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Investigating The Effect Of Water Accumulation On The Performance Of PEM Fuel Cell Under Different Reactant Stoichiometry- An Experimental Study

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***Abstract*— A proton exchange membrane (PEM) fuel cell is an electrochemical device that generates electrical energy by converting chemical energy, using hydrogen as fuel and oxygen as reactant. However, during the operation, water can accumulate in the fuel cell, leading to negative impacts on its durability and performance. The water accumulation can cause cell flooding, result in membrane degradation, eventually leading to fuel cell failure.**

In this study, water accumulation within in the fuel cell at different stoichiometry is estimated by applying water balance model and water removed from fuel cell is accounted at both anode and cathode side of the fuel cell. Experiment is carried by a fuel cell with active surface area of 25cm^2 under no external humidification. Experiment is performed at different reactant stoichiometry ratios and water accumulation , water removed through anode ,water removed through cathode is estimated under each case. Additionally, the effect of cathode stoichiometry on cell voltage is studied and is plotted under each stoichiometry. It is found that cathode stoichiometry has significant effect on water accumulation, hence it affects the performance and life of fuel cell.

Keywords—water accumulation, flooding, fuel cell, cell voltage, stoichiometry

I. INTRODUCTION

Proton exchange membrane (PEM) fuel cells are a promising technology for providing clean and efficient power for a wide range of applications. However, water management remains a critical challenge for PEM fuel cell operation, as the formation of liquid water can lead to reduced fuel cell performance and durability. To address this challenge, it is important to understand the factors that influence water accumulation in PEM fuel cells and to develop effective strategies for managing water in fuel cell systems.

One of the primary challenges of water management in PEM fuel cells is to maintain the appropriate level of moisture in the membrane. If the membrane dries out, the proton conductivity decreases, which leads to a reduction in power output. On the other hand, if too much water accumulates in the fuel cell, it can flood the electrodes, which decreases their effectiveness in generating electricity. To prevent water accumulation in fuel cells, several strategies can be employed. One common approach is to use a water management system that controls the flow of water through the fuel cell. This system may include components such as a water pump, a humidifier, or a water separator.

One key factor that affects water accumulation in PEM fuel cells is cathode stoichiometry, which refers to the ratio of the flow rates of oxygen and hydrogen to the fuel cell. In this study, the effect of cathode stoichiometry on water accumulation in a single PEM fuel cell is investigated. Water content of the outlet gas and the voltage output of the fuel cell under different stoichiometric ratios is collected and analyzed to gain insights in to the relationship between stoichiometry, water accumulation, and fuel cell performance.

II. EXPERIMENT SETUP AND METHODOLOGY

A. Experimental Setup

To investigate the effect of operating conditions on water accumulation in a PEM fuel cell, a test rig is constructed consisting of a single PEM fuel cell, mass flow controller, humidity sensor and a data acquisition system.

i) PEM fuel cell – Single cell serpentine channel fuel cell of 25cm^2 active surface area is used for the experiment.

ii) Thermal mass flow controller- used to control flowrate of hydrogen and oxygen in to the fuel cell.

iii) Humidity Sensor- to determine relative humidity of gas exit from the fuel cell .

iv) Loading of fuel cell is controlled by *DC Current Load.*

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v)Data acquisition system is used to record transient change in cell voltage.

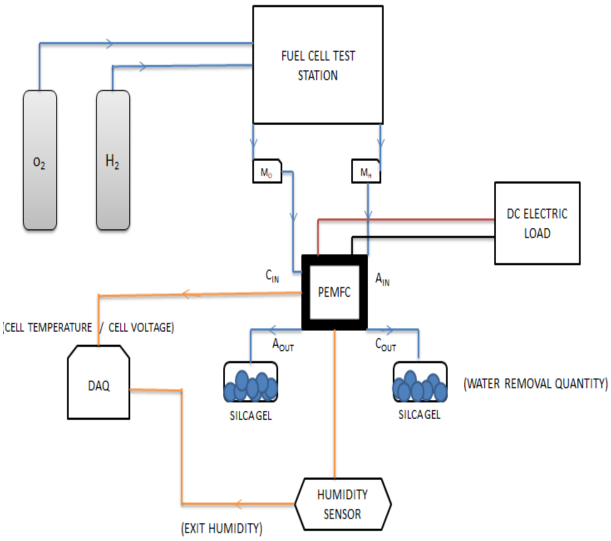

Fig 1: Schematic diagram of setup

B. *Water balance with in the fuel cell*

The water in a fuel cell is primarily generated through electrochemical reaction and humidity content present in the reaction gas present at the inlet, according to the fuel cell's operating principle. Subsequently, a portion of this water remains within the fuel cell, while the remainder is carried away by the outlet gas/water. The water balance model schematic, shown in Figure 2

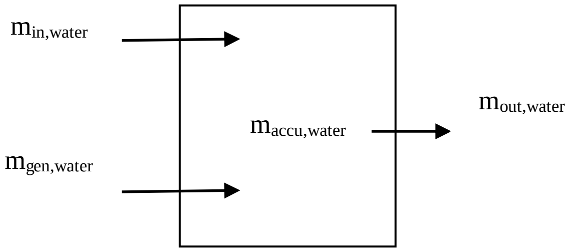

Fig 2: Schematic of water balance within the fuel cell

$$m_{accu,water} = m_{in,water} + m_{gen,water} - (m_{out,anode} + m_{out,cathode})$$

where $m_{accu,water}$ is the amount of water left in the fuel cell, $m_{in,water}$ is the amount of water brought in by the inlet reaction gas, $m_{gen,water}$ is the amount of water generated by the electrochemical reactions, and $m_{out,water}$ is the amount of water brought out through anode and cathode of fuel cell.

$m_{in,water} = 0$, no external humidification is provided so it is treated as dry. Therefore

$$\mathbf{m}_{accu,water} = \mathbf{m}_{gen,water} - (\mathbf{m}_{out,anode} + \mathbf{m}_{out,cathode})$$

C. *Methodology*

Fuel cell is fed with dry oxygen and hydrogen on the cathode and anode side respectively. Fuel cell is operated at constant current density of 20 A and transient change in fuel cell voltage is monitored till a steady state is reached. Voltage is measured between anode and cathode graphite plates. To determine the water removed from the fuel cell the outlet gas, Self indicating silca gel of size 3mm is used to measure the water coming out on both anode and cathode outlets. For this purpose both anode and cathode outlets are connected to moisture traps filled with silca gel. Thus water removed from the fuel cell can be quantified by measuring initial and final weight of silca gel traps using a precision weighing balance(SHIMADZU AUW220D). The experiment is repeated by varying the flow rates of the reactant gases. Hence variation of cell voltage , water accumulation under each stoichiometry is determined and plotted. The data is recorded for a duration of 40 minutes at each experimental condition.

To ensure the accuracy and repeatability of the data, calibration procedures were performed for all the instruments used in the experiment.

Fig 3: Experimental setup of PEM fuel cell

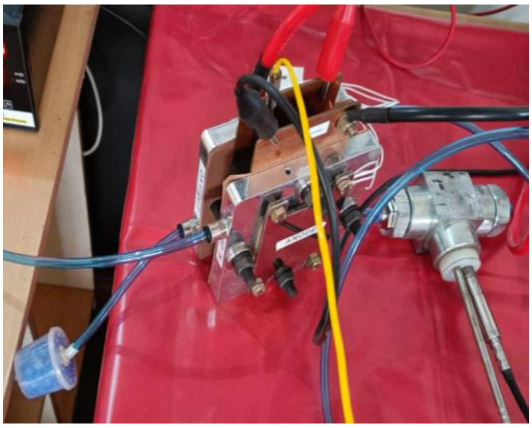

Fig 5: Fuel cell attached to moisture trap filled with silca gel

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III. RESULT AND ANALYSIS

A. Theoratical water generation within fuel cell

Theoretical water generation in a fuel cell is a function of current density and generation rate of water due to electrochemical reaction remains constant.
Theoretical water generation (g/s) is calculated by,

S_{cath}	W_{gen} g	$W_{rem,cathode}$ g	$W_{rem,anode}$ g	W_{accum} g
1.2	4.64	2.43	0.21	2
1.5	4.64	2.917	0.103	1.62
2	4.64	3.116	0.03	1.494
2.5	4.64	3.71	0.04	0.89
3	4.64	4.01	0.06	.57

$$s_w = \frac{Current\ density \times Active\ surface\ area \times Molecular\ weight\ of\ water}{2 \times Faraday's\ const}$$

Thus operating fuel cell under a load of 20 amps , 0.1116 g/s of water is generated . hence for a duration of 40 min 4.64 g water generation takes place .so to avoid flooding it must be removed through cathode and anode outlets.

B. Water accumulation at different reactant stoichiometry

The water accumulation within the PEM fuel cell was investigated by water balance model under different cathode stoichiometry.

Table 1 shows generated water, water removed through cathode, water removed through anode , accumulated water under each reactant stoichiometry.

Table1

It can seen that water accumulation increased with decreasing stoichiometry. The highest water accumulation was obtained at a stoichiometric ratio of 1, with a value of 40% of generated water. At the stoichiometric ratio of 1.5, 35% of generated water was found accumulated within the cell. At the stoichiometric ratio of 3,only 10% of total generation stay within the cell.
Water generation, water removal, water accumulation under different stoichiometry is depicted in figure 5.

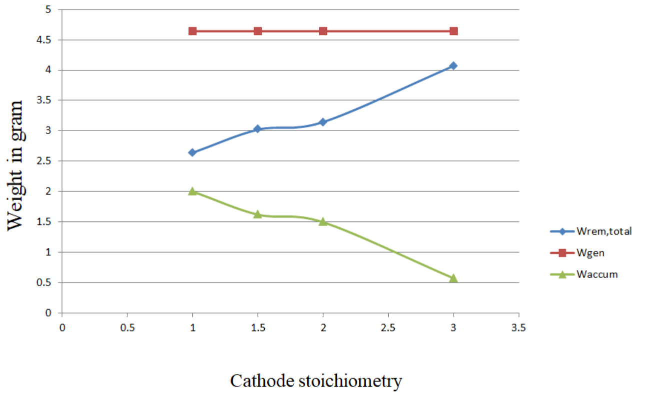

Fig 5 : plot of water balance within the cell

C. Effect of water accumulation on fuel cell voltage

The effect of water accumulation on the voltage output of the PEM fuel cell was investigated by measuring the voltage output of the cell under different cathode stoichiometry.

Figure 6 shows the voltage output of the fuel cell as a function of time under each cathode stoichiometric ratio. As the cathode stoichiometry decreases, cell voltage kept on fluctuating. At s=1.2,s=1.5 voltage drop suddenly and purging is done to remove the accumulated water. At high air stoichiometry, there is a large amount of unreacted residual air in the flow channel, which has a good purging effect on the liquid water but cell voltage decline due to drying. The voltage output decreased with decreasing stoichiometry. The highest voltage output after loading fuel cell to 20 amps was obtained at a stoichiometric ratio of 2.0, with a value of 0.54 V. At a stoichiometric ratio of 1, the initial voltage output was found to be 0.46 V but declines over time.

Thus decrease in voltage output with decreasing stoichiometry can be attributed to the increased accumulation of liquid water in the fuel cell. As the cathode stoichiometry decreases, purging effect will not be there is reduced, leading to a buildup of water in the cell.

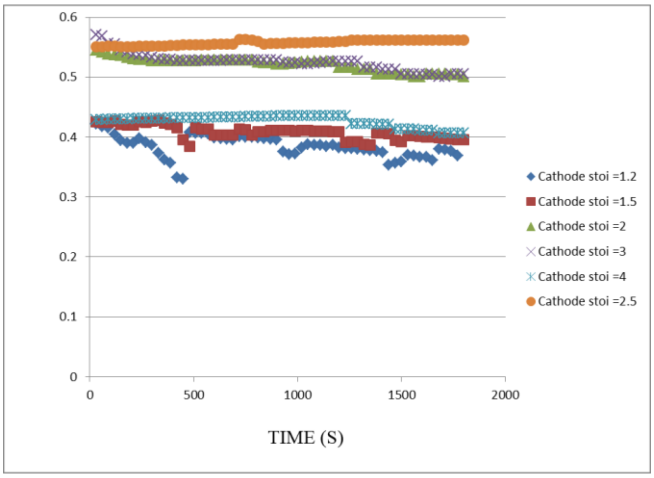

Fig 6: Effect of water accumulation on fuel cell performance

The results suggest that optimal stoichiometric ratio for maximum fuel cell performance is around 2.0.

These results demonstrate that decreasing the cathode stoichiometry increases water accumulation in the PEM fuel cell, which leads to a decrease in voltage output. The optimal stoichiometric ratio for minimizing water accumulation and maximizing fuel cell performance is around 2.5.

IV. CONCLUSIONS

Water accumulation in a proton exchange membrane (PEM) fuel cell is heavily influenced by the cathode stoichiometry. If the cathode stoichiometry is too low, there may not be enough oxygen to flush the accumulated water through fuel cell outlets leading to water accumulation and potential flooding of the cell. On the other hand, if the cathode stoichiometry is too high, there may be excess oxygen that is not utilized, which can lead to drying of fuel cell ,hence reduce the cell efficiency.

Therefore, it is important to carefully control the cathode stoichiometry to optimize the water management in a PEM fuel cell. In this study optimal stoichiometric ratio for maximum fuel cell performance is obtained between 2 and 3.

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