Energy Conversion and Management 119 (2016) 60–66

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Mitigation studies of carbon corrosion by optimizing the opening size of the cathode outlet in a proton exchange membrane fuel cell with dead-ended anode

Ben Chen [a,b,1], Jun Wang [a,1], Tianqi Yang [b], Yonghua Cai [b], Mu Pan [a], Zhengkai Tu [a,c,*], Caizhi Zhang [c], Siew Hwa Chan [c], Yi Yu [d]

[a] State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan 430070, China
[b] Hubei Key Laboratory of Advanced Technology for Automotive Components, Wuhan University of Technology, Wuhan 430070, China
[c] Energy Research Institute @ Nanyang Technological University, 50 Nanyang Avenue, 637553 Singapore, Singapore
[d] Research & Advanced Technology Department, SAIC Motor, Shanghai 201804, China

ARTICLE INFO

Article history:
Received 1 January 2016
Received in revised form 5 March 2016
Accepted 12 April 2016
Available online 16 April 2016

Keywords:
Proton exchange membrane fuel cell
Dead-ended
Mitigation
Carbon corrosion

ABSTRACT

Water management is the key issue for the cathode in a proton exchange membrane fuel cell, nearly all the humidified and generated water is flow out of the fuel cell through the outlet of the cathode. Cathode flooding can lead to dramatic performance decay and irrecoverable material degradation in fuel cell. Therefore, optimization design at the cathode outlet is a significant technical challenge for the performance and lifetime enhancement for fuel cell. To address this problem, this study optimized the opening size at cathode outlet of the fuel cell that operates under dead-ended anode mode. The designed cells were continuously operated for 100 h under dead-ended anode mode and the effect of opening size in cathode outlet on cell performance has been investigated. It was found that, with the increase in opening size at cathode outlet, the flooding electrode and the consequent carbon corrosion in catalyst layer can be substantially suppressed.

1. Introduction

Fuel cells are of great advantageous compared to traditional power generation systems due to their high power density, great energy conversion efficiency and reliability, eco-friendly nature, quiet operation, and wide range of applicability [1]. Among different types of fuel cells developed, proton exchange membrane fuel cell (PEMFC) using hydrogen as a fuel has attracted particular attention as promising power sources for transportation applications, portable devices as well as stationary applications because PEMFC exhibits additional advantages including high specific energy density, low operation temperature, fast start-up, and great durability [2]. However, one critical requirement for PEMFC is to maintain proper hydration of the membrane electrode assembly (MEA) to ensure reasonable ionic conductivity. Thus, water management is a central issue in design and optimization of PEMFC. Excessive liquid water may block the gas transport pores in the catalyst or gas diffusion layers (GDL), leading to fuel starvation and serious carbon corrosion [3]. In PEMFC, nanoscale Pt particles are usually distributed on carbon-based supporting materials to obtain maximum utilization efficiency. However, the carbon support itself is thermodynamically unstable due to its low equilibrium potential of 0.207 V with respect to the reversible hydrogen electrode (RHE) at 25 °C, and it is easily oxidized by water vapor during the operation. The mechanism of carbon corrosion can be expressed as [4]:

$$C + 2H_2O \rightleftarrows CO_2 + 4H^+ + 4e^- \quad U^{eq} = 0.207\ \text{V vs. RHE, } 25\ ^\circ\text{C} \quad (1)$$

Carbon loss phenomena under ordinary fuel cell operation conditions are less severe than start-up and starvation, but they are large enough to affect the cell performance after a long-time operation. The minimum operational life required for transportation application is 5000 h, and the rate of carbon loss may be 1–10 wt % per 1000 h, large enough to cause the decay of PEMFC performance after a long-term operation [5]. One can no longer neglect

* Corresponding author at: State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan 430070, China.
E-mail address: tzklq@whut.edu.cn (Z. Tu).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.enconman.2016.04.043
0196-8904/

the carbon oxidation during ordinary PEMFC operation. In addition, carbon corrosion can also be induced by water flooding. Cathode water flooding can lead to oxidant starvation, thus carbon corrosion occurred to meet the demand of protons in the cathode [6]. Water flooding also can be found in anode especially in dead-ended mode. Oxygen can permeate into the anode from the cathode and form hydrogen–oxygen boundary when the anode is flooding [7], resulting in high interfacial potential (1.5 V_{RHE}), leading to water electrolysis [8] and carbon corrosion in the cathode [9]. Moreover, anode flooding can also lead to anode carbon corrosion, the oxidation reaction of carbon supports predominated over the hydrogen oxidation reaction at the anode due to the abnormally increased electrode potential when hydrogen is not sufficiently supplied [10]. Consequently, water management is an effective way to mitigate the carbon corrosion behavior in PEMFC. Park et al. [11] developed a novel parallel flow field with external two-valve regulation on the cathode, which could induce cross flow across the land areas and maintain a good water removal from flow channels. Compared with the regular flow field, the fuel cell performance reached 10.9% enhancement at peak power density point under this optimization design. Chan and Li [12] investigated in the effect of different structures and propertied on water transfer behavior in the cathode, and they found that the optimized hydrophobic micro-porous structure in the micro-porous layer (MPL) or CCL could pump the liquid water to the gas diffusion layer effectively, which was helpful for the water removal in PEM fuel cells. Kim et al. [13] numerically investigated the droplet dynamics in the cathode gas flow channel of PEMFC. The results showed that the coalescence of two adjacent droplets improved the water removal ability from the fuel cell. Hydrophilic sidewall could absorb the liquid droplets on the upper corner of the channel walls, preventing liquid water from covering the GDL surface, whereas, droplets would accumulate and clog the gas channel when suffering from the hydrophobic sidewall at a low airflow rate. Kandlikar and Gopalan [14] experimentally studied the effect of different trapezoid channel open angles and GDL materials on water droplet dynamics in gas flow channels. The minimum pressure drop and velocity were both obtained for removing the droplet from the channel and GDL surface in this paper. The study clearly pointed out the importance of the channel sidewalls and the channel angle on the water droplet transport characteristics in PEMFC. As a consequence, flow field geometry plays an important role in water distribution of PEMFC.

To date, most research related to the design of flow field concentrated on the flow type or geometry size and even some work related to inlet manifold optimization were conducted to achieve better overall performance of PEMFCs. Perng et al. [15] modified the conventional flow field into three novel gas flows: rectangular obstacles opposite, staggered with the protuberant catalyst layer surface, and narrowed flow channel with ribs opposite or staggered with the protuberant catalyst layer surface. The result demonstrates that the third flow field has the best increasing rate (approximately 8%) in cell performance compared with the conventional flow field. Kuo et al. [16] comparatively investigated PEMFC performance in three flow field patterns: the wave like, trapezoid like and ladder like flow channel with the conventional straight gas flow channel, results show that the new flow fields can bring great enhancement in PEMFC performance. Wang et al. [17] numerically investigated the effect of the channel size on the cell performance of PEM fuel cells with serpentine flow field, they believed that smaller channel size with the advantages of enhancing liquid water removal, and providing more uniform current density distributions in the cell. Tiss et al. [18] improved the performance by introducing partial blocks in the gas channel of PEMFC. Kim and Kim [19] investigated the effect of airflow inlet manifold configuration on the PEMFC performance, the maximum power output increases up to 10.3% by improving airflow inlet manifold. Sung [20] developed a method for designing fuel-cell manifolds to distribute the reactants evenly among the channels within bipolar plates, thus fuel cell performance could be greatly improved.

However, little work has focused on the optimization of the gas outlet. Jacobson and his co-workers [21] investigated the water flooding phenomena in PEMFC with neutron imaging. They found that water mainly accumulated at the cathode outlet during operation of fuel cell, water flooding can lead to dramatic performance decay and irrecoverable material degradation in fuel cell [22]. Our previous study found that fuel cell suffered from water flooding much more serious at the vicinity of cathode outlet than the other regions [23]. Mutzenhardt and his co-worker [24] experimentally investigated in the water distribution and condensation characteristics in a whole fuel cell with Magnetic Resonance Imaging (MRI) method. They also found out that the positions of water condensation and liquid accumulation in the gas channel were mainly close to the gas outlet. Furthermore, our recent work also showed that moisture dehumidification at the cathode outlet could affect the cell performance apparently [25]. Hence, optimization design in the cathode outlet was very important for the enhancement of the PEMFC water management and performance. In this paper, the effect of opening size at cathode outlet on the performance of PEMFC was systematically investigated, particularly, on the electrochemical surface area (ECSA) and corrosion of carbon support in catalyst layer during long-term continuous operation of the designed cell. The results turned out that increasing opening size at cathode outlet can reduce the possibility of electrode flooding because of the reduced resistance of water removal from cathode outlet. Accordingly, the decay of cell performance and the corrosion of carbon support become less serious with the increase in opening size at cathode outlet.

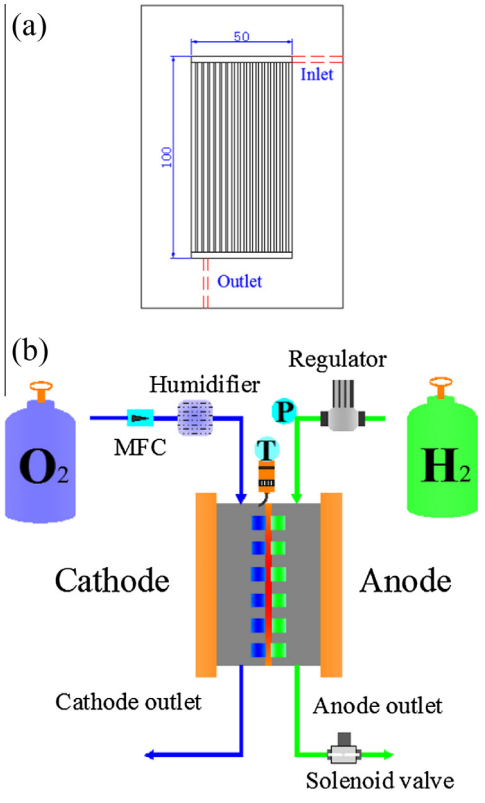

Fig. 1. Schematic diagram of the designed PEMFC used in the experiment: (a) the designed flow field of cathode, (b) schematic diagram of the operation PEMFC with dead-ended anode.