INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 7659–7665

Available online at www.sciencedirect.com

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

Development of simple diagnostic tool for proton exchange membrane fuel cell using reference electrodes in sub cells in series

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ARTICLE INFO

Article history:
Received 17 September 2015
Received in revised form
10 March 2016
Accepted 18 March 2016
Available online 12 April 2016

Keywords:
PEMFC diagnostics
Sub cells
Reversible hydrogen electrode
Water flooding
Impedance spectroscopy

ABSTRACT

Investigation focuses on development of proton exchange membrane fuel cell (PEMFC) diagnostics in a simple fashion compared to earlier studies to investigate entrance and exit effects in the presence of bends in a single channel PEMFC. For this purpose, membrane electrode assemblies (MEAs) with reversible hydrogen electrodes (RHE) were placed in a series of sub cells and current–voltage (i-V) characteristics and electrochemical impedance spectroscopy (EIS) data were collected for anode and cathode separately. By comparing i-V characteristics and EIS data between different sub cells, a dip in i-V curve was found to follow cathode polarization loss from sub cell 1 to 5. The increase in charge transfer resistance at the cathode and dip in i-V curve attributed to product water accumulation in subsequent sub cells. However, no dip in i-V characteristics and increase in cathode charge transfer resistance was observed when single sub cells operated at different locations, i.e., close to entry and exit and middle of the channel. Further, in sub cell 5, accumulation of product water at the cathode and in the exit bend leads to drastic reduction in the limiting current density due to high concentration over-potential. This observation was supported by high charge transfer resistance of the cathode in sub cell 5 when all the sub cells are in operation compared to when sub cell 5 operated alone. Based on the above premises and i-V characteristics combined with EIS data of sub cells, a simple PEMFC diagnostics may be developed.

Introduction

Proton exchange membrane fuel cell (PEMFC) commercialization [1,2] is limited by issues like membrane electrode assembly (MEA) degradation, high cost of platinum as a catalyst for ORR and HOR, stability and durability of newly developed non-platinum catalysts [3,4]. Out of these, degradation and mitigation of MEA have been one of the prime focus of research during the recent years. The reason behind the performance loss due to degradation are found out to be water accumulation, membrane drying [5], catalyst poisoning [6,7].

There are initiatives like development of fuel cell diagnostics through current mapping which is carried out to monitor the performance of the fuel cell continuously. One of the early technique developed for this is printed circuit board

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http://dx.doi.org/10.1016/j.ijhydene.2016.03.129

(PCB) approach in which the anode and cathode channels are embedded in PCB along with the current collection leads [8,9]. The drawback of PCB is that it has to be modified every time for different channel designs. Another technique is the segmented cell approach in which segmented MEAs are placed along the channel at equal distance instead of a large single MEA [10]. Using these techniques, current mapping, variation in OCV are examined from the entrance to the exit of the channel. These techniques can be further used to observe the changes occurring inside the cell due to the degradation stated above and detection of signature in current–voltage characteristics and corresponding electrochemical impedance spectroscope (EIS) data.

To further investigate the contribution of the anode and cathode electrodes towards the cell performance, studies have been done by incorporating reference electrodes into the respective electrodes [11,12]. Dynamic hydrogen electrode (DHE) and reversible hydrogen electrode (RHE) are the most commonly used reference electrode. In an RHE, a single platinum wire is placed on membrane electrolyte which is exposed to hydrogen gas and, in case of DHE, two platinum wires are placed on the membrane electrolyte and small load is applied on the two wires which forces one of the wire to act as RHE. The drawback of using DHE is that a small load has to be applied separately to the two Pt wires thus increasing the complexity of implementation in case of real time monitoring. The positioning of the reference electrode especially in equipotential area, is key to the success of measuring the anode and cathode polarization separately [13–15]. Apart from experimental studies, simulations are carried out to prove that the reference electrode has to be placed at an equipotential area where the influence of anode and cathode are equal. Further, MEA has to be pressed properly such that the anode and cathode are perfectly aligned with each other [16]. Reference electrode can be placed in two configurations, e.g., in edge configuration, the reference electrode is placed at the edge of the extended portion of the membrane and, in sandwich configuration, the reference electrode is placed in between the two membranes. It is well known that edge configuration reference electrode is superior than sandwich configuration [17]. Using edge configuration reference electrode, the disturbances at the anode or cathode electrodes can be diagnosed accurately. In Protruded Nafion® membrane approach, extruded Nafion® fibre is connected to MEA in one end while other end is dipped inside electrolyte solution outside the fuel cell along with standard hydrogen electrode [18]. The complexity of the protruded Nafion® membrane arrangement increases due to number of junctions created, such as, Nafion® membrane and the liquid electrolyte, the liquid electrolyte and the reference electrode, resulting major voltage losses and anomaly in cell diagnosis. Thus, it is imperative that a simple diagnostic tool needs to be developed which may be implemented easily in the case of fuel cell stack during real time operation.

Normally in PEMFC, hydrogen fuel and oxidant is delivered through bipolar plate having engraved serpentine, parallel and interdigitated designs. In each of the flow channel design several bends are encountered due to which flow becomes restricted and may lead to starvation of fuel and oxidant. Further in the cathode side water may be accumulated leading to increase in pressure drop and oxygen unavailability, which may drastically decrease the cell performance [19–21]. In literature, visual analysis of water buildup is carried out combined with the current–voltage analysis for fuel cell, but incorporating a RHE into the cell for a detailed analysis is rare. Further in commercial PEMFC it is difficult to carry out visual observation. The present technique developed would provide useful information of the anode and cathode polarization loss and the electrolyte condition (dry and high ohmic resistance) separately, while actual operation of a fuel cell is going on.

In this work, we have investigated the performance of a single channel PEMFC due to bends at the entrance and exit of the channel using sub cell approach. We placed MEAs as sub cells at equal distance along a channel to evaluate the polarization loss contribution of anode and cathode at each sub cells. An arrangement of RHE is incorporated into the cell design primarily following edge configuration. The polarization loss contributions and EIS of anode and cathode of five sub cells are compared with that of individual sub cell to understand the effect of bend in the entrance and exit of the channel and the influence of adjacent sub cells on water accumulation. In new cell design each sub cell is provided with a RHE, as it would help in understanding the behavior of the sub cell in terms of anode, cathode and electrolyte contribution towards different polarization losses at different location of the cell. Further, the signature obtained in current–voltage characteristics coupled with EIS data may be used in micro fuel cell and real scale PEMFC to carry out on broad fuel cell diagnosis.

Experimental

Fig. 1 shows the schematic of single channel PEMFC along with sub cell configuration used in the work. The anode and

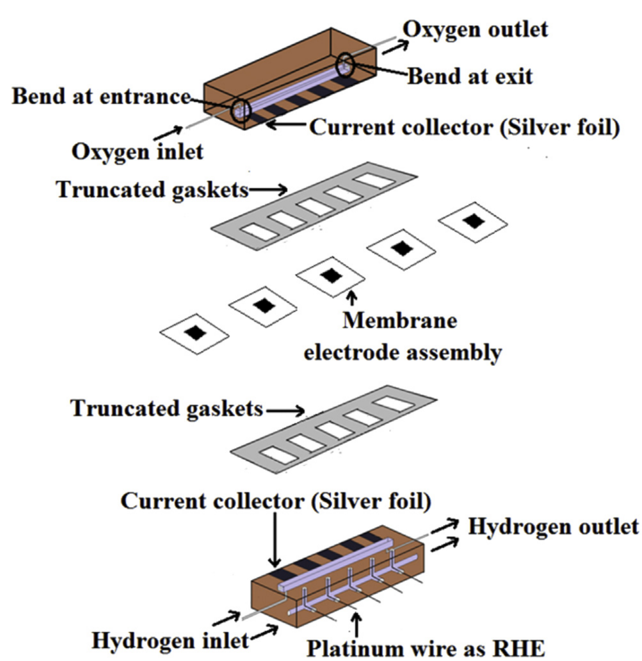

Fig. 1 – Schematic of PEMFC sub cell assembly with reference electrode.