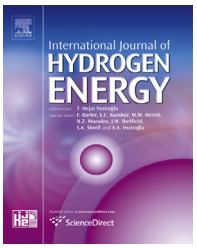
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2016) 1–10

Available online at www.sciencedirect.com

ScienceDirect

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



Simple and functional direct methanol fuel cell stack designs for application in portable and auxiliary power units

O. Barbera [a,*], A. Stassi [a], D. Sebastian [a], J.L. Bonde [b], G. Giacoppo [a], C. D'Urso [a], V. Baglio [a], A.S. Aricò [a]

[a] CNR – ITAE, National Research Council of Italy, Institute for Advanced Energy Technologies, Via Salita S. Lucia sopra contesse, 598126 Messina, Italy

[b] IRD Fuel Cells A/S, Kullinggade 31, DK-5700 Svendborg, Denmark

ARTICLE INFO

Article history:
Received 5 November 2015
Received in revised form
3 May 2016
Accepted 14 May 2016
Available online xxx

Keywords:
Direct methanol fuel cell
DMFC
Stack design
Portable application
APU systems
Air breathing

ABSTRACT

Simple and functional stack designs were developed for direct methanol fuel cells (DMFCs) with the aim of reducing capital costs. A simplified planar and monopolar ministack, with a reduced number of components, was designed for portable applications. This planar design facilitated the manufacturing of a compact passive mode operation ministack. The ministack provided an output power of 1.30 W under air breathing mode operation, at room pressure and temperature without any auxiliary. For application in auxiliary power units (APU), a self-heating and modular bipolar stack, operating up to 90 °C without internal cooling, was designed. Bipolar stacks consisted of 5–10 cells (100 cm^2 active area), providing an output power of 90–180 W. The recirculated methanol solution was used as thermostating fluid. The stacks achieved a normalised power density per cell of 180 mW cm^{-2}. Whereas, for the passive mode operation, ministack approached 30 mW cm^{-2} with 5 M methanol feed. These results favourably compare with the best performance reported in the literature for DMFCs operating under similar conditions.

Introduction

Direct Methanol Fuel Cells have received worldwide attention because of several intrinsic advantages, such as simplicity of operation, high theoretical energy density, easy refuelling. DMFCs can be simpler in construction than proton exchange membrane fuel cells (PEMFCs), and do not need pressurised hydrogen gas storage, delivery or processing. Additional simplification in DMFCs includes air breathing operation for low power application [1–9] However, the sluggish electro-oxidation kinetics and high cross-over rate of methanol are the main factors that have hindered the commercialization of DMFCs.

In recent years, technology developments have promoted interest around DMFC applications in small portable power devices and APU systems [2]. Both small power, fast recharging, portable devices and hundred-watt-class DMFC systems, designed to supply power for medium-size electrical applications, have been developed [2]. High durability for DMFC systems has been recently demonstrated using dynamic load

* *Correspondiong author.*
E-mail address: orazio.barbera@itae.cnr.it (O. Barbera).

http://dx.doi.org/10.1016/j.ijhydene.2016.05.135

profiles [10]. Portable power devices with high energy density and easy recharging are becoming important for many electronic devices, such as notebook computers, power tools and cellular phones.

Advances in the development of portable fuel cells should have a large impact on the development of modern electronic devices [1–9]. If for portable application there are some limits in terms of operating temperature range, for auxiliary power units (APU) systems, the high temperature operation approach appears more appropriate being methanol oxidation a sluggish process [11–15].

The stack designs for portable and APU applications are different both in terms of architecture and operating conditions. According to these premises, the power output and the DMFC system around the stack can be quite different for portable operating conditions and APU applications. The aim of this work was to develop simple and functional designs for two different configurations of DMFC stacks i.e. monopolar and bipolar types [12]. The monopolar configuration, in combination with a passive mode ambient operation, can be addressed to portable applications whereas the bipolar configuration operating at relatively high temperatures is selected for APU applications.

The developed stacks were characterized by simplicity of design, as needed to reduce capital costs. The devices provided excellent performance for the specific application. The monopolar stack was assembled by placing electrodes of the same polarity on the same side of the solid electrolyte (membrane) and then electrically connecting the anodes and cathodes in series [3–6]. The bipolar design, consisted of a number of repeating units of membrane-electrode assemblies (MEA) and bipolar plates [14–27]. In general, large size fuel cell stacks are characterised by thermal management issues [11]. These are generally addressed using liquid fluid-fed cooling cells, which are allocated between the electrochemical cells inside the stack. Air cooled cells can represent another option. In the present work, our approach regarded the use of a methanol solution recirculated through the anode compartment as cooling fluid. The bipolar plates contained also internal flow fields to facilitate air exchange through natural convection. In general, this approach allows the use of an easy cell sealing concept and favours a balance-of-plant simplification thus avoiding additional thermal managing systems.

Experimental

The direct methanol fuel cell mini-stack consisted of two main housings (strings) composed of 5 cells connected in series; the housings were connected in parallel. The single cell area was 4.85 cm^2. The operating conditions were: ambient pressure and temperature, air breathing, and methanol diffusion by natural convection. Two methanol concentrations were selected (1 M and 5 M) corresponding to operating conditions providing high fuel utilization or high energy density. In this passive, monopolar, DMFC, 5 electrodes were allocated on both sides of the same membrane, forming a 5-cell string. Two printed circuit boards (PCB) were chosen to clamp and support an MEA and to electrically connect the five electrodes by thin gold strips.

The MEAs were prepared by hot-pressing at 130 °C for 3 min and 20 kg cm^{-2}. The electrodes consisted of carbon cloth backings, diffusion and catalytic layers. An unsupported PtRu catalyst was employed at the anode; it was mixed with 15 wt% Nafion ionomer (Ion Power, 5 wt% solution) and deposited by a doctor blade technique onto a gas diffusion layer (0.36 mm in thickness). Whereas, an unsupported Pt catalyst was utilized for cathode fabrication; the catalyst was mixed with 15 wt% Nafion ionomer (Ion Power, Nafion solution) and deposited by a doctor blade onto gas diffusion layers (0.28 mm in thickness). A Nafion 115 membrane was used as the electrolyte [5,28–30].

Polarization curves for the ministack were obtained using a Potentiostat-Galvanostat AUTOLAB PGSTAT302. The monopolar stack was connected to an AUTOLAB electrochemical apparatus, and then the methanol reservoir was filled with 30 cc of 1 M or 5 M methanol solution with the cathode side exposed to the ambient atmosphere. By imposing a discharging current density, ranging from 0 to 140 mA cm^{-2} with a step of 10 mA cm^{-2}, the corresponding stack potential was recorded. Chrono-potentiometric discharge curves for the DMFC ministack were registered at the constant current of 0.6 A.

A direct methanol fuel cell stack based on a bipolar configuration, was instead developed for APU applications. It was operated with a gradient pressure between the cathode and anode compartments. The anode was fed with 1 M or 5 M methanol solution. The active electrode area was 100 cm^2. Two bipolar stacks were tested consisting of 5 or 10 cells. The MEA used in the bipolar stack consisted of 5-layers: two anodic and cathodic gas diffusion layers (GDLs) and a catalyst-coated membrane (CCM, three layers). These MEAs had the following characteristics: (i) Nafion 115 membrane, (ii) (1:1) PtRu/C 1.8 mg cm^{-2} (anode catalyst loading) and Pt/C 1.2 mg cm^{-2} (cathode catalyst loading), (iii) SGL35DC GDL. A thermocouple was allocated inside a cooling channel in the center of the stack, facing the cathodic side, in close contact with the composite graphite plate. This was used as reference for the internal temperature.

Tests were carried out by connecting the fuel cell stack to a Hydrogenics fuel cell test station. Polarisation curves were acquired by increasing the current in steps from 0 to 50 A and recording the corresponding potential. Chrono-potentiometric curves for the DMFC bipolar stack were registered at a constant current of 30 A. The methanol cross-over rate was determined using a conventional DMFC cell [2], operating under conditions similar to those of the stack here investigated. Methanol permeated through the membrane and oxidised to CO_2 at the cathode was determined using gas-chromatographic analysis (Varian CP-2003-QUAD micro GC).

Results and discussion

Methodology: ministack design and assembling for portable applications

The DMFC ministack was designed for operation at ambient pressure and temperature, under air breathing and using methanol diffusion by natural convection. However, since

Please cite this article in press as: Barbera O, et al., Simple and functional direct methanol fuel cell stack designs for application in portable and auxiliary power units, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.05.135