Effect of relative humidity on the performance of a PEM-fuel cell

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Introduction

This project investigates the effect of anode relative humidity on the performance of a proton exchange membrane (PEM) fuel cell in drone applications. Fuel cells are used in drones primarily to extend flight time and enable fast refueling. In drone applications, the weight is an important factor. It is therefore not feasible to implement a heavy and power consuming air compressor. A small fan is the common solution, which means no pressure or humidity regulation on the cathode side. The anode plays a crucial role in fuel cell performance, particularly in membrane hydration. Relative humidity at the anode affects proton conductivity, where low humidity can dry out the membrane and increase resistance, while excessive moisture may lead to flooding. Since there is no humidity regulation on the cathode side, humidity control on the anode becomes essential for ensuring reliable operation in drone applications. [1]

Method

The effect of anode relative humidity on the performance of a PEM fuel cell was modeled and simulated in COMSOL. Straight and serpentine flow channels with a Nafion membrane were used. A four-channel serpentine flow geometry with an active area of 25 cm² was used as depicted in Figure 1. The operating conditions and geometries were set to simulate drone environments and are listed in Table 1.

Basic parameters	Values
Operation temperature	338 [K]
Anode flow rate	0.5 [L/min]
Cathode flow rate	2 [L/min]
Membrane thickness	8.5 [µm]
Electrode thickness	50 [µm]
GDL thickness	300 [µm]

Table 1: Basic parameters of the modeled fuel cell

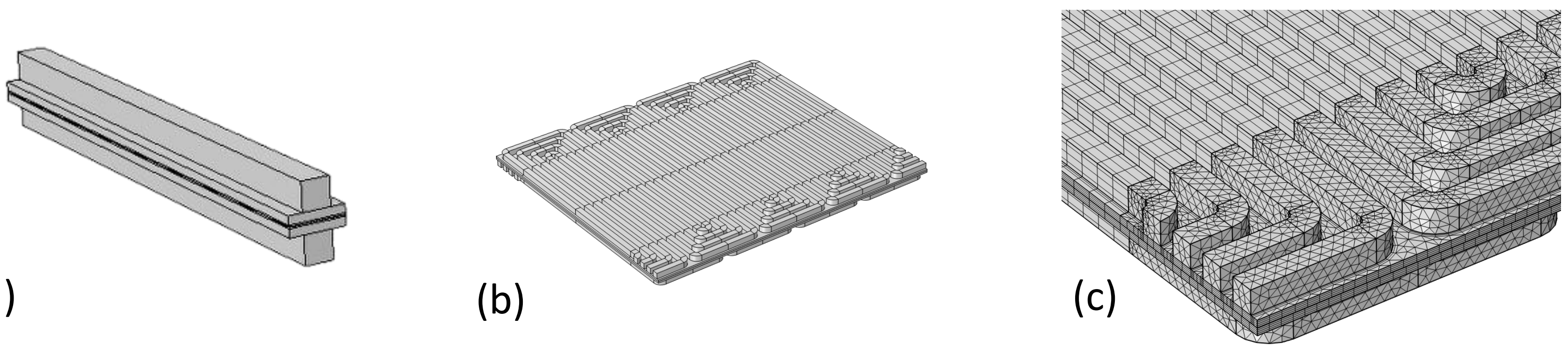


Figure 1: Geometries of a) straight flow channel, b) serpentine flow channel c) mesh density of the serpentine flow channel

Simulations were carried out over across a range of 0-70% relative humidity on the anode. Additionally, a laboratory trial was performed on a single PEM fuel cell with a respective anode and cathode relative humidity of 0% and 50%. The performance obtained was compared with that of the COMSOL model operating under similar conditions.

Results and Discussion

Serpentine channel: Influence of the anode relative humidity on cell performance

The varying relative humidity of the anode resulted in only minor differences in the activation losses in the fuel cell. A significant deviation could be observed in the region associated with the ohmic losses as displayed in Figure 2. Lower values of the relative humidity in the H_2 gas mixture resulted in a decreased cell performance. However, this effect vanished for higher current densities of 2 A/cm² and above, where we can see converging results for all investigated relative humidity's. The worse performance in dryer anode environments can be attributed to the higher resistance to the ion conduction of the membrane for insufficient or lower hydration. The convergence of the cell performance for higher current densities indicates that the membrane is sufficiently hydrated at higher reaction volumes by the continuous formation of H_2O in the cell itself.

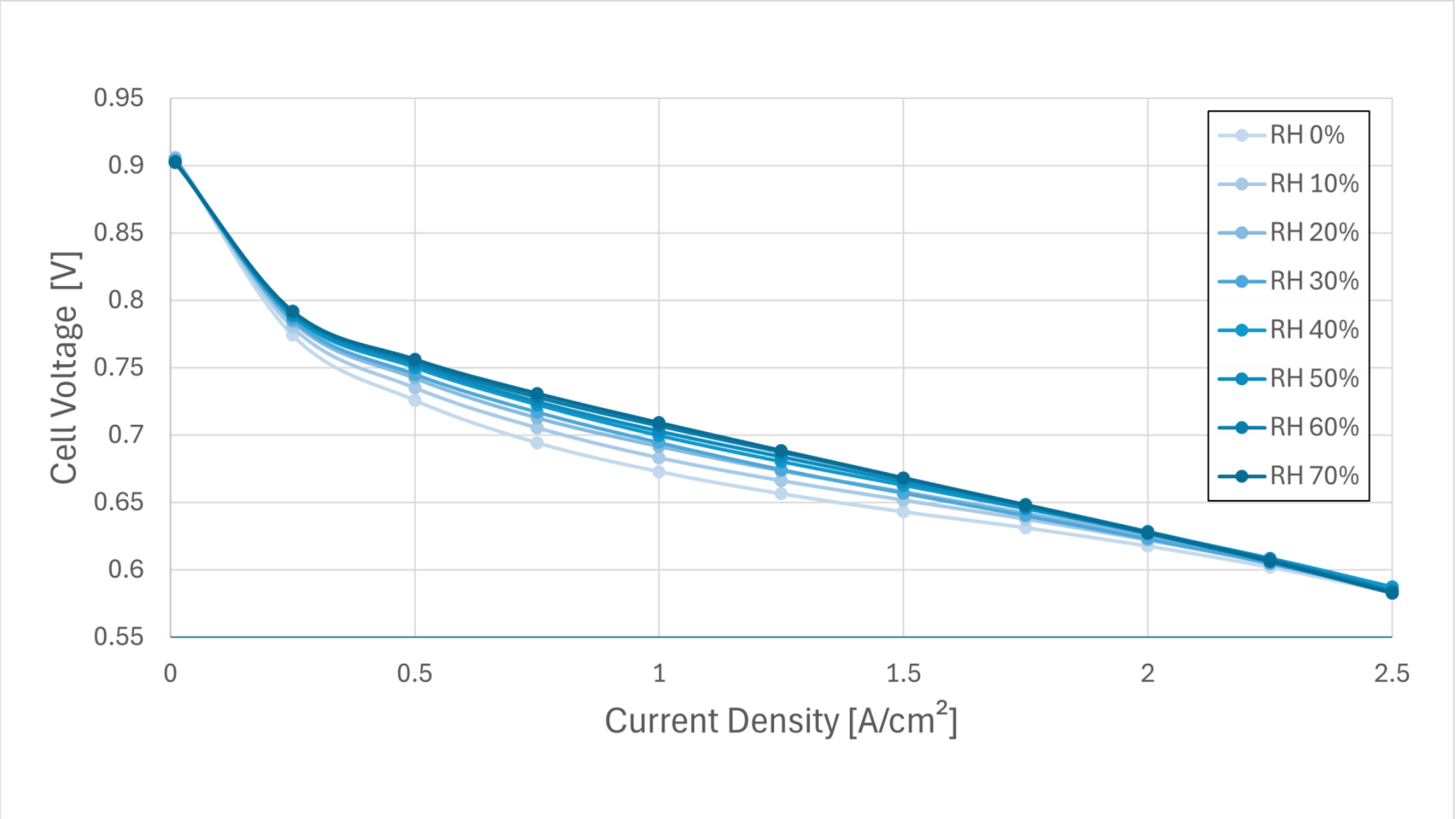


Figure 2: Simulated fuel cell performance with varying relative humidity of the anode gas mixture

Serpentine channel: Comparison of simulated fuel cell and lab equivalent

The simulation geometry varied slightly, but channel dimensions, membrane active area, and thickness remained identical. The back diffusion allows water to diffuse through the membrane to the hydrogen transporting anode channel. As can be seen in Figure 4 a) and b) we can observe an increasing amount of water accumulation toward the cathode outlet on the top left side of the graphs. Both oxygen and hydrogen mole fraction only slightly decrease which means no fuel starvation occurs under the simulated conditions. The pressure on Figure 4 e) shows an even drop on cathode side, but on the anode side, there seems to be no pressure drop. This is due to the flow 4x difference between air and H_2. Air is also significantly denser meaning it generates more drag and friction.

The simulation accurately predicts the performance of the fuel cell for current densities below 0.5 A/cm². Above that threshold, we see a massive deviation of the simulation to the real fuel cell behaviour displayed in Figure 3. Similar discrepancies, as noted by Jourdani et al. [2], arise from liquid water presence on catalyst and gas diffusion layers in real cells. Additional deviations may be caused by the idealized ohmic resistance in the simulation. Real fuel cells have increased ohmic losses due to the influence of the compaction pressure to the quality of electric connections. Additionally, cell degradation has not been considered, and mass transport losses might not be accurately modeled resulting in these performance discrepancies. The current scope of the fuel cell simulation model can thus only accurately depict a limited range of the performance curve.

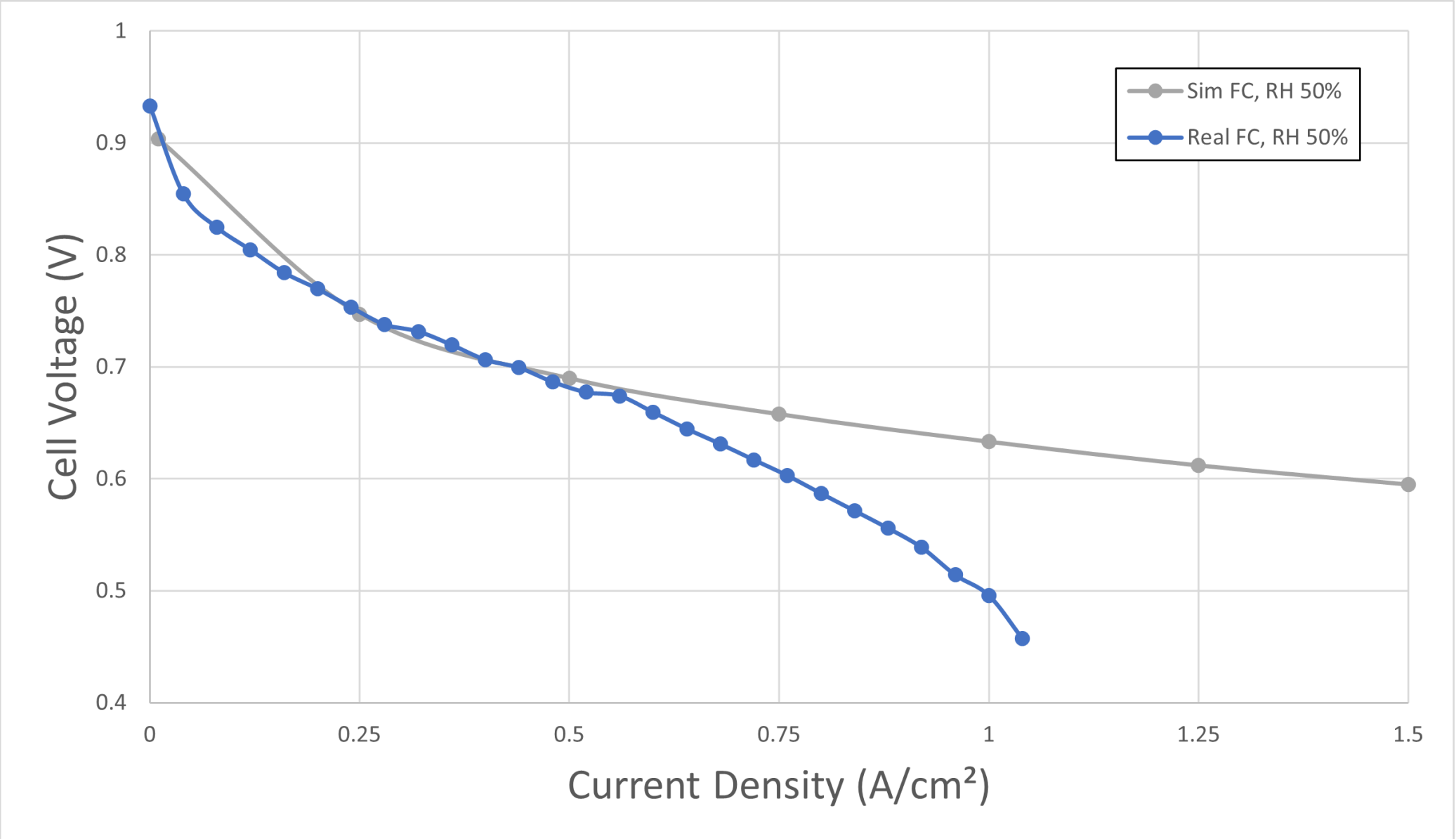
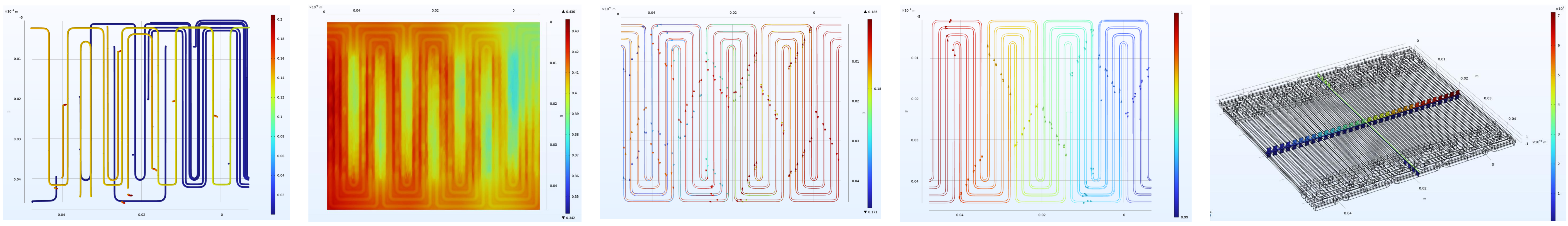


Figure 3: Comparison of simulated fuel cell and lab equivalent operated with 0% RH at the anode and 50% RH at the cathode inlet.



a) H_2O mole fraction in the FC channels

b) Membrane H_2O activity

c) O_2 mole fraction in the FC

d) H_2 mole fraction in the FC

e) Pressure state in FC channels

Figure 4: Simulation contours captured at 0.75 A/cm²

Conclusion and Reflection

The here presented COMSOL model allows for the accurate simulation of fuel cells in the activation losses dominated regime. A more accurately set up model is needed to capture the whole range of fuel cell operation conditions.

During this project we learned the basics of setting up a fuel cell simulation in COMSOL. We were acquainted with how the fuel cell MEA's are tested in test benches in the SEEL laboratory. The introduction to COMSOL required an understanding of the fundamental physics behind governing fuel cell operation. Through this process we gained hands-on experience in interpreting simulation results and comparing them with real world data.

References, Acknowledgement

[1] Zhang, Lu, Yongfeng Liu, Guijun Bi, Xintong Liu, Long Wang, Yuan Wan, and Hua Sun. 2022. "Modeling and Experimental Investigation of the Anode Inlet Relative Humidity Effect on a PEM Fuel Cell" Energies 15, no. 13: 4532. https://doi.org/10.3390/en15134532

[2] 2017. Three-Dimensional PEM Fuel Cells Modeling using COMSOL Multiphysics. The International Journal of Multiphysics. 11, 4 (Dec. 2017), 427-442. https://doi.org/10.21152/1750-9548.11.4.427

The authors would like to thank Dr Dhelipan Mahenthiran for supervising and assisting in the set up and evaluation of the project. The authors would also like to thank Prof Björn Wickman for organizing this TRACKS course.