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Optimum design parameters and operating condition for maximum power of a direct methanol fuel cell using analytical model and genetic algorithm

M. Tafaoli-Masoule [a,*], A. Bahrami [b], E.M. Elsayed [c,d]

[a] Fuel Cell Research Technology Group, Department of Mechanical Engineering, Babol University of Technology, P. O. Box 484, Babol, Iran
[b] Department of Mechanical Engineering, University of Tehran, Tehran, Iran
[c] Department of Mathematics, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[d] Department of Mathematics, Faculty of Science, Mansoura University, Mansoura 35516, Egypt

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ABSTRACT

It is well known that anode and cathode pressures, cell temperature and channel geometry are the effective parameters in the performance of DMFC (direct methanol fuel cell). In the present paper, the GA (genetic algorithm) as one of the most powerful optimization tools is applied to determine the optimal values for these parameters which result in maximum power density of a DMFC. The predominant part of the genetic algorithm is the fitness function. For the fitness function calculation, calculation of more than one thousand cases is necessary. Unfortunately, large numbers of experiments are needed, which is very time-consuming and costly. To overcome this challenge, a quasi two dimensional, isothermal model is used to obtain the power of DMFC as the fitness function of GA. For validation of this model, the results of the model are compared with experimental results and literature and shown to be in good agreement with them.

1. Introduction

Recently, developments in renewable energy technologies and high cost of energy from fossil fuels have increased the utilization of different type of fuel cells [1]. Fuel cells are devices that convert chemical energy directly into electrical energy without combustion [2]. In the recent years, polymer electrolyte membrane fuel cells which use hydrogen or methanol as fuel have received increasing attention for energy generation on small and portable scale, due to high fuel to energy conversion efficiency [3]. DMFC (direct methanol fuel cell) with liquid methanol is easy to store and apply. It is one of the most promising portable power sources and an alternative to Li-ion batteries which can be used in mobiles, laptops and urban transportation systems [4]. The basic structure and operation of DMFC are shown in Fig. 1. DMFC is well known to be influenced by large numbers of parameters such as flow rate, methanol concentration, operating temperatures, anode and cathode pressures and so forth.

In order to improve the performance of the DMFC, it is necessary to determine the effects of various parameters on the performance of the fuel cell. Other parameters include: (1) type and thickness of membrane, (2) catalyst type, (3) geometrical parameters of the flow field, and (4) the type of the gas diffusion layer. However, while these parameters are very important, they are not variable during fuel cell use. Therefore, they are not considered as operating variables.

The fuel cell performance has been the subject of several research papers. Notably, Okur et al. [5] determined the optimum operating conditions for the process of preparing anode electrocatalysts for DSBHFC (direct sodium borohydride fuel cell). In addition, Carton and Olabi [6] established some experiments for comparison between three different configurations of flow plates of a fuel cell, the manufacturer's serpentine flow plate and two new configurations; the maze and the parallel design. Moreover, Oliveira et al. [7] presented a 1D mathematical model for a microbial fuel cell in order to predict the correct trends for the influence of current density on the cell voltage while a comprehensive numerical model was developed by Xu et al. [8] to predict the electrochemical performance of SOFC (solid oxide fuel cell). A one-dimensional, steady-state, two-phase DMFC (direct methanol fuel cell) model was proposed by Johan et al. [9] to precisely investigate complex physiochemical phenomena inside DMFCs. Jeong et al. [10] developed a mathematical model to study optimum operating

* Corresponding author. Tel.: +98 21 5505 4367; fax: +98 21 8807 9656.
E-mail address: mojtaba.tafaoli@yahoo.com (M. Tafaoli-Masoule).

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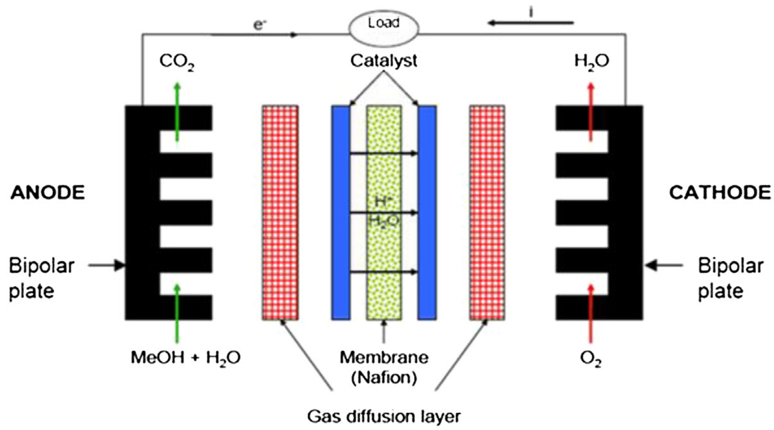

Electrochemical reaction on the anode side: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Electrochemical reaction on the cathode side: $6H^+ + 6e^- + \frac{3}{2}O_2 \rightarrow 3H_2O$

Overall reaction: $CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O$

Fig. 1. Schematic presentation of the direct methanol fuel cell principle.

strategies for minimizing methanol consumption while Wang et al. [11] focused on the effect of cell temperature and oxygen flow rate on cell response using experimental directions.

Bennett et al. [12] developed an analytical model to determine the oxygen concentration profile in the cathode backing layer and flow channel along a one-dimensional cross-section of the fuel cell. The model was then applied to examine the effects of new low-crossover membranes and to suggest new design parameters for those membranes. Furthermore, the multi-objective optimization problem was addressed by Wu and Lin [13] to improve the fuel efficiency and total exergetic efficiency of a non-isothermal DMFC (direct methanol fuel cell) system.

The main important parameters which affect the performance of the DMFC are operating parameters such as fuel cell temperature and pressure in both sides of cathode and anode as well as channel geometry. The main focuses of the mentioned works were based on evaluating the required objective function by means of simulation and experimental approaches for limited and certain values of DMFC parameters and then comparing their objective functions to find the optimal solution. This approach is quite time-consuming and the accuracy of the results depends on the selected values of the parameters in the experiments. To the best knowledge of authors, there is no complete work done on the optimization of DMFC by combining an analytic model with genetic algorithm to obtain the optimal solution. The present research work combines a valid analytic model with genetic algorithm in order to examine many different cases in the possible search domain of each parameters instead of testing limited cases which were considered in the previous studies [5–13]. The combination of genetic algorithm and a valid analytical model as fitness function is a powerful tool for the investigation of these operating parameters.

2. Genetic algorithm

The GA (genetic algorithm) method creates an artificial system according to the Darwinian mechanisms of evolution which is based on high probability for powerful solutions and low probability for weak solutions. The properties of this artificial system are similar to human genetic system and the base of the genetic algorithm method is a random search. Genetic algorithm is a parallel mathematical algorithm that transforms a set of population (namely chains of "chromosomes" using genetic operations) into a new population (namely a next-generation) based on the fitness of each "chromosome" [14].

The principle concepts of a genetic algorithm are quite simple and can be described as follows:

1. First generation: the first generation is created randomly at definite domain. The size of population is based on the number of variables.
2. Evaluation of each solution: Each solution or "chromosome" is evaluated using fitness function.
3. Tournament selection: Each of both cases is selected randomly and according to the fitness function, the most appropriate one is introduced into the mating pool.
4. Crossover: For the purpose of searching for the best solutions at definite domain, each of both cases is combined with a definitive probability. In the present work, the algorithm uses the real digits systems and the crossover is defined according to the following approach in which R is a random number between 0 and 1:

$$\mathrm{child}_{1,2} = \left(\frac{\mathrm{parent}_1 + \mathrm{parent}_2}{2}\right) \pm |\mathrm{parent}_1 + \mathrm{parent}_2| \times R$$

5. Mutation: For finding the absolute maximum value and escaping from the local maximum value, mutation is applied with certain probability. Following relation is used for this operator:

$$\mathrm{child} = \left(\frac{\mathrm{parent} + \frac{1}{n}\sum_{i=1}^{n}\mathrm{parent}_i}{2}\right)$$

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