



Experimental Study of the New Design 2.5kW Dead-End H₂/O₂ PEM Fuel Cell Stack with New Design to Improve Fuel Utilization

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ABSTRACT: Proton exchange membrane fuel cells with a dead-ended anode and cathode achieve high hydrogen and oxygen utilization by a comparatively simple system. In this paper, a new design of proton exchange membrane fuel cell stack is presented. The basic concept of the proposed design is to divide the cells of the stack into several blocks by conducting the outlet gas of each stage to a separator and reentering to the next stage, thereby constructing a multistage anode and cathode. In this design, a higher gaseous flow rate is maintained at the outlet of higher than 85% of cells, even under dead-end conditions, and this results in a reduction of purge-gas emissions by hindering the accumulation of liquid water in the cells. The result shows that the dead-end mode condition has the same performance as an open-end mode. The stack power at the current density of 1200 mA/cm² is 2.5kW and the voltage of all cells is bigger than 0.6V. This means that the stack can achieve to the power higher than 3kW, although all cells voltage is higher than the restriction voltage of 0.4V. Furthermore, the optimum time for opening and closing of purge valve are 2 and 4s for anodic cells and 2 and 6s for cathodic cells.

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1- Introduction

The ratio of hydrogen usage to generate thermal and electrical energy to the total hydrogen which is utilized to supply a fuel-cell is known as the fuel utilization. Therefore, for a 100% fuel utilization (or in dead-end mode), the amount of hydrogen fed into the anode would be the same as the flow rate of hydrogen required for the electrochemical reactions. However, in dead-end operation, there is a high risk of fuel starvation at the outlet of the fuel cell which can result in unstable cell voltages and cell degradation. The major causes of fuel starvation are the accumulation of liquid water at anode and cathode sides [1,2].

Several studies have concentrated on improving the fuel utilization. Nishikawa et al. [3] demonstrated a fuel utilization of 96% for a 5 kW-class Proton Exchange Membrane Fuel Cell (PEMFC) stack that adopted an internal counter-flow humidification and stack separation method; the stack was divided into two blocks in which the exhaust hydrogen gas from the first block was fed into the second one after being separated from liquid water. Yongtaek et al. [4] experimentally studied the characteristics of water transport through the membrane for various values of operating parameters, such as the relative humidity, air stoichiometry, current density, location of humidification, and membrane thickness. They applied the dead-end mode in the PEMFC system to evaluate the water-transport characteristics by observing the performance degradation of the PEMFC and by visualizing the accumulation of water. Kwon et al. [5] developed a flow field design using CFD simulation, experimental test, and in-situ three-channel impedance analysis. They reported that in-situ three-channel impedance analysis successfully predicted the experimental result and explained the performance of

each channel with the heterogeneous stack.

Han et al. [6] proposed a new design for a Polymer Electrolyte Membrane (PEM) fuel-cell stack that can achieve a higher fuel utilization. The basic concept of their proposed design was to divide the anodic cells of a stack into several blocks by inserting compartments between the cells, thereby constructing a multistage anode with a single-stage cathode in a single stack. They designed a 15 kW-class PEMFC stack, fabricated, and tested it to investigate the effectiveness of the proposed design. The experimental results indicated that the amount of purge gas is significantly reduced, and consequently, a higher fuel utilization of higher than 99.6% is achieved. Also, recently Han et al. [7] have developed a cascade-type PEMFC stack and cell components for the propulsion of an underwater vehicle. The stack was designed and fabricated to meet some design requirements such as air-independent operation with hydrogen and pure oxygen, high hydrogen and oxygen utilizations, low hydrogen and oxygen consumptions, a high ramp-up rate, and a long lifetime. They tested and analyzed the basic, load-following, and long-term performances of the cascade-type stack. They obtained a high stack efficiency of higher than 65% at the rated power because of a higher average cell voltage and higher operating pressure.

In this study, a novel cascade type dead-end PEMFC stack with internal manifold was ingeniously designed, fabricated and tested for the first time. In addition, using an innovative implementation led to the division of anodic and cathodic cells of the stack into two stages to achieve higher stoichiometry for the first stage while the stoichiometry of the stack was one. After activation of the stack, the basic performances such as the polarization curve, power generation, hydrogen and oxygen utilization, and hydrogen and oxygen consumptions were evaluated meticulously.

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2- New Stack Design

Fig. 1 shows the schematic diagram of the proposed design for a PEM fuel-cell stack without any hydrogen and oxygen recirculation devices. Liquid separators were used to remove liquid water from the exiting hydrogen and oxygen of each stage. The total number of cells is 14. The first 12 cells included the first stage of hydrogen while the remaining cells are considered for the second one. The second 12 cells included the first stage of oxygen. The stoichiometry values for the first and second stages were 1.17 and approximately 1, respectively.

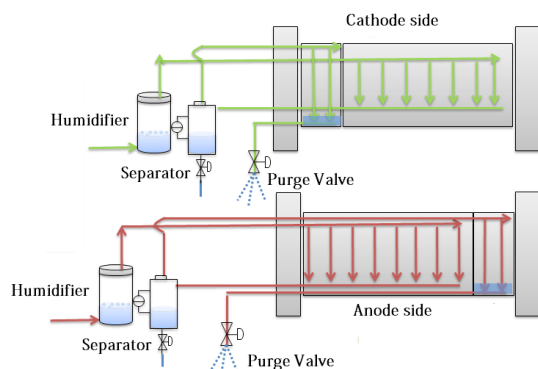


Figure 1. Schematic illustration of the proposed PEM fuel-cell stack design

3- Results and Discussion

After preconditioning, polarization curve for dead-end and open-end modes have been achieved and compared to each other. A comparison is made between the results obtained by dead-end and open-end conditions which are shown in Fig. 2. It can be seen that for the proposed design, the dead-end mode has the same performance as the open-end one. In other words, for very low hydrogen and oxygen purges in the dead-end mode (0.7% for H_2 and 1.5% for O_2), its efficiency is higher than the open-end mode.

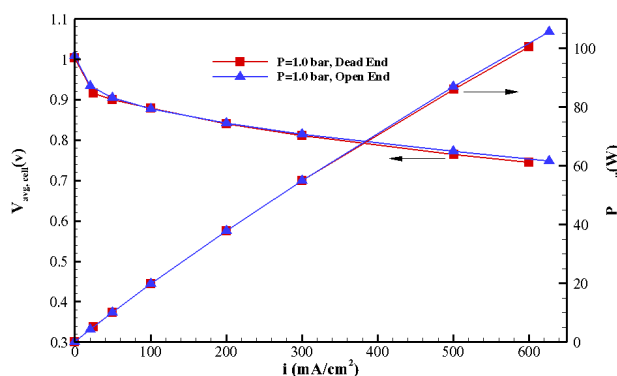


Figure 2. Polarization curves of dead-end and open-end mode (St at open-end mode ($H_2=1.2$, $O_2=1.5$) and at dead-end mode ($H_2=1.007$, $O_2=1.015$), $P=1$ bar)

The vacillation of voltage in the oxygen purge cells is shown in Fig. 3. The same result can be seen but the fluctuation of voltage is higher than the hydrogen side. It can be explained by the formation and accumulation of water at cathode sides

and accumulation of impurities in the purge cells. This is conducted to decreasing purge interval for the water removal from channels. It is found that both cathode purge cells show the same behavior that is a sign of uniform gas distribution between cells. In addition, it is understood that when the time period for closing solenoid valve increases due to water and impurities accumulation, the reduction of purge cells voltages increases.

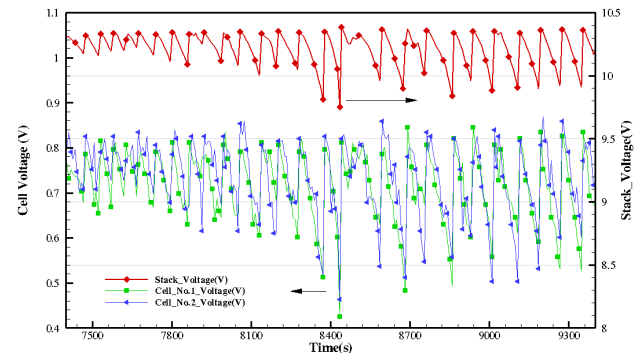


Figure 3. Variation of stack and Oxygen purge cells voltage in the voltage base purge process (St ($H_2=1.007$, $O_2=1.015$))

4- Conclusions

In this study, a cascade type dead-end PEMFC stack with internal manifold is designed, fabricated and tested. Both anode and cathode sides were kept in dead-end mode. The anodic and cathodic cells of a stack are divided into two stages resulting in a stoichiometry higher than one for the first stage and approximately equal to one for the second one. This approach leads to a better handling of flooding problem. The results show that for the proposed design, the dead-end mode has almost the same performance as the open-end one and a higher efficiency than open mode. As well, the fluctuations of voltage and pressure drop are decreased as compare with conventional dead-end stack. It is also understood that the fluctuation of voltage in cathode purge cells is higher than hydrogen's one which can be explained by the formation and accumulation of more water at cathode sides. It is confirmed that the cascade-type stack is superior to the single stage dead-end stack with external manifold in terms of hydrogen and oxygen utilization, weight, size and stack efficiency.

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