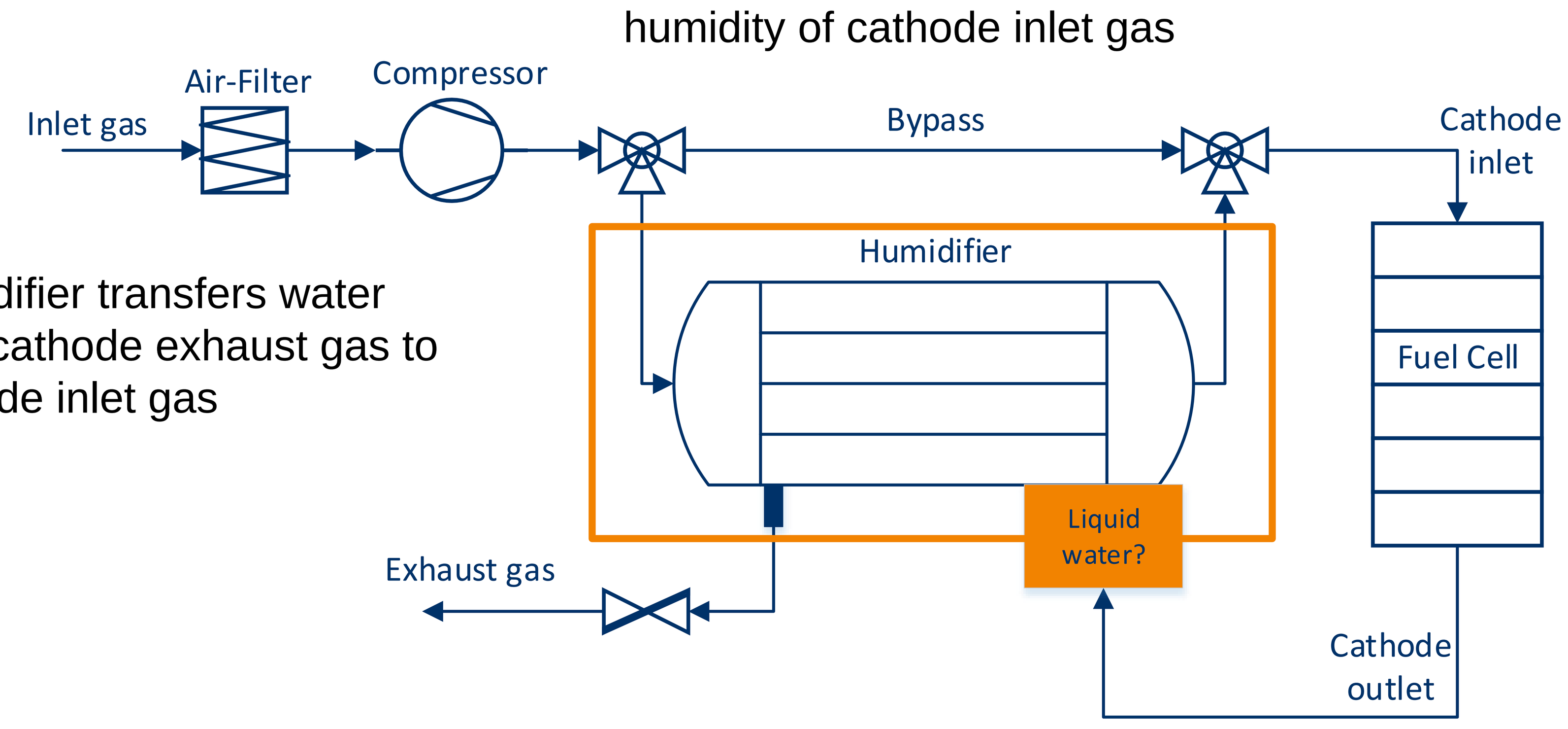
Liquid water makes the difference

Simulation and experimental analysis of a membrane humidifier

- Current models and experiments [1] neglect the presence of liquid water at the humidifier inlet even if it is possible for multiple operating points
- In this work a new 1D model and experimental setup for membrane humidifier is introduced that accounts for the differences in the water transport depending on the physical state of the water

Bypass for controlling relative humidity of cathode inlet gas

Humidifier transfers water from cathode exhaust gas to cathode inlet gas



Specific relative humidity for avoiding drying-out stack

Hydration for high efficiency and long lifetime

Transport of product water to stack outlet to prevent flooding

Presence of liquid water in the cathode exhaust gas depends on multiple factors (e.g. operating point, stack, system, thermodynamic boundary conditions)

Simulation

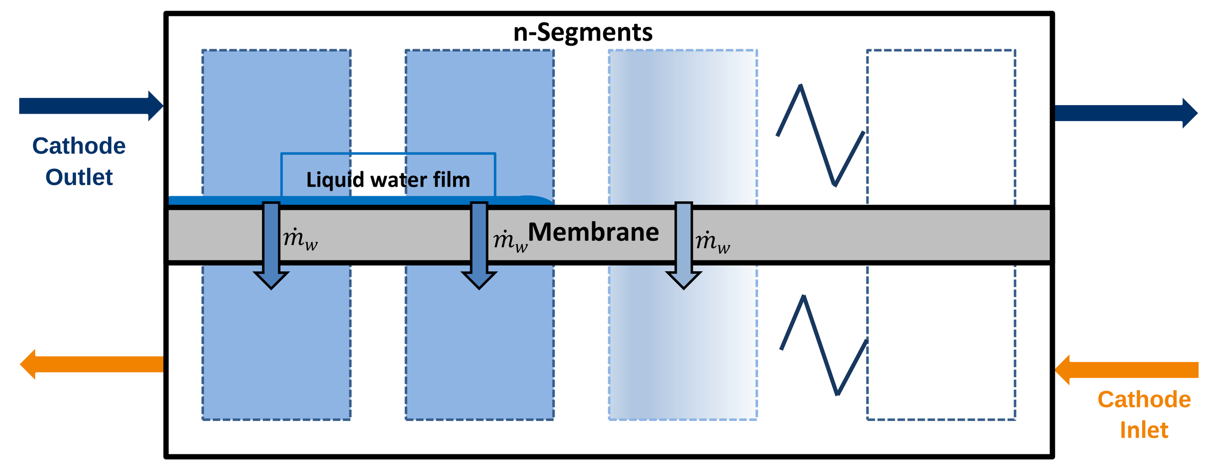


Figure 1: Schematic figure of the discretized humidifier simulation model, the blue color indicates the relative humidity of the gas stream

- Simulation environment: Matlab Simulink
- Goal of simulation: calculation of the water transport through the membrane in dependency of: RH, T, p, flow rate, flow field, membrane type, membrane surface area and presence of liquid water
- The humidifier system was implemented as a counter flow system
- Discretization in ten segments along the main flow path of the inlet and exhaust air path (along the channel)

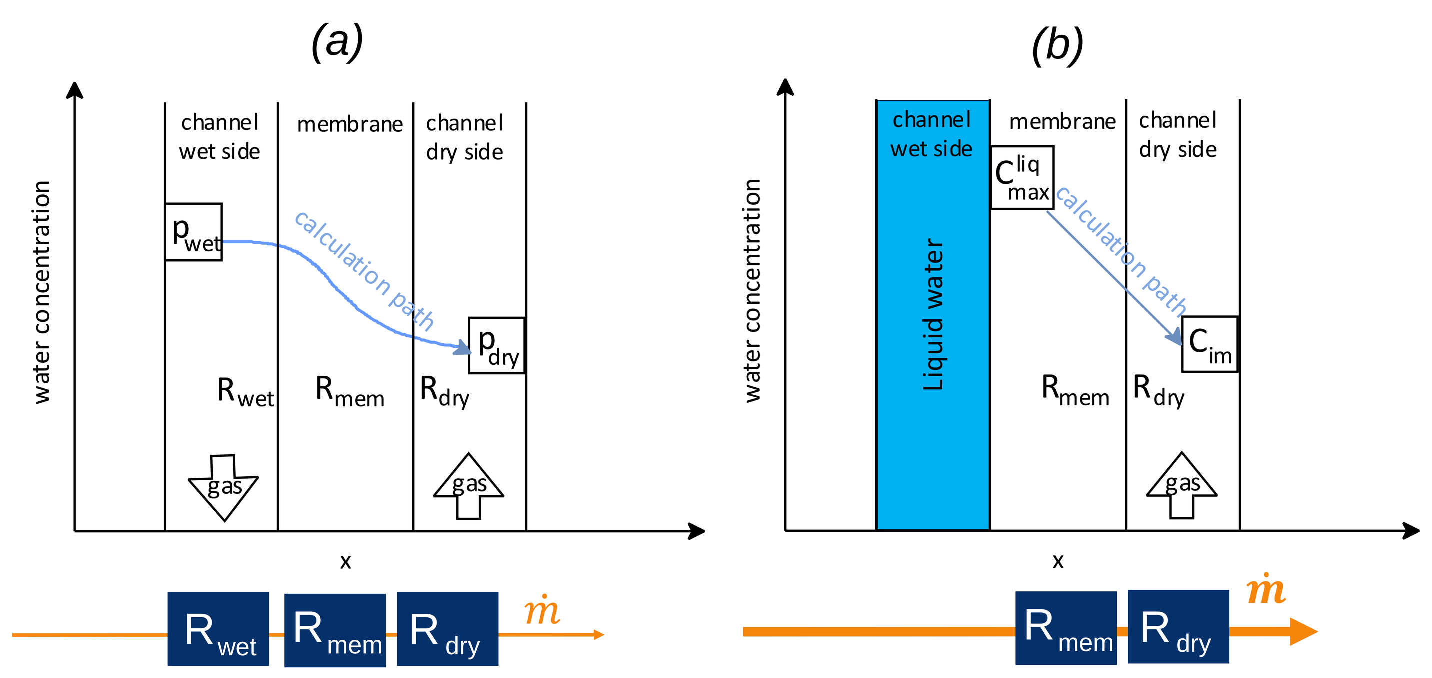


Figure 2: Schematic calculation path for (a) vapor-vapor-transport (VVP) and (b) liquid-vapor-transport (LVP)

Mass transport depends on:

- - Driving force (concentration difference)
- - Resistance

→ Liquid water enhances mass transport!

Experimental Setup

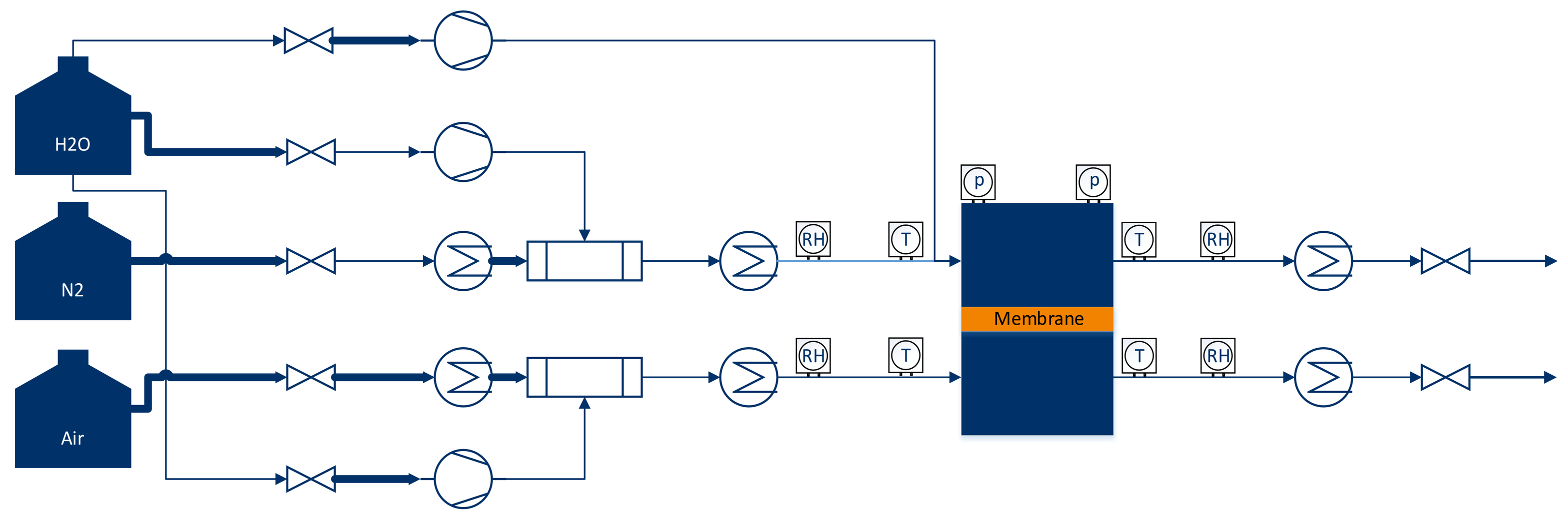


Figure 3: Schema of test stand for analysing the membrane transport properties in dependence of the aggregation state of the inlet water

- Possible measurements: Water transfer of water in only vapor phase, only liquid phase or liquid and vapor phase in dependence of different temperatures, pressures, flow rates, membranes, flow fields
- Direct liquid water insert on membrane surface possible by a bypass pump

Results & Validation

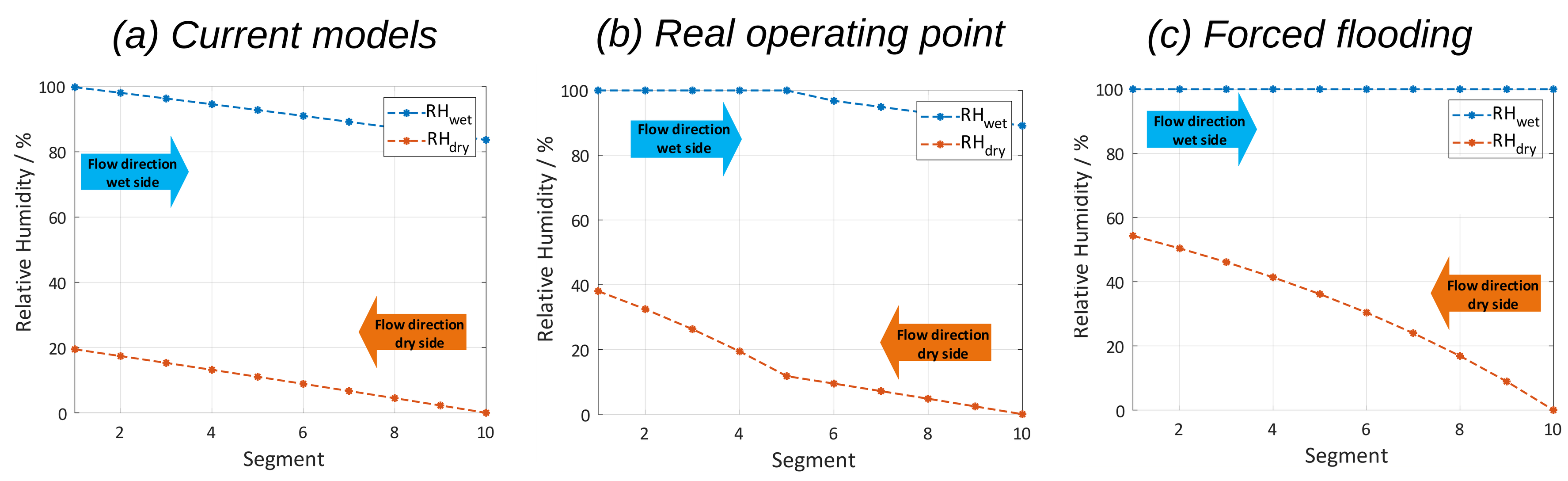


Figure 4: RH slope of the wet and dry gas streams over the segments.

- Current models underestimate the water transport ratio
- Forced flooding as possibilty for humidifier performance improvement

Channel geometry		Input Parameter wet side		Input Parameter dry side	
Width	1.25 mm	Pressure	2.5 bar	Pressure	2.5 bar
Length	54 mm	Temperature	350 K	Temperature	350 K
Height	1 mm	Volume flow	1 lpm	Volume flow	1 lpm
Quantity	26	RH	100%	RH	0%
Geometry	Rectangular	Mass flow liquid water	(a) 0 g/s (b) 0.075 g/s (c) 0.2 g/s	Mass flow liquid water	0 g/s

Table 1: Input Parameters for Figure 4

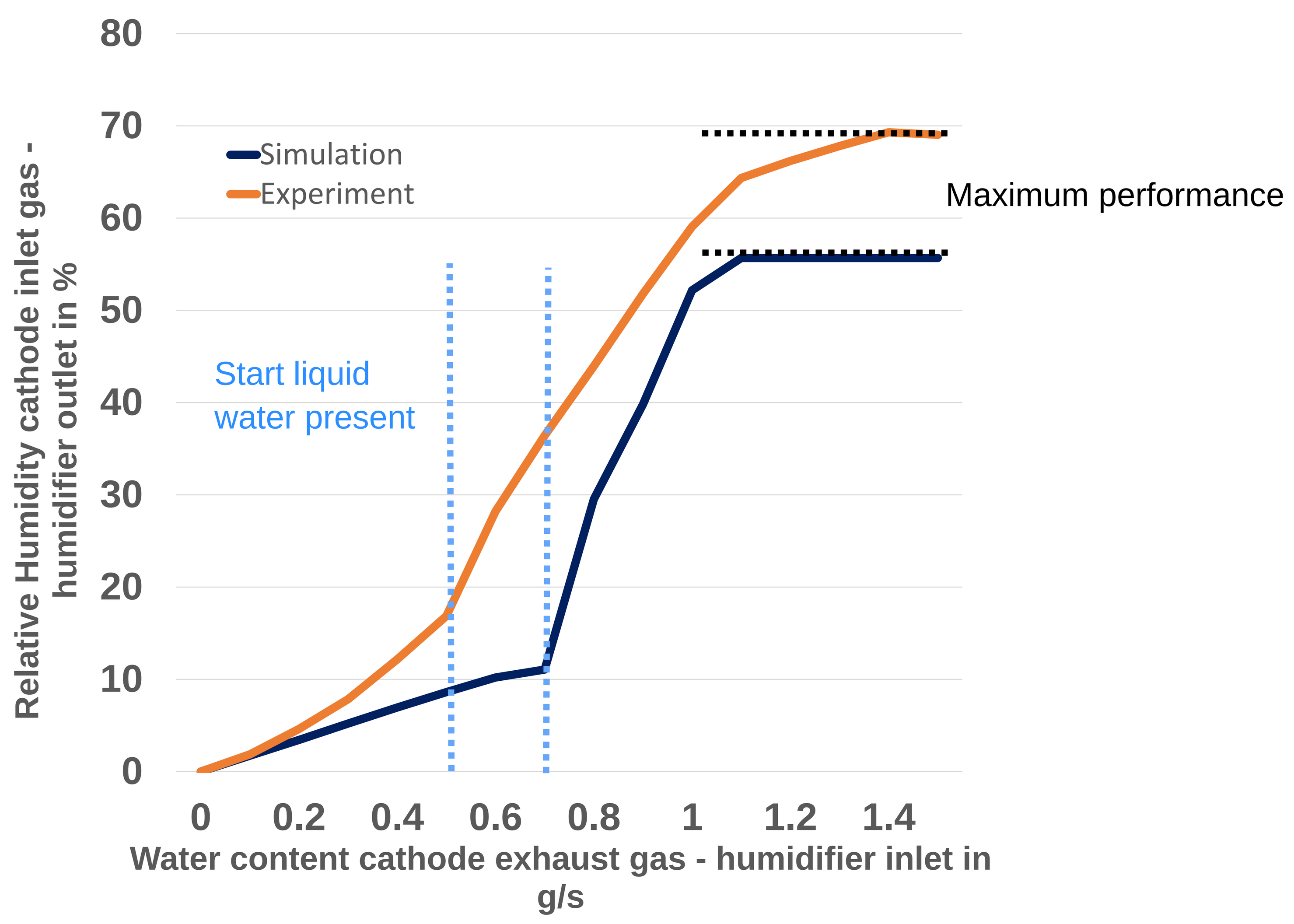


Figure 6: Comparison between simulation and experiment

Experiment confirms both effects:

- Higher transport rate due to liquid water
- Maximum water transport rate is achieved with complete flooding

Table 2: Input Parameter for Figure 6

Channel parameter		Flow parameter	Wet side	Dry side
length	70 mm	Flow rate	10 lpm	10 lpm
width	1 mm	Pressure	2 bar	2 bar
height	0.5 mm	Temperature	44° C	44° C
number	34	Water content inlet	0 – 1.4 g/s	0 g/s

Conclusions & Outlook

- Liquid water is present at the humidifier at various operating points; Current membrane humidifier models neglect the presence of liquid water, the goal of the presented model here is to close this gap
- The simulative and the experimental results show that the consideration of liquid water significantly improves the water transport characteristics of the humidifier and thus the performance of the humidifier
- Next step: Optical visible test chamber for validation of liquid film formation

Literature

[1] Cahalan, The Analysis of Membranes for External Humidification of PEM Fuel Cells, 2018

[2] Springer et al, Polymer Electrolyte Fuel Cell Model, 1991