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Numerical optimization of channel to land width ratio for PEM fuel cell

Mohammad Ziauddin Chowdhury [a,b,*], *Omer Genc* [a,b], *Serkan Toros* [a,b]

[a] *Nigde Omer Halisdemir University Prof. Dr. T. Nejat Veziroglu Clean Energy Research Center, Nigde, Turkey*
[b] *Mechanical Engineering Department, Faculty of Engineering, Nigde Omer Halisdemir University, Nigde, Turkey*

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ABSTRACT

Flow field plays a vital role in proton exchange membrane (PEM) fuel cell where channel geometry being the primary factor. Most of the channel geometry analyses were limited to few number of case studies, whereas in this study total 73 case studies were analyzed for the optimization of channel and land width. A three dimensional isothermal single phase flow mathematical model is developed and further validated with experimental study to optimize the channel and land width through parametric sweep function for a staggering 73 number of case studies. The optimization analyses are carried out for a straight channel geometry considering a fixed operating voltage of 0.4 V and channel depth of 1.0 mm. Due to the large number of case studies, the analyzed performance parameters i.e. current density and pressure drop are easily understandable for the change in different channel and land width. The numerical results predicted that the pressure drop is more dependent on channel width compare to the land width and anode pressure drop is less significant than cathode pressure drop. However, both channel and land width have an equal importance on the cell current density. Considering channel pressure drop and current density, the optimization analyses showed that the channel to land width of 1.0 mm/1.0 mm would be best suitable for PEMFC channel geometry.

Introduction

Proton exchange membrane (PEM) fuel cell is an emerging sustainable energy source [1] that can fulfill the growing demand especially for automotive sectors [2,3]. For this reason, large scale research interest is on the rise for the efficient PEM fuel cell system development. Bipolar plate is one of the major component in PEM fuel cell contributing 60% weight and 30% cost of the PEM fuel cell system [4]. Ozden et al. [5] numerically investigated that cell degradation is more prone to the bipolar plate than other system components of PEMFC. Bipolar plate facilitates flow fields through which reactants flow, electron conduction and removal of waste heat and water from the cell take place as well. That's why bipolar plate has a great significance on the PEM fuel cell system. The optimization of bipolar plate flow field geometry is very difficult through experimental approach, whereas numerical procedure is an effective tool for the optimization [6–8].

The cell performance of PEM fuel cell largely relies on the proper flow field design. For the effective flow field design, channel geometry is the primary dominant factor. This is because improper channel geometry can results in maldistribution of reactants transport [9,10] faulty water

* *Corresponding author*. Nigde Omer Halisdemir University Prof. Dr. T. Nejat Veziroglu Clean Energy Research Center, Nigde, Turkey.
E-mail addresses: zia72822@gmail.com (M.Z. Chowdhury), omergenc@ohu.edu.tr (O. Genc), serkantoros@ohu.edu.tr (S. Toros).
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Nomenclature

A_c	Tafel slope
E_{eq}	Equilibrium voltage
μ	Dynamic viscosity
a_v	Active surface area
C_x	Species concentration
D_{ik}	Diffusion coefficient
F	Faraday constant
i	Current Density
i_0	Exchange current density
i_v	Total local current density
K	Permeability
M	Molecular mass
P	Pressure
R	Universal gas constant
R_i	Species source term
S	Current source term
T	Cell temperature (K)
u	Velocity
ω	Mass fraction
x	Mole fraction
J_i	Diffusive flux
N_i	Total flux
η	Electrochemical overpotential
ρ	Mixture density
σ	Electric conductivity
φ	Phase potential
α	Charge transfer coefficient
ε	Porosity

Subscript

a	anode
c	cathode
o	initial condition
l	electrolyte phase
s	solid phase
ik	species
ref	reference
eq	equivalent
v	totality

management [11–13] and high pressure drop [10,14] across the flow field active area resulting poor cell performance. In the flow field geometry, channel width/land ratio plays a significant role for the optimized flow field design as well as for better cell performance. There are several studies for the channel width/land ratio optimization with numerical investigation [8,15,16]. The increase of channel width causes better cell performance reducing the concentration loss effectively which leads to an increasing of current density [17]. On the other hand, narrow land width increase ohmic loss by increasing contact resistance between bipolar plate and gas diffusion layer [18]. Yu et al. [19] investigated that the land width has little influence on the improvement of cell performance for interdigitated flow field due to the forced convection gas transfer mechanism. Goebel et al. [20] recommended minimum land fraction of a 50% for low contact resistance with a maximum 1.0 mm channel span. Channel to land width ratio found to be less significant for transient temperature distribution while scale ratio of 1.0 is highly desirable for the power gain function [21]. Pressure drop increases with the decreasing channel size and if pump work is neglected small channel cross-sectional area would be better for cell performance [22].

Understanding the in-situ characteristics of the mass transport phenomena and electrochemical process, numerical technique is becoming more popular approach [23–25] and due to this, reliability is a major concern of the numerical solution of PEMFC. Anderson et al. [26] made comprehensive analyses on flow phase of PEMFC modeling techniques. Finite element method by Comsol multiphysics interface was used for the PEM fuel cell simulation in several studies [27–31]. Hasse et al. [32]. investigated differential pressure using finite element analyses. Verma et al. [33] numerically analyzed membrane properties and water management on PEM fuel cell performance considering two dimensional single phase flow. Ismail et al. [34]. employed a three dimensional single phase flow model to explore the effect of permeability on the gas diffusion layer. Cooper et al. [35] presented a three dimensional single phase flow to investigate the effect of channel aspect ratio on cell performance. To optimize flow field design, single phase flow was considered, explaining the standard working temperature of 80 °C is sufficient enough for gas flow phase to be unchanged especially for isothermal condition [6,8,36,37]. Furthermore, for the small active area, eliminating the liquid water formulation and transport will not be a major issue as the single phase transport can be assumed for the comparative flow fields' study of mass transport concentration, pressure and current density distribution analyses considering steady state isothermal conditions. Ghanbarian et al. [38] explained that single phase module can detect condensing regions using the concentration profile analyses of two phase transport.

So far, there are so many studies being accomplished considering only few number of cases for the channel to land width optimization. In this study, a three dimensional isothermal single phase flow numerical model is considered for the optimization of channel to land width for PEM fuel cell. The most significant aspect of this study is that a total number of 73 cases of channel to land width ratio are analyzed for optimization with the parametric sweep function analyses.

Mathematical model

A mathematical model is developed based on two major consequences of PEMFC, which are the charge phenomena and fluid flow dynamics. Mathematical model consists of the governing equations considering assumptions, initial conditions and boundary conditions, numerical technique, mesh independency test for reliable solution and model validation.

Geometry of interest

The generalized computational 3D domain of the considered cases is shown in Fig. 1, while the considered channel width and land width are listed in Table 1. All the studied cases have