Energy 51 (2013) 457–461

Contents lists available at SciVerse ScienceDirect

Energy

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

A passive method of water management for an air-breathing proton exchange membrane fuel cell

P. Manoj Kumar*, V. Parthasarathy

PSG Institute of Advanced Studies, Coimbatore, India

ARTICLE INFO

Article history:
Received 6 October 2012
Received in revised form
9 December 2012
Accepted 17 December 2012
Available online 16 January 2013

Keywords:
PEM fuel cell
Air-breathing
Experimental
Water management
Performance

ABSTRACT

Water management in an AB-PEMFC (air-breathing proton exchange membrane fuel cell) poses a big challenge due to its passive operation. The issue is addressed in a passive way by designing the fuel cell with low thermal conductivity materials. Use of low thermal conductivity materials for cell fabrication led to higher cell temperatures. The liquid water formation was delayed to high current densities due to increase in saturation pressure and higher buoyancy induced flow. Peak power density was increased by 36% and the limiting current density was increased by 37.5% when the cell was redesigned with low thermal conductivity materials. Fabricating the cells with low thermal conductivity materials can be very effective method of water management for air-breathing single PEM (proton exchange membrane) fuel cells and stacks of low capacity.

1. Introduction

Air breathing PEM fuel cell (AB-PEMFC) use natural convection air flow for the supply of oxygen to the cathode and forced convection supply of hydrogen to the anode. Natural convection flow and diffusion are the primary transport mechanism for delivering oxygen to the cathode of air breathing fuel cell. Water and thermal management of PEM fuel cells is a challenge due to its low temperature operation. Ongoing research includes in-situ visualization of water formation, in-situ temperature distribution measurement, active and passive ways of water and thermal management during the fuel cell operation. Carton et al. [1] computationally studied the slug formation and droplet accumulation in PEM fuel cell mini-channels. They also conducted ex situ visualization of the same to compare their computational data. Su et al. [2] developed three dimensional CFD (computational fluid dynamics) fuel cell model to study the effect of operating conditions on high temperature PEM fuel cell performance. Huang et al. [3] developed a three dimensional, two phase, non-isothermal model to study the interaction between heat and water transport in proton exchange membrane fuel cells. Their modeling results show that providing a linear porosity gradient in the gas diffusion layer enhances the capillary diffusivity, increases the electrical conductivity and improves oxygen transport and hence the overall cell performance. Hassan et al. [4] successfully prevented 'flooding' by saturating the hydrogen feed and using dry air at the cathode. Flow channel design procedure based on pressure drop determination was suggested by Li et al. [5] for avoiding liquid water formation.

Due to passive operation of air-breathing fuel cell the water and thermal management poses a big challenge. The hydrogen flow rate is the only operating parameter that can be actively controlled in an air-breathing PEM fuel cell. With increase in anode gas flow rate the back diffusion of water from cathode to anode improves and hence flooding on the cathode side can be controlled to an extent. Schmitz et al. [6] conducted studies on planar air-breathing PEM fuel cells made of printed circuit boards and found that the water removed from the anode side of the fuel cell was found to be less than 30% of the total water produced. Optimum cell temperature of 60 °C was reported by Fabian et al. [7]. They experimentally studied the effect of ambient conditions on the performance of air-breathing PEM fuel cell and identified three regions of operation characterized by increasing current density: partial membrane hydration, full membrane hydration and membrane dry-out. They observed that the membrane transition from fully hydrated state to dry-out regime occurs at a GDL (Gas Diffusion Layer) temperature of approximately 60 °C, irrespective of the ambient temperature and humidity conditions. Himanen et al. [8] operated the free-breathing fuel cell at dead end mode. Studies were conducted at different hydrogen pressures, humidity and frequency of opening of purge valve. Their experimental results show that the cell could be

* Corresponding author. Tel.: +91 422 4344 000; fax: +91 422 2573 833..
E-mail address: manojpanthalingal@gmail.com (P. Manoj Kumar).

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http://dx.doi.org/10.1016/j.energy.2012.12.015

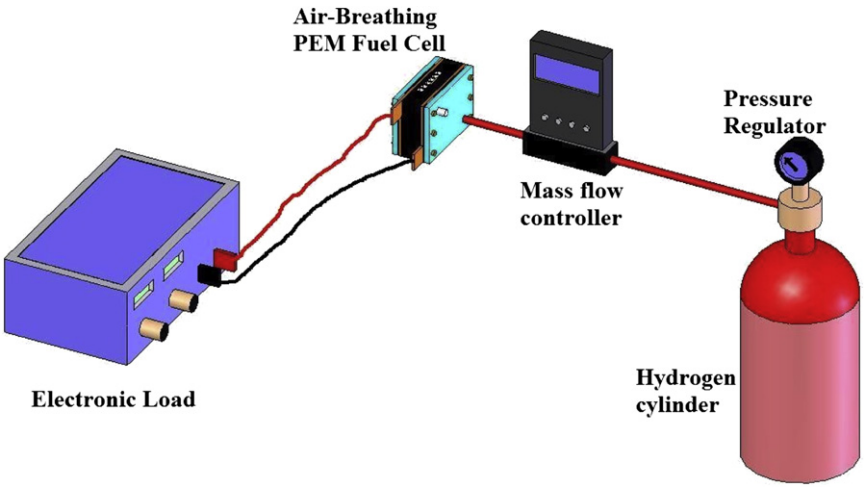
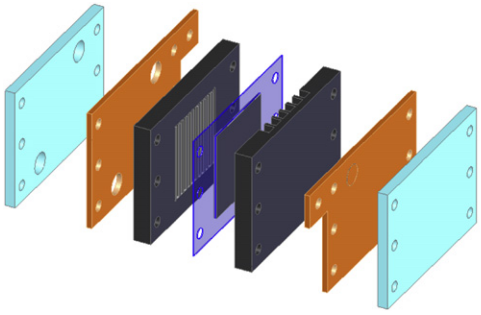


Fig. 1. Schematic of the experimental setup.



Design 1
Aluminium End Plate
Silver coated copper current collector
Graphite anode flow field plate
Membrane Electrode Assembly
Graphite cathode flow field plate
Silver coated copper current collector
Aluminium End Plate

Fig. 2. Exploded view of air-breathing fuel cell.

operated at dead end mode, making high utilization rates possible. Paquin and Frechette [9] developed a simple one dimensional model and did experiments to understand the phenomena of flooding and membrane dry-out in air-breathing fuel cell. According to them the ratio of thermal and mass transport resistance is the critical aspect for water management in air-breathing fuel cell. High ratio of this resistance leads to dry-out of the membrane and low ratio of this resistance leads to flooding of the cell. Ous and Arcoumanis [10] developed an optical setup to observe the water droplet formation on the surface of the GDL at various operating conditions. Air and hydrogen stoichiometry affected the droplet aggregation inside the channels but had no effect on the water removal from the channel. They reported that change in operating temperature is the most effective water removal mechanism in an air-breathing fuel cell. Fabian et al. [11] used an integrated porous, hydrophilic, electrically conductive layer coupled to an electro-osmotic pump for active removal of water from the cathode side of the fuel cell. The electro-osmotic pump consumed only 2% of the power output from the fuel cell. Fabian et al. [12] passively addressed the issue of flooding by using a porous wick that could collect and redistribute water across the entire cathode.

In the present study, the issue of water management is addressed in a passive way by redesigning the fuel cell with low thermal conductivity material like acrylic.

2. Experimental setup and procedure

The schematic of the experimental setup is shown in Fig. 1. Compressed hydrogen stored in a cylinder at a pressure of 150 bar is used to supply the reactant to the anode side of the fuel cell. A pressure regulator is used to reduce the pressure of hydrogen gas from cylinder pressure to the required supply pressure of 1 bar. Dry hydrogen was directly supplied to the anode side of the fuel cell without any humidification. Mass flow controller from ALICAT SCIENTIFIC INC., USA (Model No.: MC-10SLPM-D) is used for controlling the mass flow of hydrogen from the cylinder to the fuel cell. A DC electronic load bank (KPAS, India) is used to vary the load on the fuel cell. Oxygen is not supplied from any external sources. Oxygen supply to the cathode of the fuel cell happens by natural convection flow of the air on the cathode side due to the temperature and concentration gradients that exist along the height of the fuel cell.

MEA (Membrane Electrode Assembly): The MEA used for the experimental study was imported from Lynntech Inc., Texas, USA.

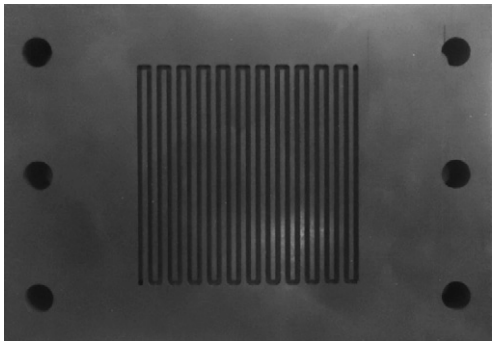


Fig. 3. Anode flow field machined on graphite plate.