Journal of Power Sources 260 (2014) 243–250

Contents lists available at ScienceDirect

Journal of Power Sources

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

Experimental investigation of dry feed operation in a polymer electrolyte membrane fuel cell

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HIGHLIGHTS

- Product water is used to hydrate the polymer electrolyte membrane.
- Non-uniform under-rib convection in the mixed distributor aids to retain water.
- Voltage depends on operating temperature and stoichiometry in co-flow mode.
- Voltage independent of operating temperature and stoichiometry in counter-flow mode.
- Horizontal orientation of the flow field is ideal for self-humidified operation.

ARTICLE INFO

Article history:
Received 12 January 2014
Received in revised form
26 February 2014
Accepted 1 March 2014
Available online 12 March 2014

Keywords:
Polymer electrolyte membrane fuel cell
Water management
Self-humidification
Under-rib convection

ABSTRACT

The possibility of achieving self-humidified operation of a polymer electrolyte membrane fuel cell, without any major modifications to the conventional fuel cell design, is investigated experimentally. The flow distributor is designed such that the non-uniform under-rib convection aids to retain product water in the fuel cell enabling a dry feed operation. The fuel cell is operated in a pseudo co-flow and pseudo counter flow modes at a constant current density and the transient change in voltage and temperature are recorded. In the pseudo co-flow mode, the voltage drops at higher temperature and reactant stoichiometries which is attributed to membrane dehydration at the inlet region of the cell. In the pseudo counter-flow mode, the voltage remains same at both low and high temperature operation and is found to be independent of reactant stoichiometry. A horizontal orientation of the flow field, in pseudo counter flow mode, is found to be ideal for self-humidified operation at low reactant stoichiometries and cell temperature.

1. Introduction

Water management is one of the important challenges that needs to be addressed to make polymer electrolyte membrane (PEM) fuel cells a commercially viable product. In water management, the supply, generation and removal of water is balanced in such a way that the electrolyte membrane is always well hydrated. The proton conductivity of the electrolyte membrane increases with the water content in it [1], and thus ensuring a well hydrated membrane is essential to get maximum performance from the fuel cell [2,3].

Conventionally, external humidification systems are provided to humidify the reactant gases before entering the cell so that sufficient water is available to hydrate the membrane. In self-humidification approach, the water generated in the fuel cell itself is used to humidify the reactants and hydrate the membrane. Excess water, if not removed effectively, will hinder reactant transport through the gas diffusion layer and will also reduce the active area available for reaction [4]. Hence, the reactant flow is maintained at a sufficiently high rate to flush out the excess water.

Self-humidification eliminates the complexity, cost, weight and parasitic power loss associated with an external humidification system. Büshi and Srinivasan [5] showed through experiments that with suitable choice of operating conditions self-humidification of PEM fuel cells are possible. The performance of a self-humidified PEM fuel cell depends on the operating temperature, pressure and reactant flow rate as these factors directly affect the amount of water generated and carried away from the fuel cell [6–9]. High operating temperature is critical in deciding the fuel cell performance as it has a negative impact on water retention but favors

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http://dx.doi.org/10.1016/j.jpowsour.2014.03.002
0378-7753/

reaction kinetics. Depending on the level of membrane hydration, multiple steady states of current and voltage can occur at same operating conditions [10]. In another important work, Feindel et al. [11] experimentally observed the formation and distribution of liquid water on cathode side and its effect on the performance of a self-humidified PEM fuel cell.

There are many interesting studies in literature on achieving self-humidification in PEM fuel cells. In one of the earlier works Watanabe et al. [12], proposed using a thin electrolyte membrane impregnated with small amounts of platinum catalyst to benefit from oxidation of cross-over hydrogen and subsequent adsorption of the generated water with a hygroscopic material. A novel method for preparing such self-humidifying membranes is given by Yang et al. [13]. Ge et al. [14] presented an experimental study in which, two strips of wick made of polyvinyl alcohol sponge is mounted to the flow distributor plate to retain product water and humidify the cathode stream.

Tolj et al. [15] achieved internal humidification by employing spatially variable heat removal rates to maintain the relative humidity of cathode stream near the saturated state from cell inlet to outlet. Other important works include using a porous carbon flow field plate on the cathode side to benefit from the capillary distribution of water [16], adding silica to the catalyst layer on the anode side to retain water and humidify the membrane [17,18] and recirculating the cathode exhaust gas to replace the external humidification system [19].

Qi and Kaufman [20] investigated dry feed operation of a PEM fuel cell stack with a double-path-type counter-current flow field. A stable operation of the stack is obtained as the flow arrangement is found to provide better hydration of the membrane and even distribution of reactants. The effect of flow field design, flow field combination and flow direction in a PEM fuel cell stack for portable applications is investigated by Tüber et al. [21]. The experiments showed that a meander flow field with outwards-vectored flow direction exhibits better performance. The effect of flow direction on self-humidification in PEM fuel cells is numerically investigated using a two dimensional, steady state model by Ge and Yi [22]. The simulations showed that a counter flow mode of operation gives high performance and proper humidification as well as better current density distribution with dry or low humidity reactant gases, compared to a co-flow mode of operation.

From the literature it can be seen that most of the works on self-humidification in PEM fuel cells either requires a modification to the materials used or to the system itself. In the present study, self-humidification is achieved by employing a mixed flow distributor, which due to its inherent flow maldistribution and non-uniform under-rib convection, retains product water in the cell. This flow distributor is selected based on our previous computational study on liquid water distribution characteristics of different type of flow distributors [23]. The study showed that a mixed flow distributor exhibits more uniform liquid water distribution from cell inlet to outlet. The objective of the present study is to investigate the possibility of using a mixed flow distributor to achieve self-humidified operation of a conventional PEM fuel cell, without any additional modifications to the system or components.

2. Experimental section

The experiments are conducted on a PEM fuel cell of 25 cm^2 active area. The membrane electrode assembly (Dura-MEA®5Pt5L25) consists of Nafion NR-212 membrane as the electrolyte and Ballard carbon paper (MGL 370) as gas diffusion layer. The catalyst layers has a platinum loading of 0.5 mg cm^{-2} on the cathode side and 0.25 mg cm^{-2} on the anode side. The flow field is machined on graphite plates of 10 mm thickness. The end plates are made of stainless steel, since the low thermal conductivity of the material reduces heat loss to the surroundings.

To regulate the reactant flow rate, a mass flow controller (Aalborg®-GFC17) is used for hydrogen and a rotameter is used for oxygen. The rotameter is used so as to purge the cathode side easily whenever the voltage drops due to liquid water accumulation in the cell. A data acquisition unit (Agilent-34970A) is used to record the transient change in cell voltage and temperature. The temperature of the cell is measured using a J-type thermocouple. The accuracy of voltage measurement is ±80 μV and that of temperature is ±1.1 °C. An electronic load box (K-Pas Instronic Engineers India Private Ltd) is used to apply electrical load to the fuel cell.

2.1. Mixed flow distributor

A schematic of the mixed flow field used in the present study is shown in Fig. 1. The mixed flow distributor exhibits better water distribution characteristics compared to a parallel or serpentine distributor [23]. The distributor is similar to the series-parallel design employed in the self-humidification experiments by Büshi and Srinivasan [5] and Ge et al. [14].

It is well known that in flow distributors used in PEM fuel cells, the pressure difference between adjacent channels induce an under-rib convection or cross flow of reactants through the porous gas diffusion layer. Under-rib convection aids to bring in fresh reactants to the active area below ribs and also flushes out product water from these regions, thus enhancing the performance of the fuel cell [24].

The advantage of a mixed flow distributor is that, the rate of under-rib convection will be different below each rib due to the flow maldistribution in the header. For example, in the present configuration, when flow is getting divided in to three channels from the common header, the third channel ch3 (see Fig. 1) in the flow sector, will receive higher flow rate due to high momentum in $-Y$ direction and channel ch1 will receive less flow rate. This results in a high rate of under-rib convection below rib rb3, and a low rate of under-rib convection below rib rb1. Hence, more water will be removed from region below rb3 whereas water removal will be less in region below rib rb1. Additionally, as under-rib convection is strong at the inlet of the channel and becomes weak towards

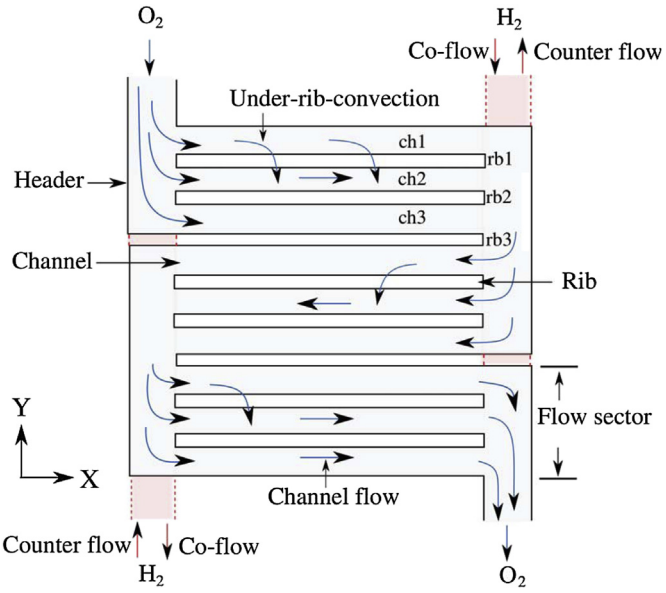

Fig. 1. Schematic of the mixed flow distributor showing the co-flow and counter-flow modes of operation.