ARTICLE IN PRESS

Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Optimization of an open-cathode polymer electrolyte fuel cells stack utilizing Taguchi method

Agus P. Sasmito [a,*], Jundika C. Kurnia [b], Tariq Shamim [c], Arun S. Mujumdar [a]

[a] Department of Mining and Materials Engineering, McGill University, 3450 University, Frank Dawson Adams Bldg., Montreal, QC H3A0E8, Canada
[b] Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia
[c] Institute Center for Energy (iEnergy), Department of Mechanical and Materials Engineering, Masdar Institute of Science and Technology, Masdar City, Abu Dhabi, United Arab Emirates

HIGHLIGHTS

- Design and operating parameters of an open-cathode PEFC stack is optimized.
- Optimization is carried out with regard to current density and net power.
- Fuel cell length plays important role on stack performance.
- Interaction between each parameter is evaluated.

ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 21 December 2015
Accepted 23 December 2015
Available online xxxx

Keywords:
Fuel cells stack
Open-cathode
Net power
Optimization
Taguchi

ABSTRACT

The design of open-cathode polymer electrolyte fuel cells (PEFC) stacks with forced-convection requires a careful consideration on the geometrical and operating conditions as well as the operating characteristic of PEFC stacks and fan used. This paper evaluates the effect of key geometrical and operating parameters on the stack characteristic and their interactions to the thermal, water and gas managements as well as stack performance. A validated three dimensional model for open-cathode PEFC stack with fan and immediate ambient were solved to evaluate the effect of studied parameters on the stack performance. In tandem, an L_{27} orthogonal array (OA) of Taguchi matrix of six factors and three level designs to determine the optimum combination of parameters as well as their interactions for high, medium and low voltage operation. The result indicates that fuel cell length plays important role on determining the fuel cell performance in term of system characteristic, current density and net power. Optimum combination of design and operating parameters were obtained with the objective function of maximizing net power generated by stack by taking into account the parasitic loads.

1. Introduction

In order to achieve optimum operating condition of polymer electrolyte fuel cells (PEFC) stacks, it is essential to maintain an efficient gas, water and thermal management. For a PEFC stack with capacity range between 100 and 2000 W, an open cathode design with fans to supply simultaneous air (oxidant) and cooling is desirable due to its less overall system complexity as compared to those with liquid cooling [1,2]. In this design, however, air supply system configurations (fan, blower or compressor) and their operational parameters are critical in determining the performance of PEFC stack as they do not only maintain the optimum temperature (thermal management) but also ensure sufficient reactant air (gas management). Selection of the air supply system usually depends on the system and fan characteristic curves [3]. In PEFC stack, several key factors determining the system characteristic curve (SCC) are overall stack geometry, cathode opening area, cathode flow field type and overall length, stack voltage, and additional coolant channels for separated cooling air. Meanwhile, several factors deciding the fan characteristic curve (FCC) are power rating, type, size and blade.

To date, many researchers have been focusing on the open-cathode fuel cells stack due to its potential to be used for portable and automotive applications [4]. Strahl et al. [5] experimentally investigated the degradation of open-cathode fuel cell stack. They found that cells located close to the end plates show the biggest performance decay. Huang et al. [6] developed and tested a hybrid

* Corresponding author. Tel.: +1 514 398 3788.
E-mail address: agus.sasmito@mcgill.ca (A.P. Sasmito).

http://dx.doi.org/10.1016/j.apenergy.2015.12.098

system with small stack (sub-kW) open-cathode PEM fuel cell stack to simulate vehicle operation with dynamics loading. Liu et al. [7] experimentally improved the membrane electrode assembly of open-cathode fuel cell. Tang et al. [8] developed a hybrid system combining a 2 kW air-blowing open-cathode proton exchange membrane fuel cell (PEMFC) stack and a lead–acid battery pack for a lightweight cruising vehicle. The dynamic performances of this PEMFC system with and without the assistance of the batteries were systematically investigated in a series of laboratory and road tests. The results showed that such a hybrid system was able to dynamically satisfy the vehicular power demand. While most of open-cathode fuel cell design suffers from membrane drying due to lack of humidification, Kong et al. [9] developed a self-humidifying system by using double gas diffusion backing layers. Obeisun et al. [10] characterized the flow field geometry of open-cathode PEMFC using printed circuit boards flow fields and found that circular opening yields lower Ohmic resistance. The mathematical modeling of open-cathode fuel cell started by Sasmito et al. [11] for which the fuel cells stack, fans and immediate ambient is taken into account. Flow reversal concept were introduced to overcome hot-spot at the near outlet region [12], while open-cathode with edge-cooling designs were proposed and investigated to improve thermal management of the stack [13,14]. Tadbir et al. [15] developed cell level modeling of the hygrothermal characteristics of open-cathode fuel cells. Ismail et al. developed two-dimensional model for open cathode fuel cell [16] and later developed a simple model of open cathode fuel cell to quantify heat generation from joule heating and entropy generation [17]. Henriques et al. [18] experimentally and numerically investigated approach to improve open-cathode fuel cell efficiency by altering the cathode channel geometry. Recently, Meyer et al. [19] optimized the operating parameters of commercial open-cathode fuel cells using electro-thermal performance map. Despite wide range studies have been conducted worldwide, none of this study has focused on optimizing both design and operating parameters simultaneously which is the theme of this paper.

Design of experiments Taguchi method has in recent years become popular tool for engineering optimization due to its simplicity and robustness. Several researchers have implemented Taguchi optimization in fuel cells area. Solehati et al. [20] optimized operating parameters of liquid-cooled fuel cell stack coupled with CHP system. Wu et al. [21] optimized the modified flow field design using Taguchi method. Besseris [22] optimized the fuel cell design using qualimetric engineering (Taguchi) and extremal analysis. They concluded that the proposed technique is simple and practical offering more accuracy, convenience and flexibility when compared with other competing algorithmic schemes. Given the capability of Taguchi method in determining the most significant factor influencing the performance of a fuel cell system, it is therefore of interest to apply this method to assess and evaluate the key parameters affecting the performance of forced-convection open cathode fuel cell and determine the optimum conditions for its operation. Therefore, the aim of the study presented here is threefold: (i) to investigate the effect of design and operating parameters at different operating cell voltage, i.e. low (0.4 V), medium (0.6 V) and high (0.8 V); (ii) to optimize fuel cell performance based on average current density and net power generated; and (iii) to evaluate interaction between each design and operating factor with regards to the stack performance.

The layout of the paper is as follows. First, the model development is introduced; it comprises of two-phase conservation of mass, momentum, species, energy, charge together with its immediate ambient and fan. The pertinent electrochemistry is accounted for by an agglomerate model and Butler–Volmer equation. Taguchi statistical method is then employed to study the sensitivity of each design and operating parameter under various conditions. Interaction between each parameter is evaluated. Optimum design and operating parameters are then calculated based on average current density and net power generated by stack. Finally, conclusions are drawn and extensions of the work are highlighted.

2. Model development

2.1. Mathematical model

The mathematical model is based on the validated mathematical framework model developed in previous work [11]. Schematics of the repetitive cell unit a PEFC stack, ambient and fan(s) considered in this study is presented in Fig. 1. The governing equations can be found in Table 1. For the sake of brevity, details on the model derivation and validation are not repeated in this paper. Instead the reader can refer to our previous article [11].

2.2. Performance evaluation

To evaluate the system, net power of the system is calculated as the power generated by the stack minus the parasitic load of the fan and anode humidifier, i.e. $P_{net} = P_{stack} - P_{fan} - P_{hum}$. The power generated by the stack is given by voltage and current density, i.e. $P_{stack} = E_{cell} n_{cell} I_{tot}$. The total current is given by $I_{tot} = i_{ave} A_{cl}$ where i_{ave} is the average current density and A_{cl} is the area of the catalyst layer while E_{cell} is the cell voltage of the repetitive unit. The fan power is obtained from the fan manufacturer specification.

2.3. Taguchi statistical method

Developed by Genichi Taguchi, Taguchi statistical method is widely known as a robust and powerful engineering tool for experimental optimization and design method. This method is employed to assess sensitivity of each parameter and determine the optimum combination of the design factors. In this study, six key parameters determining the performance of PEFC system are evaluated; those are fuel cell length, cathode channel height, cathode channel width, flow configuration, fan power and relative humidity at the

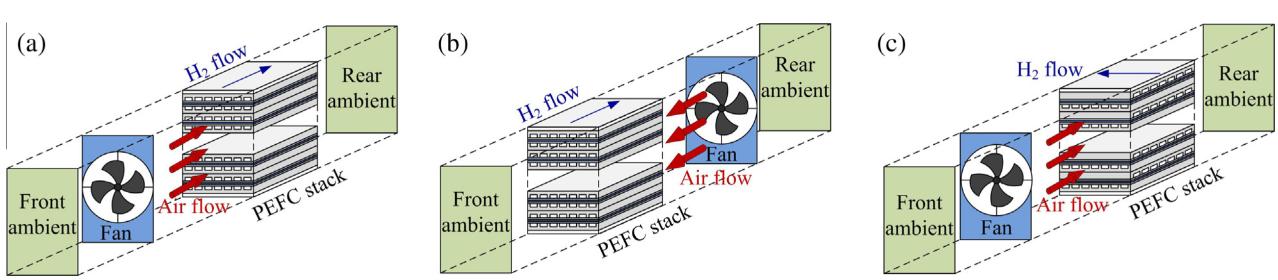

Fig. 1. Schematic representations of (a) co-flow, (b) counter-flow and (c) cross-flow forced-convection PEFC system.

Please cite this article in press as: Sasmito AP et al. Optimization of an open-cathode polymer electrolyte fuel cells stack utilizing Taguchi method. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2015.12.098