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Experimental Analysis of Operating Modes Effect of Open-end and Dead-end on Water Management in H2/O2 Proton-Exchange Membrane Fuel Cells Stack

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ABSTRACT: The management of consumption the reactive gas in proton-exchange membrane fuel cells is classified into three types: open-end, recirculation and dead-end. In dead-end mode, reactant gasses due to accumulating of water and inert gas should be purged alternatively. In this paper a proton-exchange membrane fuel cells stack with transparent end plates and a unique design for investigation of water management is designed, manufactured and fabricated. In this paper, for the first time, the discussion of water management in a dead-end anode and cathode proton-exchange membrane fuel cells stack with details of form and remove of water has been investigated. The results have shown that at the current density of lower than 200 mA/cm2, the produced water is in the form of separate droplets and there is no film flow and slug flow of water in the channel. Also, as expected, the accumulation of droplets and film flow in the lower half was more than the upper half and therefore the reduction of the number of channels to increase gas speed and effective water removal in this part was essential. The results have shown that for steady-state operation, the maximum time possible for closing the output valves is 5 seconds and the minimum time required to open it is 5 seconds.

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1- Introduction

Due to remarkable advantages such as high energy conversion efficiency, high power density, quick startup, and low environmental pollution, Proton Exchange Membrane Fuel Cell (PEMFC) is considered as the main alternative power source for automobiles, steady power stations and submarines [1-3].

In conventional PEM fuel cell systems, pure hydrogen is normally used as the fuel, and unused hydrogen is discharged along with inert gases into the atmosphere. For a given output power, in order to maximize the efficiency and safety, these systems should consume as little fuel as possible and minimize the emission of hydrogen to the atmosphere.

At dead-end PEM fuel cell the inlet hydrogen into anode is almost the same as consumed hydrogen for electrochemical reaction. So, there isn't enough inertia force foe removing accumulating water and the risk of flooding increases [4-5]. Due to produced liquid water at the cathode side the probability of this phenomenon is higher than anode side [5-6].

Recently In-Su Han et al. [7] developed a cascade-type PEM fuel cell stack for the propulsion of an underwater vehicle. They tested and analyzed the basic, load-following, and long-term performances of the cascade-type stack. They obtained a high stack efficiency of more than 65% at the rated power because of a higher average cell voltage and higher operating pressure.

There are different methods for investigation of water management such as: neutron radiography, gas chromatography, capturing use of X-ray and capturing use of inferred ray. Due to high cost and many hazards these methods at most cases cannot be used. So, in this manuscript direct visualization using a transparent PEMFC as a simplest, most accessible and the most suitable method for investigation of water management is presented.

In this manuscript performance of PEMFC at dead-end mode is studied and the effect of purge time on performance of stack at time base approach is analyzed. Water distribution in flow field at dead-end and open-end mode is investigated. The effect of water film flow and slug flow on variation of pressure and voltage at different current densities is analyzed. Also, variation of voltage losses in single cell and stack is reported. Additionally an experimental correlation for setting purge parameters at dead-end mode for any PEMFC in different operating parameters is extracted. This applied design and strategy increased hydrogen and oxygen utilization, which consequently a higher performance has been achieved.

2- Experimental Setup

The Process Flow Diagram (PFD) process of test bench is presented in Fig.1. An in-house fuel cell test station was used to test the PEMFC. Hydrogen and oxygen are fed into the humidifiers and separators before entering the stack. Two solenoid valves are used after gas tank for controlling the entering type of gas to stack: reactant gas or nitrogen. The inlet pressures of hydrogen and oxygen are regulated using the forward pressure regulators. The residual gases from the stack are intermittently discharged into the surrounding environment by opening the purge valves under certain conditions: the anode purge valve opens for a short period whenever the voltage of the

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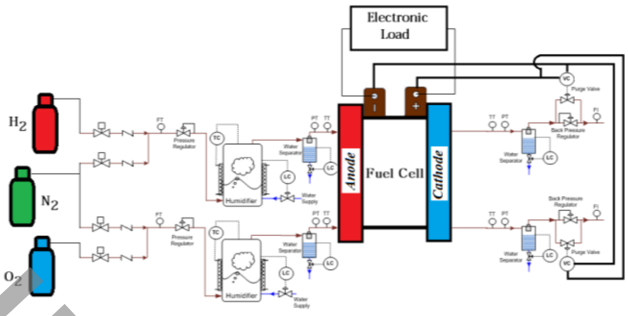

Fig. 1. Process flow diagram of applied test bench

anode cell monitoring drops by a specified amount below the average cell voltage of the stack, and similarly, the cathode purge valve opens whenever the voltage of the cathode cell monitoring drops by a specified amount below the average cell voltage. The purge-gas flow rates are measured using mass flow indicators installed at the anode and cathode outlets of the stack.

3- Results and Discussion

Water accumulation within the channels of the fuel cell can result in a degradation of a performance of the fuel cell. Particularly, water accumulation causes reactant flow misdistribution in individual fuel cell plate and within the fuel cell assembly, which can lead to voltage instability and a degradation of the electrodes. Water accumulation in the channel region includes the water by-product of the electrochemical reaction and water entrained in the reactant flow stream from the cathode inlet header and the anode inlet header.

In this manuscript the process of production, accumulation and purging of water at dead-end mode is investigated by direct visualization. Also, the proper time for purge parameters is presented and an empirical correlation for accounting purge parameters in any arbitrary stack is reported. Before activation process the stack is hydrated for 48 hr to minimize ionic resistance. As shown in Fig. 6 this process is implemented using a column of water over the stack. The test bench can be seen in Fig. 1, too.

Fig. 2 compares voltage and power of single cell and 3 cell stack. Due to uniform pressure distribution and control of stack temperature a significant promotion in performance of stack is seen. An appreciable difference between voltage and power of stack and single cell at high current density, that the effect of cooling process is premier, can be seen.

4- Conclusion

Water accumulation within the channels of the fuel cell can result in a degradation of a performance of the fuel cell. Due to specific time for removing accumulated water and impure at dead-end mode, water management should be analyzed carefully. In this manuscript a transparent PEMFC stack is designed, manufactured and tested for investigating and analyzing of water management and evaluating of performance at dead-end and open-end mode.

Using applied design and adjusting proper purge parameters the dead-end mode can follow the open-end mode polarization curve. Therefore, due to lower stoichiometry, the efficiency of dead-end mode is higher than open end

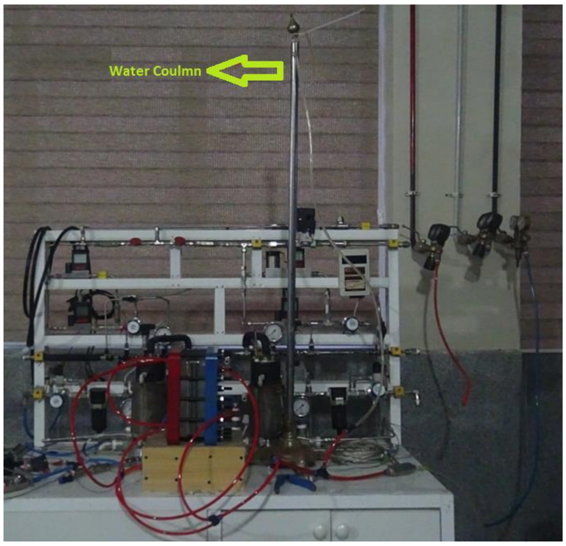

Fig. 2. Hydrating of stack before activation process

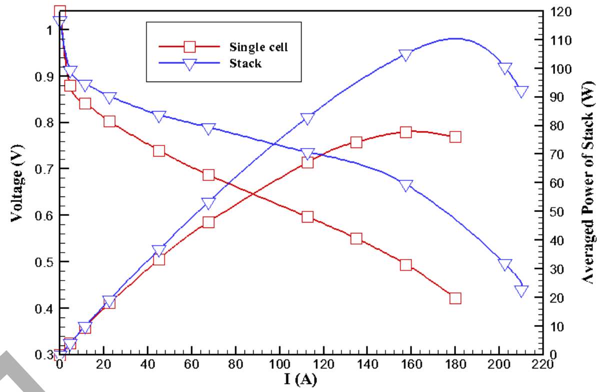

Fig. 3. Comparison of voltage and power of stack and single cell

mode. The result showed that the minimum time for purge duration with permanent stability of voltage is 5 s and the maximum time for closing purge valve is 5s too. The result show that up to i=200 mA/cm2 produced water is in the form of separate droplet and there is no film water and slug flow. As it expected, accumulating of water in the lower half part is more sensible than the upper half part. So, reducing number of channel at the lower part for increasing velocity and water removal is essential. By increasing current density to 300 mA/cm2 the film water and in some cases slug flow is seen at the lower half part of flow field. At the higher current density the produced water occupy the channels and by decreasing active area, significant reduction of current density will be happened. Accordance to results, flooding phenomena only at the cathode side is likely. So, purge period time at the anode side can be adapted longer than cathode side to increase PEMFC performance.

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