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Optimization of air mass flow in a PEM fuel cell

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Abstract. In our work, we focused on measuring the performance characteristics of a test hydrogen fuel cell with an open cathode. The aim of the work was to verify the effect of the mass flow through the fuel cell on the power output as a function of the current density and voltage on the fuel cell. A test bench capable of testing fuel cells up to 2000 W was used to measure the power characteristics. The test fuel cell was composed of three cells and its total membrane area was 100 cm2. A PIV measurement system was used to measure the mass flow. The mass flow measurement was performed at the inlet of the fuel cell. The measurements included the determination of the inlet temperature distribution using a thermal imaging camera. The presented measurements were performed for two configurations with original and optimized diffuser at the inlet of the fans. Finally, the effect of mass flow and overall thermal management on the fuel cell performance is discussed, including the effect of the newly designed diffuser.

1 Introduction

The aim of our work was to verify the influence of air flow rate and air distribution inside a hydrogen fuel cell with a proton exchange membrane PEM on the performance characteristics. In open cathode fuel cells, electrical and thermal energy is produced by the electrochemical reaction of hydrogen and oxygen contained in the air. This type of fuel cell operates optimally at temperatures typically below 60°C (for example, ([1], [2], [3]). An additional advantage of PEM cells is their short ramp-up time to maximum zero-emission performance. For these reasons, it is clear that the use of hydrogen fuel cells will experience rapid development in the coming decade. In open cathode fuel cells, the air flowing through the fuel cell carries oxygen which is consumed by the electrochemical reaction and, on the other hand, removes excess heat outside the fuel cell. This dual role of air in this type of fuel cell leads to a simpler PEM cell design but, due to the sensitivity of open cathode fuel cells to operating parameters, places great demands on the control of the input air parameters such as its temperature humidity and mass flux distribution across the bipolar plate. A critical parameter for open cathode PEM cell operation is the thermal balance of the water mass flux ([4], [5], [6]).. Excess water inside the fuel cell leads to flooding and reduces the mass transfer across the membrane, leading to a decrease in fuel cell performance. A small mass flux of water leads to drying of the membrane and a decrease in the electrochemical reaction. High or low fuel cell temperature then reduces fuel cell performance and higher temperatures lead to reduced lifetime and in limiting cases can lead to membrane destruction. It is clear that maintaining the optimum thermal management of an open cathode fuel cell is essential for its operation. For this reason, a number of studies have been carried out to investigate the effect of heat and mass transport within fuel cells on their operating characteristics ([7], [8])... Another parameter that significantly affects the performance characteristics of the fuel cell is the shape and distribution of the flow channels of the bipolar plate on both the hydrogen and air sides. Much attention is paid to the shape of the cooling channels for air flow. In these studies, both the effect of channel geometry on oxygen transport through the membrane and the effect of channel shape on water movement and droplet shape on the channel walls are investigated ([9]). The effect of the channel shape on the overall aerodynamic drag is also investigated. The effect of changing the channel cross-section across the fuel cell leading to improved reactant mixing, better water drainage and thus increased fuel cell performance is also investigated. The reaction at the anode and cathode of the PEM cell can be written using the following equations:

$$2H_2=4H^++4e^- \quad (1)$$

$$O_2+4e^- =2O_2^- \quad (2)$$

$$2O_2^- + 4H^+=2H_2O \quad (3)$$

$$H_2+O_2=2H_2O \quad (4)$$

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2 Experimental set up

To measure the effect of the mass flow through the fuel cell, we used a LEANCAT test station with a maximum output of up to 2KW. This test station is capable of automatically recording and adjusting all provoyance parameters such as pressure and hydrogen flow, measuring the current and voltage on individual fuell cells, including temperature monitoring both inside the fuel cell and on its surface. The station is equipped with nitrogen for cleaning and inertia. The schematic of the

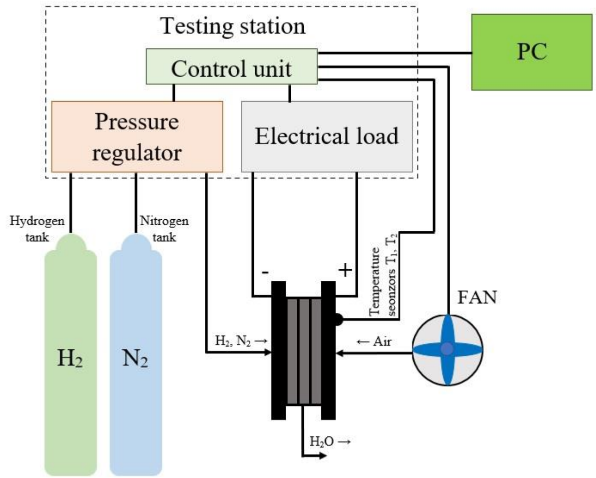

Fig. 1. Set up of the test bench.

test station and the circuitry is shown in Figure 1. Fuel cell test station is shown in Fig.2. Shape of the channels of the bipolar plate on the air side is rectangular with a width of 1 mm and a channel depth of 2 mm. The membrane inside the harness is MEA-7 from Altpolymer. The maximum provoyage temperature of the membrane is 65°C and the surface area is 100 cm2. The operating hydrogen overpressure during testing was set to 300 Pa and the purge duration was 200 ms. The fuel cell was operated in constant voltage mode at 2V, 1.8V and 1.6V. At each fuel cell load, the effect of mass flux magnitude was tested for both the original fan connections to the fuel cell and the optimized diffuser shape Figure 3. The optimized diffuser shape is designed with internal bars that distribute the mass flow across the fuel cell. The partitions are designed to increase the mass flow on the sides. 3D printer with FDM printer technology with a PTEG print filament was used to produce the optimized dofuzor. The temperature inside

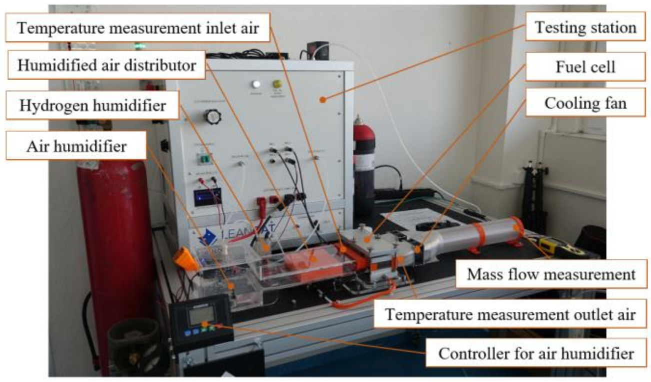

Fig. 2. Fuel cell test bench.

the fuel cell was measured with a type T thermocouple and was also monitored with a thermal camera Fig.6. The mass flow distribution at the inlet of the fuel cell was measured with a 2D PIV system from Lavision. The resolution of the CMOS camera was 5Mpixel; with a bit depth of 16 pit;. A 200 mJ/pulse Nd:YAG laser was used to illuminate the inlet plane. We used condensed oil droplets of about 1-2um as marker particles. The evaluation was performed by the classical multistem

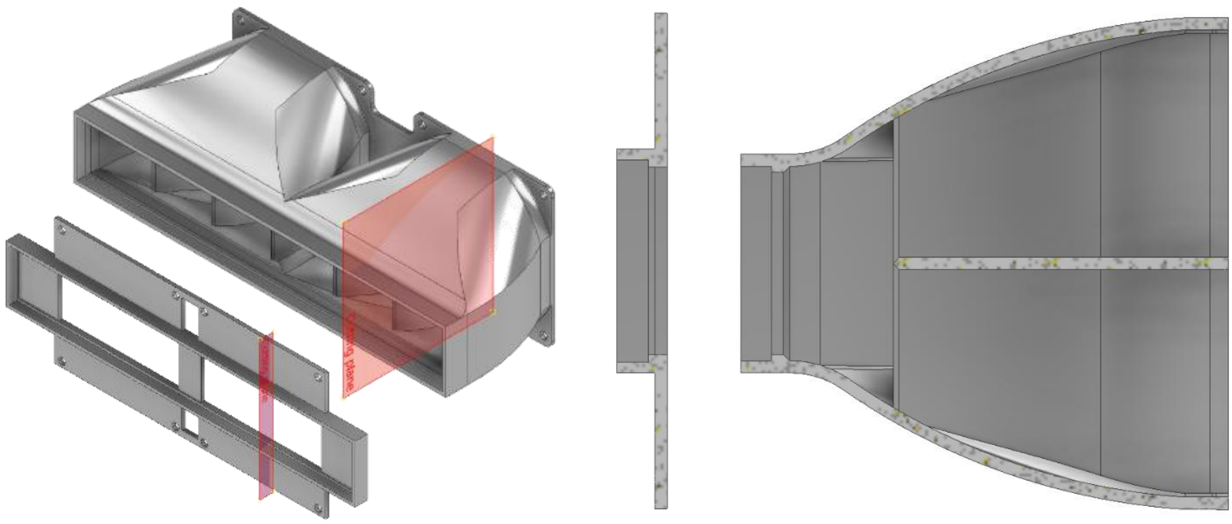

Fig. 3. Original and optimized diffuser shape for air outlet from the fuel cell with the indicated cutting plane on the left. Cross section of the original and optimized diffuser on the right.

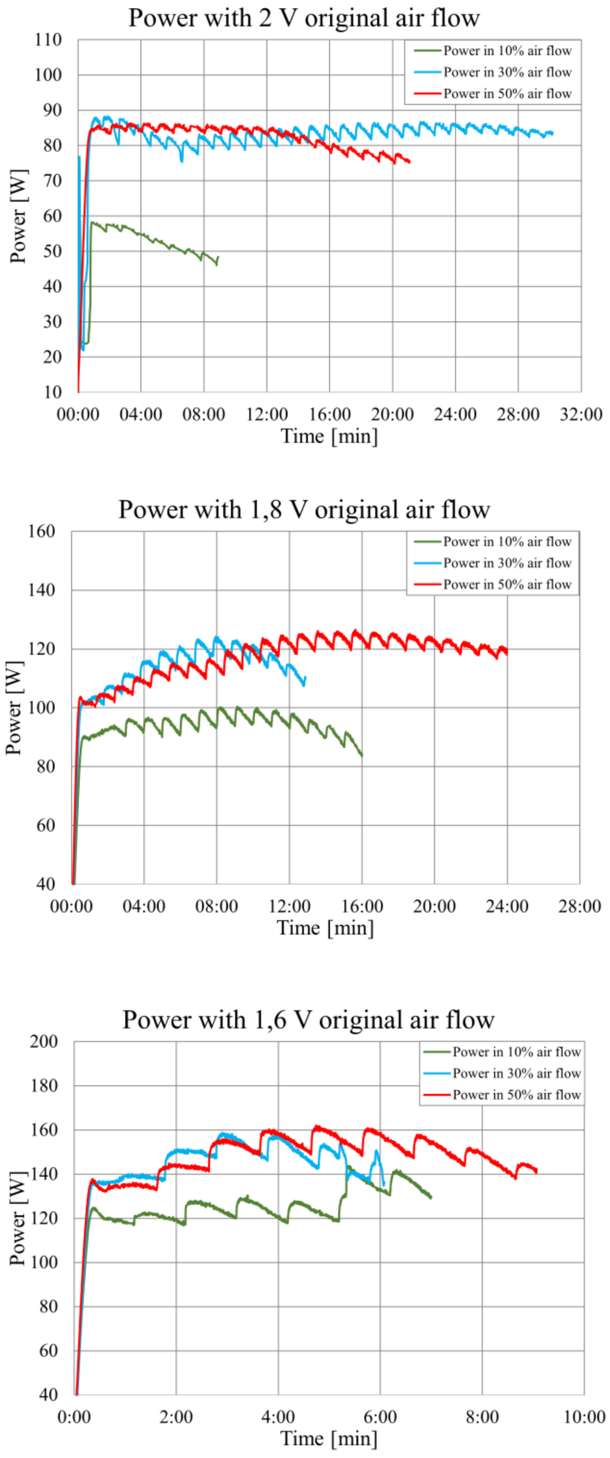

Fig. 4. Dependence of fuel cell performance on air flow and voltage - original adapter.

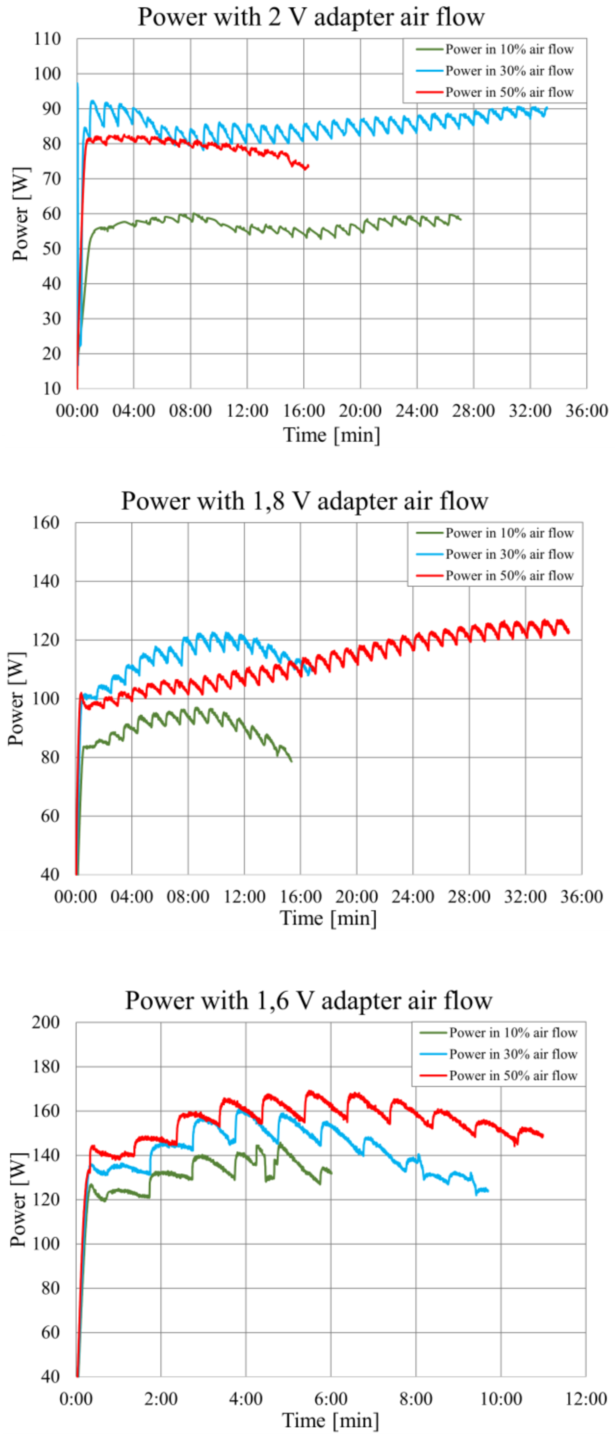

Fig. 5. Dependence of fuel cell performance on air flow and voltage – optimised adapter.

stndard cros corelation algorythm algorithm using the DaVis environment. The measurements were performed in the axis of symmetry of the fuel cell and for all three fan speed modes both in the original configuration and for the newly designed diffuser.

3 Results

In the experiments performed, we recorded the current density, temperature and power of the tested fuel cell stack for different flow rates and two diffuser configurations. The comparison of the time course of the fuel cell stack as a function of the tested parameters is summarized in Fig. 4. The original diffuser configuration is on the left and the adequate results for the optimized diffuser shape as shown in Fig. 5 are on the right. In addition to the power ratio measurements, a quantitative determination of the inlet temperature of the fuel cell and a measurement of the mass flux distribution were performed. From these results, it is clear that the temperature distribution of the bipolar plates at the inlet exhibits considerable non-uniformity. As far as the measured dependence of the fuel cell performance for each voltage level and mass flow is concerned, it is clear that the positive effect of increased air flow and thus

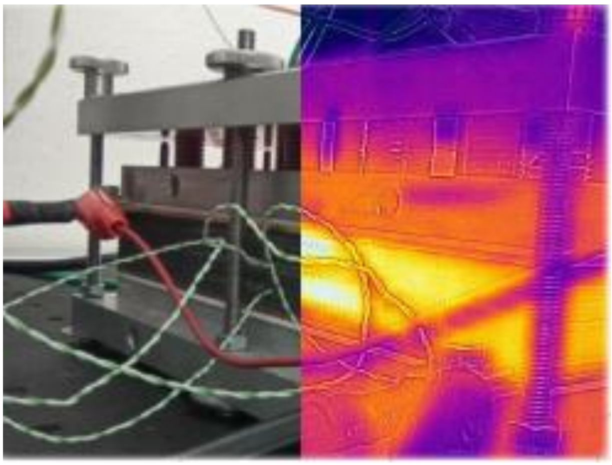

Fig. 6. Visualization of the temperature distribution at the fuel cell inlet - original adapter.

increased cooling effect and oxygen supply has a positive effect on the fuel cell performance. This effect is particularly noticeable when the fan power is increased from 10% to 30%. In the original configuration, however, there is no increase in performance with further increases in fan power. For the optimized diffuser shape, the positive effect of uniform air distribution and thus also the increase in performance with increasing airflow through the fuel cell is evident. With this configuration, however, only one difference in the fuel cell behaviour is seen and that is at low load (2V). In this mode, the negative effect of maximum air flow on fuel cell performance is visible. At this low load, as the air flow rate increases, the diaphragm dries out resulting in a decrease in fuel cell performance.

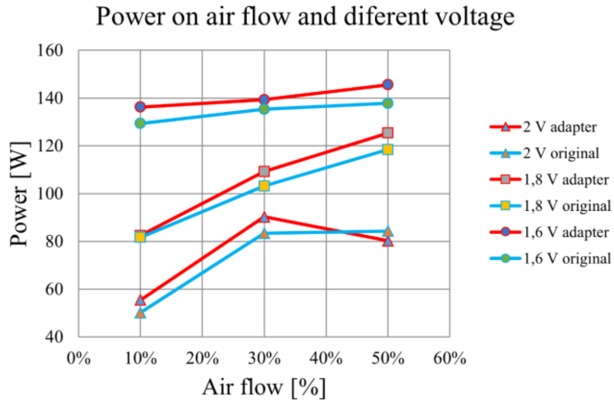

Fig. 7. Effect of air flow and fuel cell voltage on fuel cell performance.

4 Conclusion

When testing the influence of the diffuser shape and air flow through the fuel cell, we verified the positive influence of the appropriate shaping of the diffuser connecting the axial fans and the fuel cell stack Fig.7. However, it is clear from the presented results that for long-term operation of the fuel cell at maximum power for a given voltage, it will be necessary not only to control the air flow and its temperature, but it will be necessary to control the air flow depending on other parameters such as the temperature of the fuel cell and the humidity of the intake air. For these reasons, for the next experiment, it will be necessary to upgrade our measurement station and incorporate the fuel cell into an aerodynamic test bench with controlled inlet and outlet parameters to find a complete correlation between the operating conditions of the fuel cell and its performance characteristics. In the design of this new test bench, care will have to be taken to clearly determine the optimum balance of the mass flow of water through the fuel cell. In future work, we will take a detailed measurement of the mass flow uniformity at the fuel cell stage, which will then serve as a boundary condition for numerical simulations for further optimization tasks.

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