsating flow and found an optimized power performance for PEMFC. Hwang et al. [28] applied pulsating flow on the cathode side of PEMFC to enhance the oxygen diffusion rate between the channel and the catalyst layer. They found that by applying flow pulsation the oxygen concentration increases and causes an improvement in the cell performance. Kim et al. [29] also performed an experimental and theoretical study to show the influence of cathode pulsation flow on enhancing the PEMFC performance.

According to the author's knowledge, none of the studies conducted in the recent past has considered effect of pulsation on the intertigated flow field. The present study concerns a new solution for improving cell performance consisting of using interdigitated flow field and also air flow pulsation at cathode side of PEMFC. In this paper the two-dimensional, two-phase, isothermal, multi-component model for the cathode side of proton exchange membrane fuel cell developed by Abdollahzadeh et al. [5], is further developed to consider transitional effects of flow pulsation. Then the model is used to investigate the effects of adding pulsation to inlet air flow on the water removal from cell and distribution of reactants, and therefore performance of cell with interdigitated flow field. Also the influence of pulsation key parameters such as amplitude, frequency and mean inlet pressure on the performance of cell with interdigitated flow field is determined.

2. Model description

2.1. Computational domain

A 2*D*, cross sectional schematic of PEMFC with interdigitated gas distributor is shown in Fig. 2. The computational model only

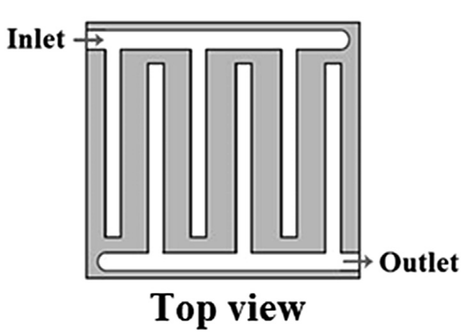

Fig. 1. Schematic diagram of PEMFC with interdigitated flow field.

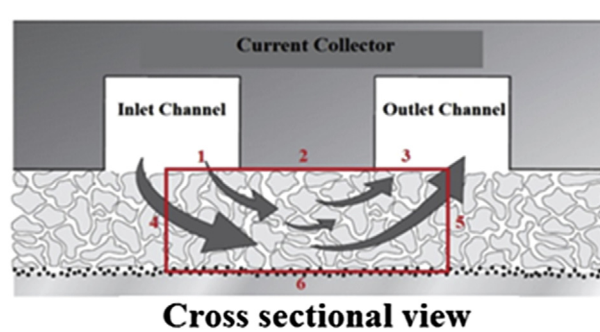

Fig. 2. Computational domain.