Institute of
Engineering Thermodynamics

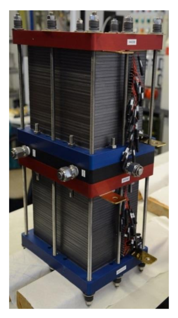
A PEMFC Stack with Extended Operating Temperature Range up to 120 °C and Related Water Management Considerations

Andreas Dreizler, Tiziana Ruiu, Jens Mitzel, Erich Gülzow
German Aerospace Center (DLR), Pfaffenwaldring 38-40, D-70569 Stuttgart, Germany
andreas.dreizler@dlr.de

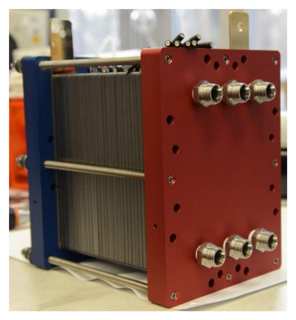
Why extended temperature range?

- stack for automotive applications: able to perform transient operation at high load even with critical cooling conditions (higher power required → higher heat production):
  - long uphill drive
  - driving in hot areas, e.g. deserts (reduced cooling)
- downsizing of cooling system: lower cooling power is necessary (increased heat dissipation) if higher stack temperature is allowed
  - shorter cooler operating time (energy/fuel saving)
  - smaller cooler size (space/weight saving in vehicles)

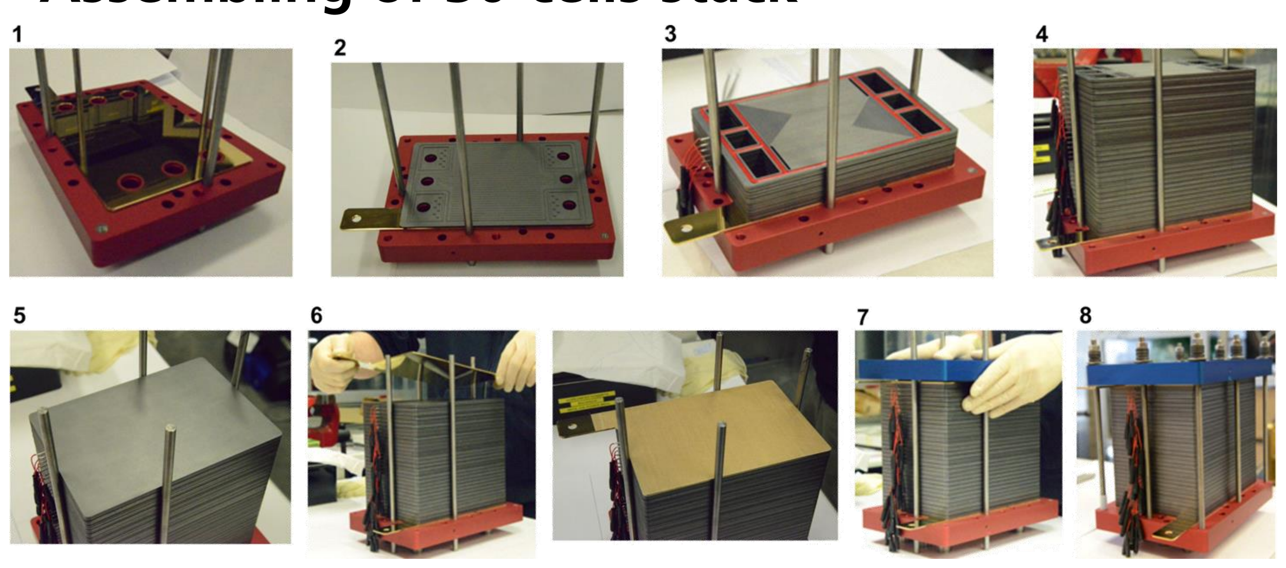
Wide-temperature-range stack goals



- development of a PEMFC stack (module):
  - 2.5 – 5 kW_{el}
  - 30 – 60 cells
- stack requirement conditions:
  - extended temperature range up to 120 °C
  - 20 temperature cycles feasible
    - → duration of each cycle: 65 min
    - → reversible max. power loss at 120 °C with unmodified humidification: 30 %
- durability test:
  - long-term test over 1000 h

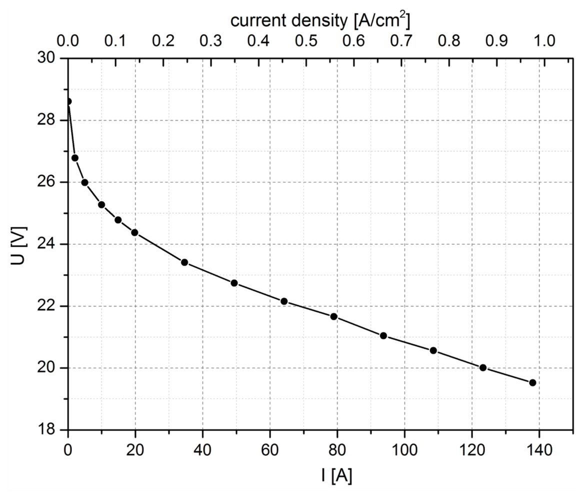


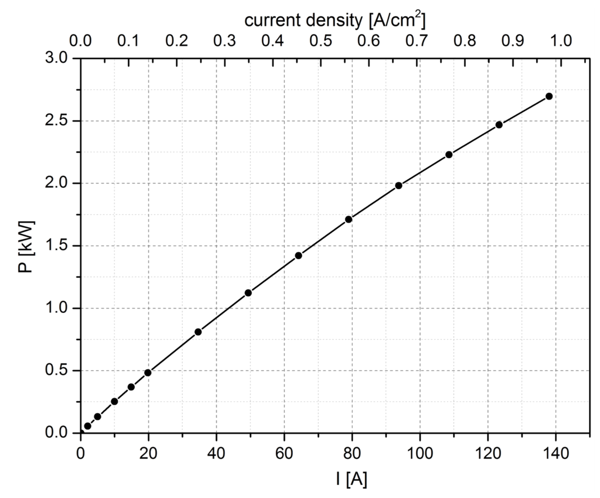
Assembling of 30-cells stack



Experimental results

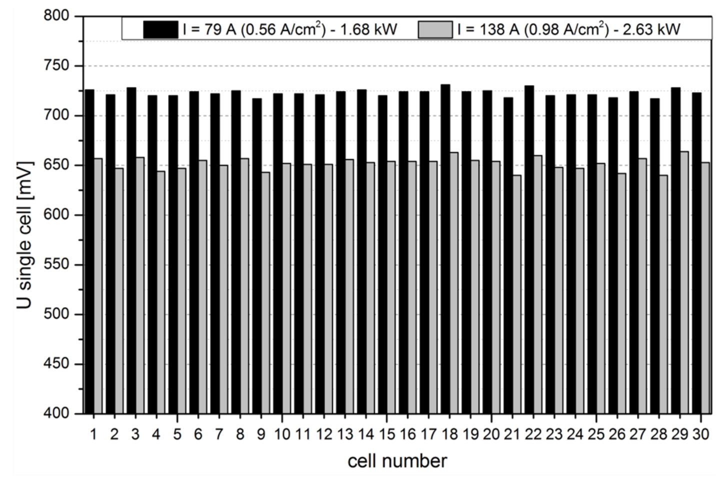
Polarization curve





ca. 2.7 kW_{el} at 19.5 V and 140 A (ca. 1 A/cm²)

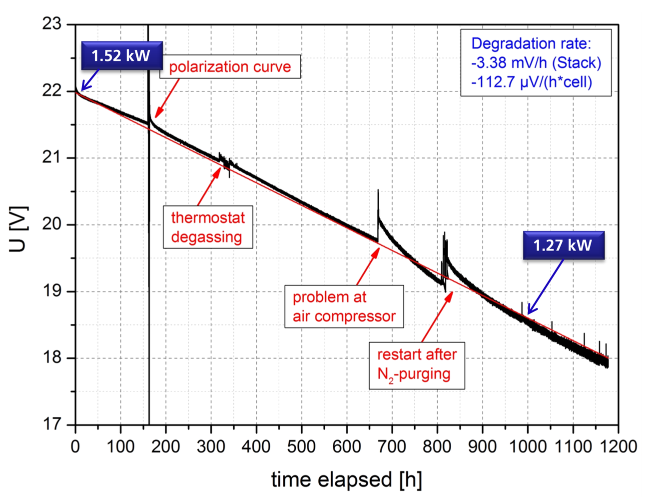
Parameter	Set-up value
T_{stack}	80 °C
$p_{anode} = p_{cathode}$	1.5 bar_{abs}
RH_{anode}	15 %
$RH_{cathode}$	60 %
λ_{anode}	1.5
$\lambda_{cathode}$	2.5
t_{dwell}	5 min



- high homogeneity of 30 single cell voltages
- all 30 cells are fed homogeneously with reactants

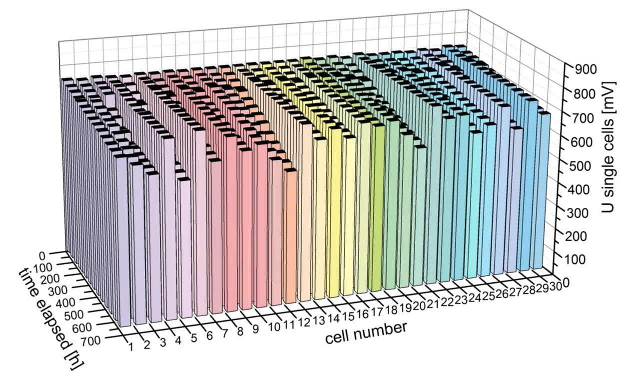
Long-term test

- more than 1000 h at 70 A: output power 1.5 kW_{el}
- degradation rate nearly constant: linear voltage drop
- 16 % power loss in 1000 h; ca. 250 W and 3.5 V → 0.016 %/h, 250 mW/h or 8.3 mW/(h·cell)

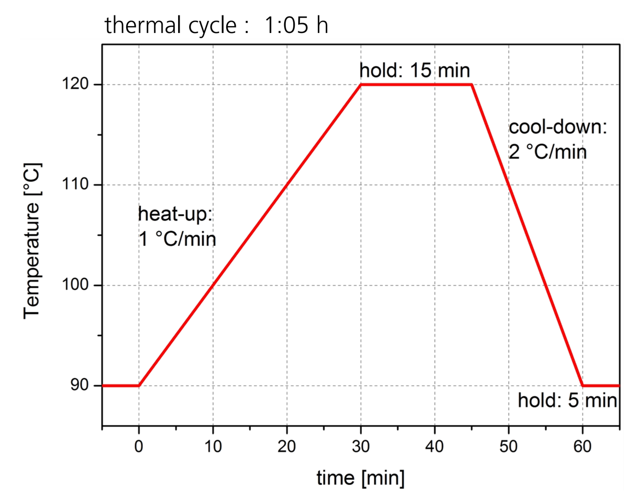


Parameter	Set-up value	Parameter	Set-up value
T_{stack}	80 °C	$\dot{V}_{anode}$	22 l/min
I_{stack}	70 A (0.49 mA/cm²)	$Q_{water, anode}$	52 g/h
$p_{anode} = p_{cathode}$	1.5 bar	$\dot{V}_{cathode}$	87.3 l/min
RH_{anode}	15 %	$Q_{water, cahode}$	969 g/h
$RH_{cathode}$	60 %	λ_{anode}	1.5
		$\lambda_{cathode}$	2.5

single cell voltage behavior:



Thermal cycles 90–120 °C

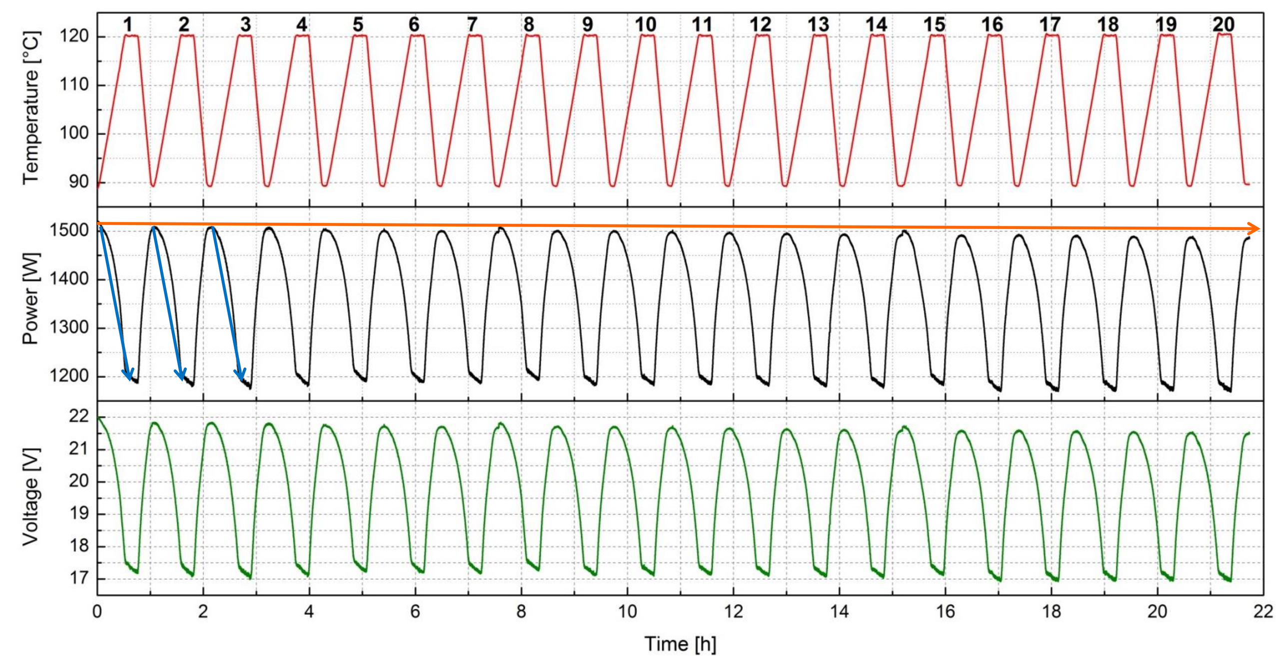


Parameter	lower limit	upper limit
T_{stack}	90 °C	120 °C
$p_{anode} = p_{cathode}$	1.5 bar	
I_{stack}	70 A	
$\dot{V}_{anode}$	22 l/min	
$Q_{water, anode}$	907 g/h	
$\dot{V}_{cathode}$	87.3 l/min	
$Q_{water, cathode}$	2464 g/h	
RH_{anode}	100 %	35 %
$RH_{cathode}$	80 %	28 %
λ_{anode}	1.5	
$\lambda_{cathode}$	2.5	

- 20 thermal cycles at 70 A (0.49 A/cm², 1.5 kW)
- cycle duration: 1:05 h
  → 45 min (transient operation) + cool-down
- gas humidification: dew points are held constant during the cycle
- goal: max. 30 % power loss within a cycle

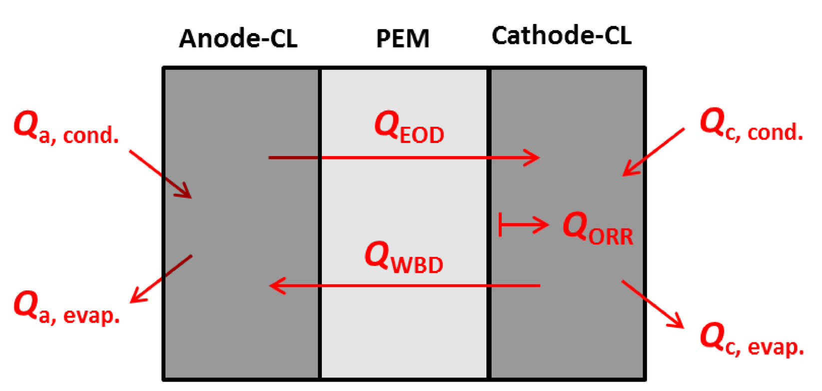
Information obtained on:

- reversible power loss within a cycle (membrane drying)
- irreversible degradation over all cycles



- constant reversible power loss within a cycle: 21 ± 1 %
- irreversible stack power loss at 90 °C: 33 W in 22 h → < 0.1 %/h, 1.5 W/h or 50 mW/(h·cell)
- degradation rate: 21.4 mV/h or 714 µV/(h·cell)
- good stack homogeneity over all cycles
- irreversible stack performance drop is small enough for automotive applications

Outlook: water management considerations



Mass flow Q_i	Legend for indices
a, cond.	anode water condensation
a, evap.	anode water evaporation
c, cond.	cathode water condensation
c, evap.	cathode water evaporation
EOD	electroosmotic drag
WBD	water back diffusion
ORR	oxygen reduction reaction

- determination of gas humidity at stack gas in-/outlet for both anode and cathode (4 humidity sensors)
- short stack with 15 cells; 1.25 kW_{el}
- steady state measurements: 0.33, 0.66 and 1.00 A/cm²; RH = 30, 55 and 80 % (variation on both sides) → 27 single measurements
- goal: mathematical correct balancing model of incoming/outgoing and produced water verified by experimental results

$$Q_{water,in} = \frac{\dot{V}_{gas}}{22414\,\frac{\mathrm{cm^3}}{\mathrm{mol}}} \cdot \frac{p_{vap}\,[\mathrm{mbar}]}{p_{system}\,[\mathrm{mbar}] - p_{vap}\,[\mathrm{mbar}]} \cdot 18.015\,\frac{\mathrm{g}}{\mathrm{mol}} \cdot 60\,\frac{\mathrm{min}}{\mathrm{h}}$$

$$Q_{water,ORR} = x_{cells}\,\frac{18.015\,\frac{\mathrm{g}}{\mathrm{mol}} \cdot I \cdot 3600\,\frac{\mathrm{s}}{\mathrm{h}}}{2 \cdot 96485\,\frac{\mathrm{A \cdot s}}{\mathrm{mol}}}$$

List of abbreviations	
$Q_{water,in}$	water mass flow ingoing humidified gas hydrogen/air
$Q_{water,ORR}$	water mass flow oxygen reduction reaction
$\dot{V}_{gas}$	gas flow reactant gases hydrogen/air
p_{vap}	water vapor pressure
p_{system}	system pressure anode/cathode
x_{cells}	number of single cells in stack

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