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An experimental study on anode water management in high temperature PEM fuel cell

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ABSTRACT

An investigation into the effect of water in the anodic compartment on the performance of a high-temperature PBI-based PEM fuel cell (HT-PEMFC) has been carried out. This study shows that proper water management is as crucial to HT-PEMFCs as its low temperature (LT-PEMFC) counterpart. Excessive water content strongly affects the performance and stability of HT-PEMFCs. Here, a systemic study on the key parameters of anodic purging pressure, duration and frequency has been carried out in order to understand and propose a proper water management strategy for HT-PEMFCs. The results showed that proper programming of the anode purging process can effectively eliminate the serious water dilution effect in anode (similar to anodic flooding in LT-PEMFCs) and improve both the performance and fuel utilisation.

Introduction

Fuel cells offer high efficiency and scaling flexibility, and are an environmentally friendly solution for electrical power generation [1,2]. High-temperature PEM fuel cells (HT-PEMFCs), in particular, come with several other advantages such as (1) improved electrode kinetics, (2) higher CO tolerance, (3) high quality of heat generated suitable for combined heat and power (CHP) applications and (4) simple balance of plant (BOP) requirement, and are considered as a promising generation of PEM fuel cells for mobile and stationary applications [1,3–5]. To improve the fuel utilisation, fuel cells typically operate at anodic dead-end mode, rather than anodic flow-through mode since the stoichiometry of the fuel in the latter is 1.2 or higher [6,7]. Essentially, the anodic dead-end mode blocks the anode outlet resulting in marginally increased fuel pressure while flow-through mode

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refers to operating the cell normally under the constant ambient pressure. In conventional low-temperature PEM fuel cells (LT-PEMFCs), the anodic flooding phenomenon is a unique problem referring to the accumulation of excessive liquid water at the anode [8–13]. This typically occurs when the PEM fuel cell is operated under anodic dead-end mode due to insufficient water removal. Flooding leads to severe performance degradation due to liquid water filling up the micro pores in the gas diffusion layer (GDL), thereby preventing the reactants from reaching the catalytic reaction sites [14,15]. Purging is an effective way to flush out the water in the flow-field and restoring performance by periodically switching a solenoid valve installed at the outlet of the fuel cell on-and-off [16–19]. Proper management of water within LT-PEMFC enables one to ensure high fuel efficiency [14,20] and to achieve stable performance under long operation [21]. Significant work has been presented in literature to further understand water transport and their association with flooding [22–24], as well as mitigation measures such as the oscillating hydrogen pressure method [16] and optimization of purge cycle [25,26].

HT-PEMFCs operate under dry and high-temperature conditions without relying on water as proton carriers, as opposed to LT-PEMFCs [27]. Furthermore, water exists in HT-PEMFCs in a single vapour phase, thus making it less complex than that in LT-PEMFCs. Lobato et al. [28] studied the effect of anodic humidification on HT-PEMFC performance and observed that the presence of water vapour in anode would improve the cell performance. The water vapour in anode can improve the conductivity of the electrolyte and the solubility of hydrogen in the PBI [29]. Jalani et al. [30] studied the effect of water content in hydrogen on HT-PEMFC performance by varying the dew point of the inlet fuel and observed that excessive water content would reduce the cell performance. Daletou et al. [31] reported that the water vapour is the only gas species to cross the PBI/polysulfone copolymer from cathode to anode, and that the water produced can hydrate the polymer and promote cell performance. Bezmalinovic et al. [32,33] experimentally and mathematically investigated the effects of anodic humidity levels and stoichiometries of dry cathode on the water transport phenomena in HT-PEMFC, and found that water vapour transport from cathode to anode increases with current density, but decreases with cathode stoichiometry. Galbiati et al. [34]studied the water transport from cathode to anode and reported that up to 18% of water produced in the cathode was found in the anode with dry fuel supply. With the increase of humidity level in the feed streams, the partial pressure of hydrogen is reduced, which leads to increased mass transport resistance and reduced performance [28,30]. Therefore, the water management is still a challenge in HT-PEMFCs operating with dead-end mode. However, minimal work has been performed in the area of water management in HT-PEMFCs operating under anodic dead-end conditions. In this study, the water management of a PBI-based HT-PEMFC stack was investigated with dry H_2 supply under anodic dead-end mode. The objective of this paper is to study systemically study the impact on water management on the performance of HT-PEMFC in order to improve both performance and fuel utilisation.

Experimental

Experimental setup

The schematic of a test rig used in this study is shown in Fig. 1. The test rig includes the following components:

- A single HT-PEMFC which is a single cell stack. The MEA (Celtec® P1000)was from BASF Fuel Cell GmbH (Frankfurt, Germany) with an active area of 45 cm^2. The flow-field in graphite plates of anode and cathode are 5-stepserpentine and the geometrical specifications of flow-field are presented in author's pervious study [35].
- A programmable temperature-control oven (Memmert GmbH). It houses the single cell stack for controlling the operating temperature.
- A load bank with a data acquisition. A PLZ-664 WA electronic load, fuel cell impedance meter KFM2150 and its supporting software were used to measure the performance and the ohmic resistance of the HT-PEMFC stack.
- Solenoid valves installed to perform various purging protocol and are programmable by a microcomputer system.

The single cell stack was operated with pure H_2 and air in co-flow configuration. Dry H_2 and dry air were supplied to the cell from two compressed gas cylinders (1, 8) after passing two dryers, respectively. The regulators (2, 7) were used to step down the pressure of compressed gases. The flow rate of air in cathode was controlled by a mass flow controller (6, MFC, Alicat scientific) in flow-through mode. In anode, a regulator (2) was used to maintain the inlet pressure (0.025, 0.05, 0.1 bar) and the outlet of anode purging was controlled by a solenoid valve (5). A mass flow meter (4, MFM, Alicat scientific) located at the inlet of anode to measure the flow rate of H_2.

Investigations on purging parameters

Investigations on purging parameters (operating pressure, purging interval and purging duration) were carried out to analyse their effects on performance of HT-PEMFC. A schematic of a typical purging cycle is shown in Fig. 2. The purging duration refers to the time when the solenoid valve opens.

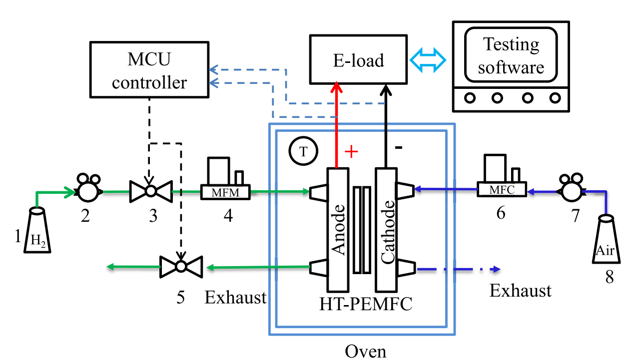

Fig. 1 – Schematic of the test rig.