Pressurized Solid Oxide Fuel Cells with Reformate as Fuel

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Motivation

Hybrid power plant

Pressurized SOFC-system coupled with gas turbine:

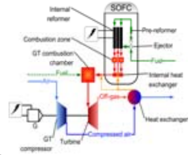
- High electrical efficiency (> 60 %) [1]
- Fuel: natural gas, reformates
- Low emissions
  - → Goal: 50 kW-class plant (construction starts in 2013)

Characteristics of each component required

Pressurized SOFC:

- Deduction from ambient conditions not possible
- Insufficient literature data

→Testing and characterization of pressurized SOFC



Effect of pressure on:

- Cell and stack behavior
- Reformate gas composition, reforming reactions
- Electrochemical processes
- Steady state and transient operational behavior
- Operational limits

Experimental

Test rig [2]

- Pressure: 1 to 8 bar
- Pressure difference (anode/cathode/pressure vessel): up to 500 mbar
- Temperature: up to 950 °C
- Anode gas: H_2, N_2, CH_4, CO and CO_2 with adjustable water vapor content
- Cathode gas: Air, O_2, N_2 and He
- Analysis: - V(i)-characteristics
  - Gas analysis

Conditions

- H_2/N_2
- Reformate 1: 18% H_2, 34% H_2O, 2% CO, 27% CO_2 and 19% CH_4
- Reformate 2: 58.4% H_2, 20% H_2O, 12.2% CO, 5.5% CO_2 and 3.9% CH_4

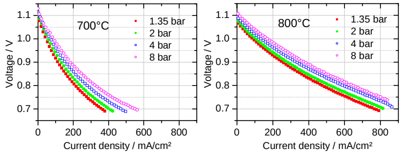
Results

Pressurized polarization curves

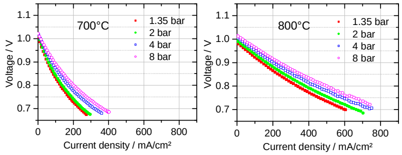
Current voltage characteristics for one cell from the middle of the stack

- Pressures 1.35 to 8 bar
- Three gas compositions
- 700°C and 800°C

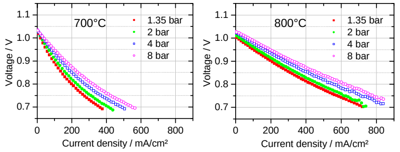
- Elevated pressure
  - leads to higher OCV
  - affects the gradient of the curve under load.
- Higher current density leads to greater difference between i-V curves at different pressures.



Pressure dependent current voltage curves for H_2/N_2 at 700°C (left) and 800°C (right).



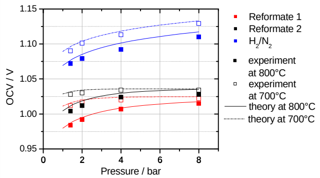
Pressure dependent current voltage curves for Reformate 1 at 700°C (left) and 800°C (right).



Pressure dependent current voltage curves for Reformate 2 at 700°C (left) and 800°C (right).

Gas composition and OCV under pressure

Pressure and temperature dependence of OCV



theoretical OCV obtained by

$$OCV = -\frac{RT}{2F}\ln\frac{\sqrt{p_{O_2,cathode}}}{\sqrt{p_{O_2,anode}}}$$

assuming equilibrium composition of fuel at cell using open-source software CANTERA [3]

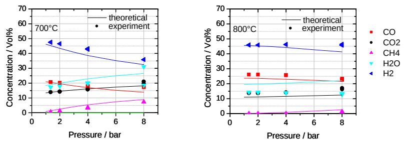
- Good agreement between experiment and theory
- OCV increase with pressure
- Increase greatest for H_2/N_2

- For reformate gases temperature has a strong influence on OCV increase through pressure:
  - gain in OCV through pressurization is smaller for lower temperature
  - OCV for reformate 2 at 8 bar is almost the same at 700°C and 800°C

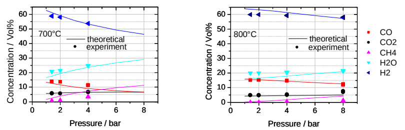
Equilibrium compositions of reformate gases and gas composition at OCV after stack

- Good agreement between measured and theoretical equilibrium composition
- At 700°C gas composition varies more with pressure than at 800°C:

higher pressure → smaller hydrogen and CO content of fuel gas
→ lower increase in OCV at low temperatures



Calculated equilibrium gas composition and measured values over pressure for Reformate 1

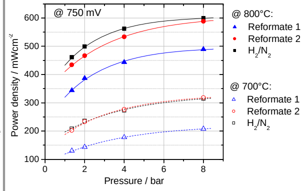


Calculated equilibrium gas composition and measured values over pressure for Reformate 2

Performance gain under pressure

Influence of pressure on performance at constant voltage of 750 mV

- Logarithmic behavior for all fuels



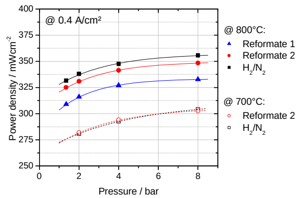
At 800°C:

- Power density highest for H_2/N_2
- Power density gain slightly greater for reformates.
- Highest absolute increase for reformate 2 (154 mW/cm²)
- Highest relative increase for reformate 1 (60%)

At 700°C:

- Smaller increase in power density than for 800°C.
- Smallest increase for reformate 1
- Reformate 2 and H_2/N_2 : similar power densities

Power density at constant current density of 0.4 A/cm²



- Power density increase similar for all fuels
- Increase in power density higher at 700°C than at 800°C
- At 700°C reformate 2 and H_2/N_2: similar performance

Conclusions

Pressure increase leads to:

- Higher OCV
- Higher performance
- Change in gas composition

- For reformates OCV increase through pressurization depends on temperature due to the changing of gas composition with pressure and temperature
- Absolute power gain through pressurization highest for prereformed reformate
- Higher power gain at higher temperatures
- Performance gains of up to 60% at 750 mV can be achieved by raising pressure to 8 bar

References

1. S. Singhal, K. Kendall, *High Temperature Solid Oxide Fuel Cells Fundamentals, Design and Application*, Elsevier, Oxford, pp. 374 (2003).
2. S. Seidler, M. Henke, J. Kallo, W.G. Bessler, U. Maier and K.A. Friedrich, *Pressurized solid oxide fuel cells: Experimental studies and modeling.* Journal of Power Sources, 196, p. 7195-7202 (2011).
3. D.G. Goodwin, *An Open-Source, Extensible Software Suite for CVD Process Simulation.* in Proceedings of Chemical Vapor Deposition XVI and EUROCVD 14, Electrochemical Society (2003).

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