A PEMFC Stack with Extended Operating Temperature Range up to 120 °C

Institute of Engineering Thermodynamics

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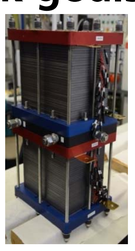
Why extended temperature range?

➢ 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)

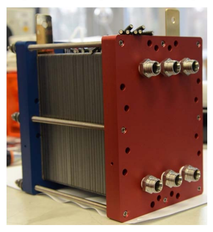
➢ **downsizing of cooling system**:
lower cooling power is necessary (increased heat dissipation) if higher stack temperature is allowed
- shorter cooler operating time (energy/fuel saving)
- smaller cooler size (space/weight saving in vehicles)

Wide-temperature-range stack goals



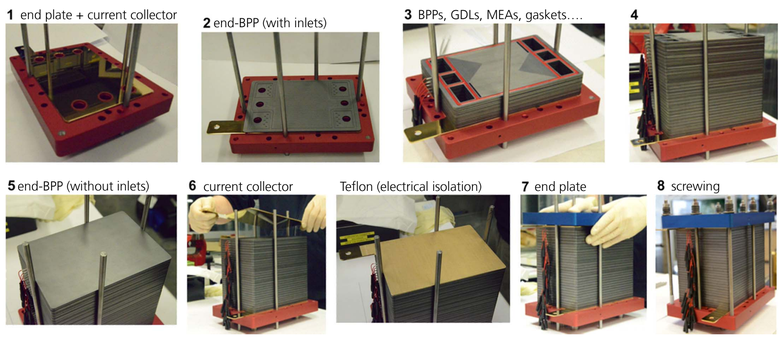
➢ development of a PEMFC stack:
- 2.5 – 5 kW_{el} (module)
- 30 – 60 cells

➢ feasibility of WTR-conditions:
- extended temp. range **up to 120 °C**
- **20 temperature cycles** feasible
  – duration of each cycle: 65 min
  – aim: reversible maximum power loss at 120 °C with unmodified humidification: 30 %



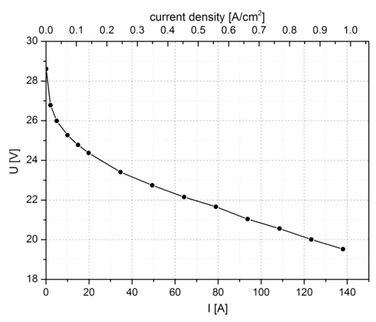
➢ durability test:
- long-term test over **1000 h**

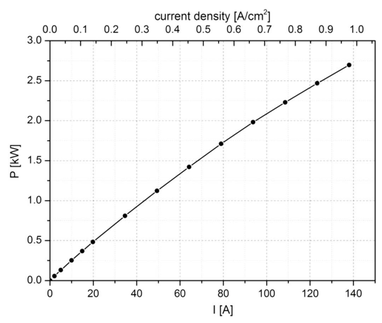
Assembling of 30-cell stack



Experimental results

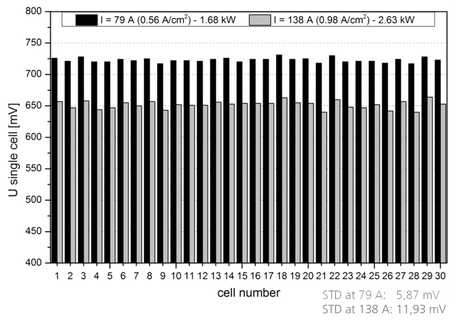
Polarization curve





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

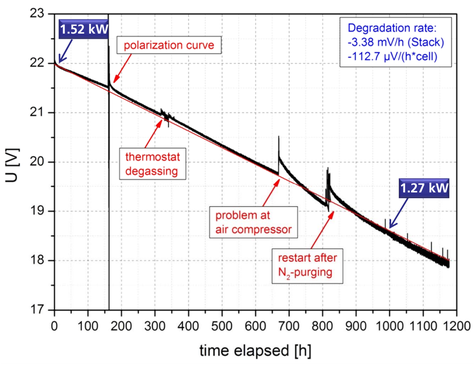
Parameter	Set-up value
T_{stack}	80 °C
$p_{anode} = p_{cathode}$	1.5 bar_{abs}
RH_{anode}	15 %
$RH_{cathode}$	60 %
λ_{anode}	1.5
$\lambda_{cathode}$	2.5
t_{dwell}	5 min



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

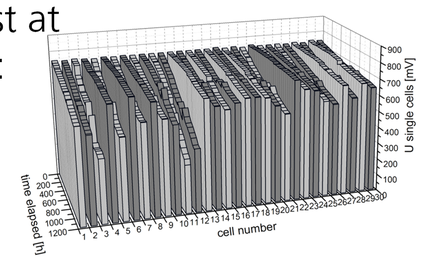
Long-term test

- > 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, 3.5 V) → 0.016 %/h (250 mW/h or 8.3 mW/(h·cell))

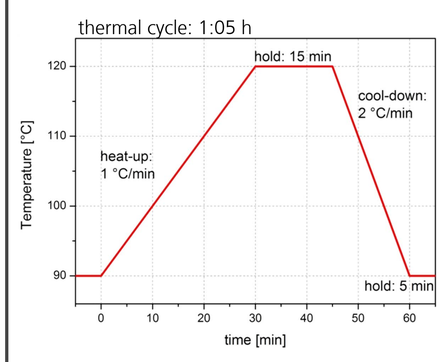


Parameter	Set-up value
T_{stack}	80 °C
I_{stack}	70 A (0.49 mA/cm²)
$p_{anode} = p_{cathode}$	1.5 bar_{abs}
RH_{anode}	15 %
$RH_{cathode}$	60 %
Q_{anode}	22 l/min
$Q_{water,\ anode}$	52 g/h
$Q_{cathode}$	87.3 l/min
$Q_{water,\ cahode}$	969 g/h
λ_{anode}	1.5
$\lambda_{cathode}$	2.5

single cell voltage behaviour during long-term test at 70 A (0.49 mA/cm²):



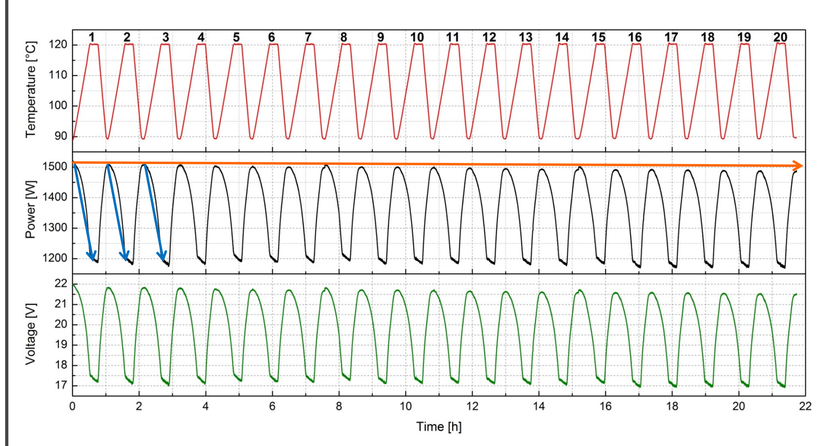
Thermal cycles 90–120 °C



Parameter	lower limit	upper limit
T_{stack}	90 °C	120 °C
$p_{anode} = p_{cathode}$	1.5 bar_{abs}	
I_{stack}	70 A (0.49 mA/cm²)	
Q_{anode}	22 l/min	
$Q_{water,\ anode}$	907 g/h	
$Q_{cathode}$	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 (90 → 120 °C) +
  15 min cool-down (120 → 90 °C) +
  5 min recovery (90 °C)
- gas humidification: on both sides 100 % at 90 °C (cycle start), then no variation
- goal: max. 30 % power loss within a cycle

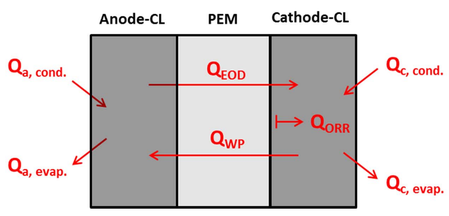
Information obtained on:
- reversible power loss within a cycle → membrane drying
- irreversible degradation → stack stability over all cycles



- stable 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)
- good stack stability 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	electro-osmotic drag
WP	water permeation
ORR	oxygen reduction reaction

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

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

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

List of abbreviations

$Q_{water,in}$	water mass flow ingoing with humidified gases (H_2/air)
$Q_{water,ORR}$	water mass flow from oxygen reduction reaction
$\dot{V}_{gas}$	gas flow of reactant gases (H_2/air)
p_{vap}	water vapour pressure
p_{system}	system pressure anode/cathode
x_{cells}	number of single cells in the stack

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Knowledge for Tomorrow

Wissen für Morgen

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