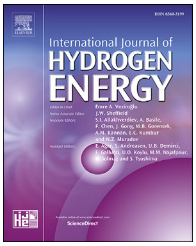
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–24

Available online at www.sciencedirect.com

ScienceDirect

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



Modelling and simulation of Proton Exchange Membrane fuel cell with serpentine bipolar plate using MATLAB

Tabbi Wilberforce [a], *Zaki El-Hassan* [a,*], *F.N. Khatib* [a], *Ahmed Al Makky* [a], *Ahmad Baroutaji* [b], *James G. Carton* [c], *James Thompson* [a], *Abdul G. Olabi* [a]

[a] *Institute of Engineering and Energy Technologies, University of the West of Scotland, UK*
[b] *School of Engineering, Faculty of Science and Engineering, University of Wolverhampton, UK*
[c] *School of Mechanical & Manufacturing Engineering, Dublin City University, Dublin, Ireland*

ARTICLE INFO

Article history:
Received 1 February 2017
Received in revised form
2 June 2017
Accepted 9 June 2017
Available online xxx

Keywords:
PEM fuel cell
MATLAB
Polarization curve
Voltage
Current

ABSTRACT

This report presents experimental results derived from a Proton Exchange Membrane fuel cell with a serpentine flow plate design. The investigation seeks to explore the effects of some parameters like cell operational temperature, humidification and atmospheric pressure on the general performance and efficiency of PEM fuel cell using MATLAB. A number of codes were written to generate the polarization curve for a single stack and five (5) cell stack fuel cell at various operating conditions. Detailed information of hydrogen and oxygen consumption and the effect they have on the fuel cell performance were critically analysed. The investigation concluded that the open circuit voltage generated was less than the theoretical voltage predicted in the literature. It was also noticed that an increase in current or current density reduced the voltage derived from the fuel cell stack. The experiment also clearly confirmed that when more current is being drawn from the fuel cell, more water will also be generated at the cathode section of the cell hence the need for an effective water management to improve the performance of the fuel cell. Other parameters like the stack efficiency and power density were also analysed using the experimental results obtained.

Introduction

Energy is the backbone of any modern society. It forms the hub that determines the survival of all living creatures [1]. Fossil fuel has powered the economies of the developed world since the industrial revolution [2]. This in effect has led to elevated levels of prosperity and the general welfare of human society on earth. The high depletion of petroleum based energy resources and the environmental pollution and climate change caused by the burning of fossil fuel has raised many concerns for the need to look for alternatives to generate energy for society. A fuel cell is an electro-chemical power source that transforms chemical energy in fuel, directly into electrical energy. However unlike most electrical power sources like the batteries which store their reactants within a cell, the reactants of the fuel cell are normally stored

---

* Corresponding author.
E-mail address: zaki.el-hassan@uws.ac.uk (Z. El-Hassan).

http://dx.doi.org/10.1016/j.ijhydene.2017.06.091
0360-3199/© 2017 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Please cite this article in press as: Wilberforce T, et al., Modelling and simulation of Proton Exchange Membrane fuel cell with serpentine bipolar plate using MATLAB, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.06.091

externally. The electrodes in a fuel cell are not consumed as in battery -irreversibly in a primary cell and reversibly in a secondary cell- and do not take part in the reaction. Fuel cells are already in use to produce electricity for small portable applications, and more recently being used for stationary applications such as emergency power generators [1–3].

A fuel cell is made up of negatively charged electrode (Anode), a positively charged electrode (Cathode) and an electrolyte membrane [4]. Protons are carried from the anode to the cathode through the electrolytic membrane and the electrons are carried to the cathode over an external circuit. In real life situations, it is impossible for molecules to stay in an ionic state hence they merge with other molecules in order to return to the neutral state. Hydrogen protons found in the fuel cells often stay in the ionic state by travelling from molecule to molecule and diffusing through the membrane. The PEM Fuel cells depicted in Fig. 1 function through the principle of an electrochemical reaction between hydrogen and oxygen in the presence of a platinum catalyst. Reactive gases are carried through the fuel cell through the anode and the cathode. The anode serves as the path where the hydrogen travels through to the reactive site. The hydrogen on the anode eventually converges on the membrane electrode assembly (MEA) which has the platinum catalyst deposited on it. The hydrogen is split into a proton and an electron at the anode [2], the cathode serves as the collective site where the electrons that could not pass through the MEA eventually meet to form water. MEA is only permeable to protons and not to electrons. The electrons that failed to pass through the MEA then pass through an external circuit producing the current [3].

In order for a fuel cell to produce electricity effectively and efficiently, the cell must be supplied continuously with the fuel and oxidant [4]. The product water must be well controlled and removed as it build up tends to reduce the efficiency of the fuel cell.

There are several losses that are experienced during the process. These are activation losses, ohmic losses and mass transport losses. Mass transport is defined as the flow of species and this have negative effect on the performance of the fuel cell [5–7]. Losses caused by mass transport are called concentration losses. The electrolyte layer is also another important region of the fuel cell. The electrolyte layer is essential for a fuel cell to work properly. In PEM fuel cells (PEMFCs), the fuel travels to the catalyst layer and is then split into protons (H^+) and electrons. Electricity is generated as long as the electrons flow through the load [8]. The membrane found in a fuel cell must also meet these requirements: high ionic conductivity, present an adequate barrier to the reactants, be chemically and mechanically stable, low electronic conductivity, ease of manufacturability/availability and preferably of low cost.

Mathematical modelling for PEMFC

The model developed intends to explain the fundamental electrochemical transport characteristics and charge transfer that usually occurs in the fuel cell. These mathematical models can best be used to describe the phenomenon occurring in the fuel cell, predict the fuel cell performance under different operating conditions and optimize the design of the fuel cell. The results obtained mathematically were compared to the experimental results.

Thermodynamic performance of the fuel cell

The anodic reaction leads to the hydrogen gas breaking into protons and electrons. The electrochemical reaction takes place on the catalyst layer that is made of platinum as shown in equation (1) [9].

$$2H_{2(g)} \rightarrow 4H^+ + 4e^- \quad (1)$$

The released electrons are not permeable to the proton exchange membrane hence only the protons are able to go through the membrane whiles the electrons go through an external load where electrical work is done and then flow back to the cathode. The protons or hydrogen ions move to the cathode section of the fuel cell where it meets the oxygen and the electrons from the external circuit forming water from equation (2).

$$4H^+ + 4e^- + O_2 \rightarrow 2H_2O_{(l)} \quad (2)$$

The entire chemical reaction can be summarised in Eq. (3):

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)} \quad (3)$$

The overall reaction in Eq. (3) could be likened to combustion with hydrogen being the reacting fuel. Combustion is considered as an exothermic process hence there is significant

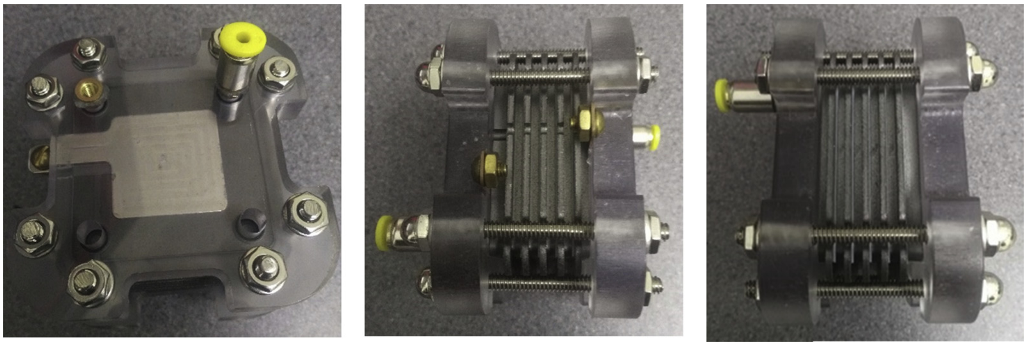


Fig. 1 – Serpentine PEM fuel cell with 11.56 cm² active area.

Please cite this article in press as: Wilberforce T, et al., Modelling and simulation of Proton Exchange Membrane fuel cell with serpentine bipolar plate using MATLAB, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.06.091