System Considerations on On-Board Methanol Steam PEM Fuel Cells

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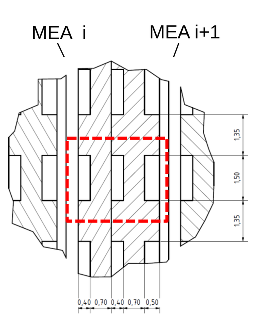
Motivation & Approach

- Energy density optimization of a high temperature PEM fuel cell system
  ⇒ Increasing the competitiveness of fuel cells in mobile applications
- Objective: Refueling pure methanol instead of water diluted fuel
- On board water recovery for methanol steam reforming as an option?
- Sensitivity analysis of operation parameters and environmental effects

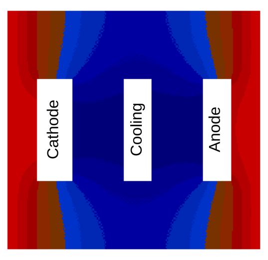
- System Simulation based on component approach
- 1D fuel cell and 1D methanol steam reforming model
- Experimental water recovery

Component Modeling Fortran 90 → AspenPlus®

- High temperature PEM fuel cell

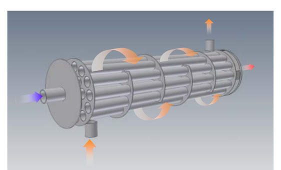


Modeling Domain: Cross section through the stack perpendicular to the flow direction through the channels



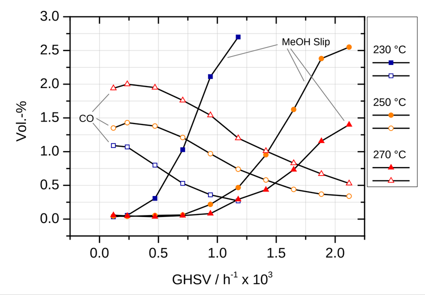
2D Heat Conduction: → Determination of the thermal distribution within the cell [1]

- Methanol Steam Reformer

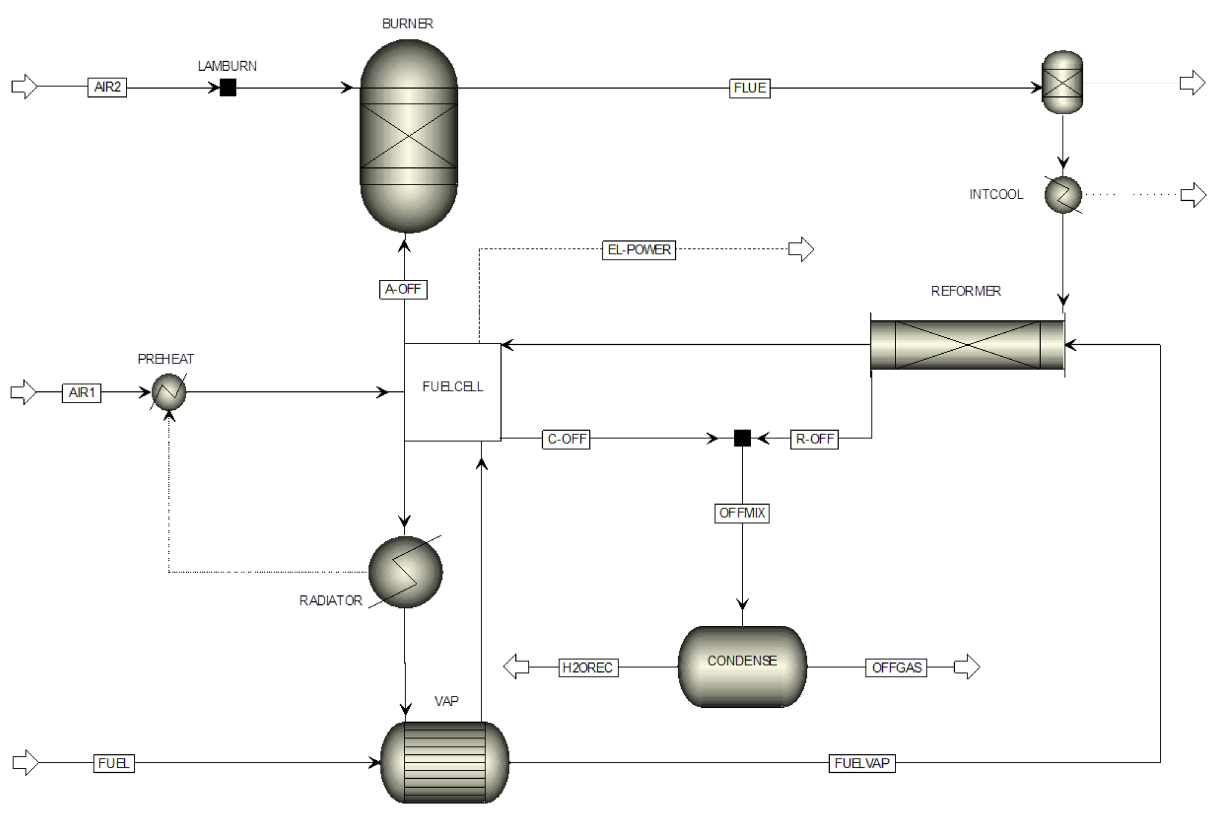


Reaction Kinetics MSR: Based on the approach of B.A. Peppley and J.C. Telotte [2,3]

Experimental MSR Operation:
Variation of
- W/F_0
- Temperature



Analysis of the fuel cell – reforming interaction via system simulation and experiments



Process simulation of the fuel cell system
Implementation of the fuel cell and reformer model into a process environment with a waste gas burner and heat exchangers including system controls

Operation Parameters

1. Pressure ↑
   + increasing condensing temp.
   + partial pressure increase
   - Δp control
   - equilibrium MSR → educts

2. Steam to Carbon Ratio ↑
   + reduced CO output
   - reduced H_2 concentration

3. Cathode Stoichiometry ↓
   + increased H_2O concentration
   + reduced compression power
   - reduced O_2 partial pressure

Control Parameters

4. Burner Temperature ↑
   + high exergy stream
   + MSR temperature control
   + increased H_2O concentration
   - hardware degradation

5. CO_2 / N_2 ↓ by Cleaning
   + increased condensing temp.
   (+ increased O_2 concentration)

Environmental Effects

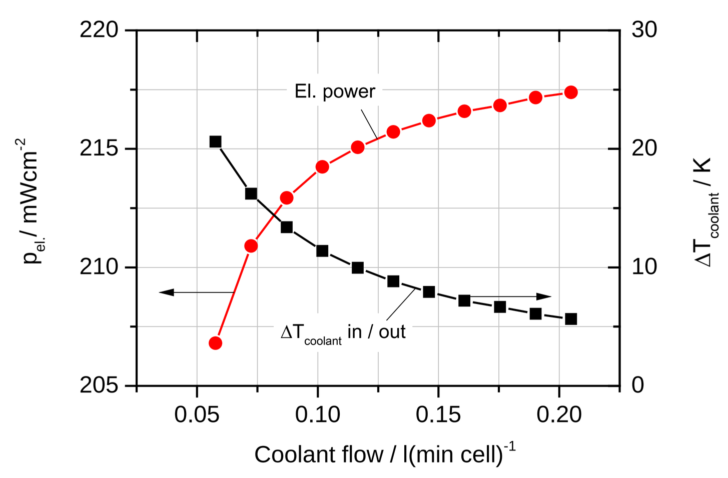
6. Relative Humidity ↑
   + increased condensing temp.
   - reduced O_2 partial pressure
   - influence on MSR control

Experimental Water Recovery

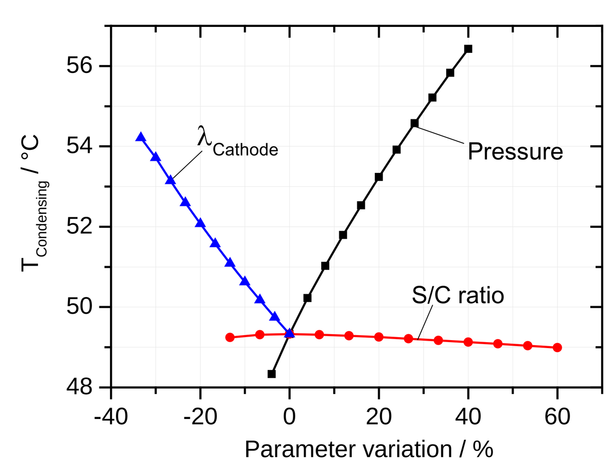
Operation of a Serenergy H3-5000 module generation II in two climate chambers

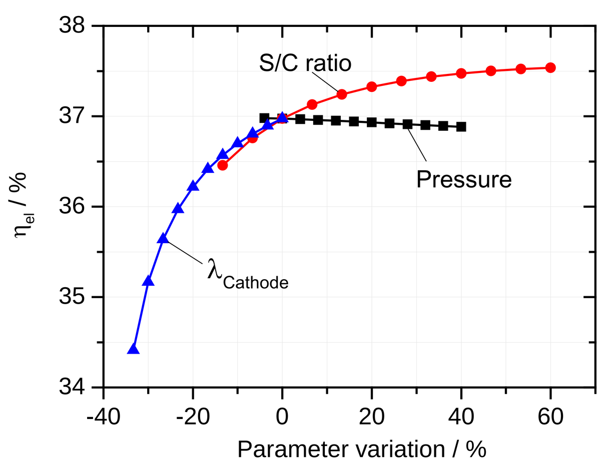
Test set-up
- Simulation of different environments → temperature and rel. humidity
- Water recovery at different temperature levels in chamber II

Results



- Responsive thermal control required for efficient operation
- Control strategy: Outlet temperature of the fuel cell kept constant





Effect of parameter variation on condensing temperature and system efficiency
Reference: 0.4 Acm⁻², 1250 mbar, S/C = 1.5, $\lambda_{Cathode}$ = 3.0

Chemical Analysis of the Condensed Water

pH 3.28

Compound	mg/l
Silicate	9.45
Aluminum	2.60
Sulfate	1.22
Phosphate	0.70
Calcium	0.5
Sodium	0.5
Magnesium	0.5

Additional compounds of formic acid and ethylene glycol were found

⇒ Water treatment required

Summary & Outlook

- Detailed fuel cell and reformer model reveal an insight into the relevance of operation parameters on system performance and the effect on condensing temperatures
- Experimental results show the necessity of an additional water cleaning unit required for water recycling
- The combination of an increased burner temperature with an intercooler allows for high condensing temperatures and good MSR temperature control at a time
- The intercooler receives gas at high temperatures which could be used thermodynamically for compressing cathode air by expansion via a turbo unit which additionally increases the condensing temperature. In this case the anode compartment is pressurized hydraulically via the fuel stream

Acknowledgements:

The research leading to these results has received funding from the German government within the "Nationale Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP) under grant agreement n° 03BI205I.

References:
(1) B. Glück, Bericht Wärmeleitung, 2011
(2) B. A. Peppley et al., Applied Catalysis A: General 179, 1999, p. 31-49
(3) J. C. Telotte et al., Journal of Chemical Reactor Engineering, Vol. 6, 2008, Art. 64

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