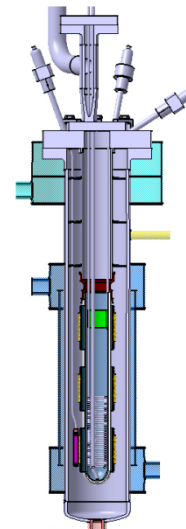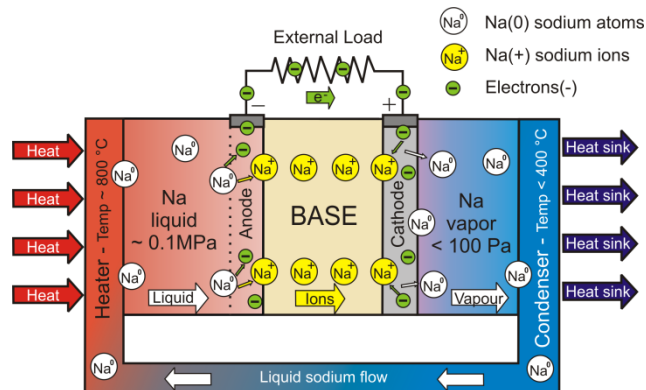# B4: Phase changes in liquid metals for direct energy conversion.
Alkali Metal Thermo-Electric Converter (AMTEC)

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LIMTECH Ph.D Summerschool, 12-13.07.2016 Ilmenau

Institute for Neutron Physics and Reactor Technology (INR)
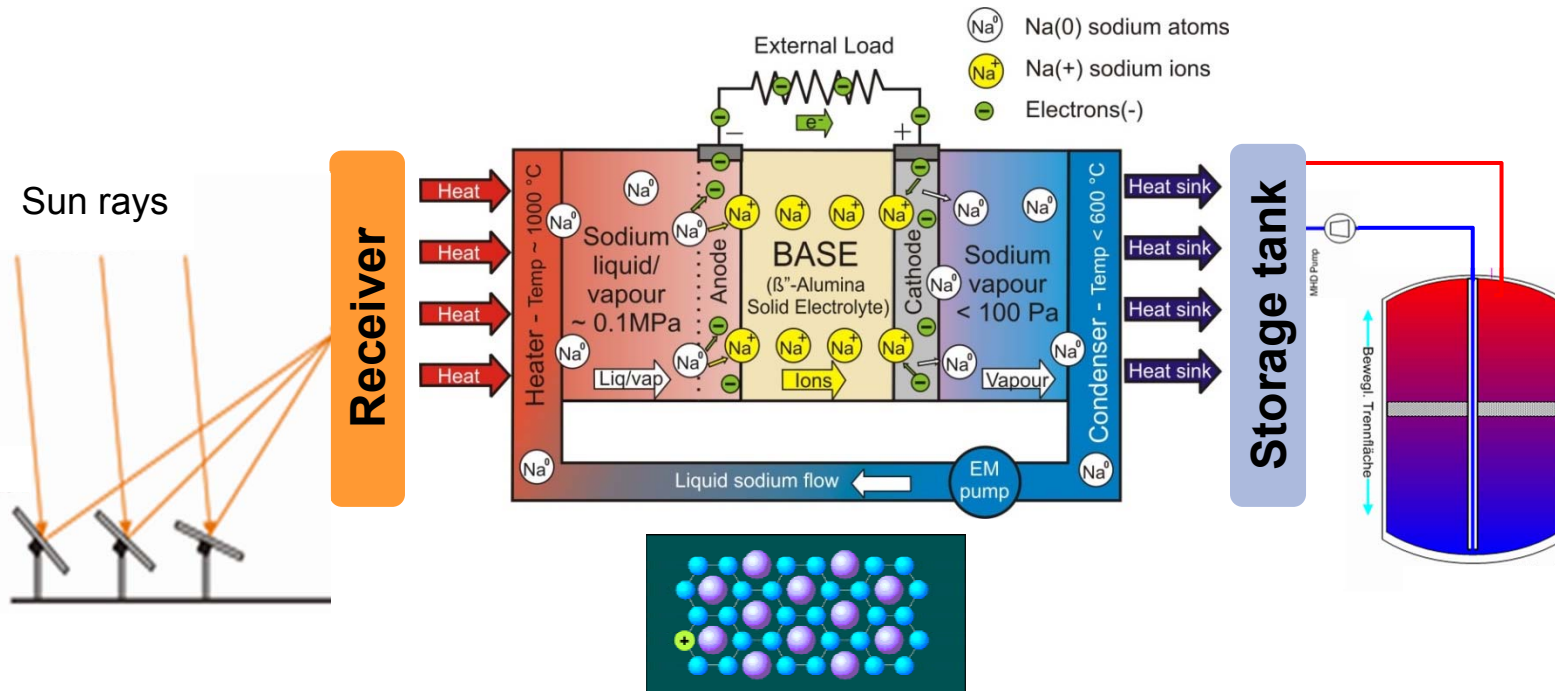
Content

- Introduction – AMTEC process

- Experimental setup
  - ATEFA
  - AMTEC test cell

- Analysis of former measurement data (Heinzel et al. 1993)

- Summary & outlook

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AMTEC – direct heat to electricity conversion

Alkali Metal Thermo-Electric Converter

- Key component: β''-Alumina Solid Electrolyte (BASE)
- Key process: Na-ionization
  ΔP across BASE → Δ(sodium activity)

$$Na \longrightarrow Na^+ + e^-$$

Experimental setup
AMTEC Test Facility (ATEFA)

- Data acquisition and control system finished (test phase ongoing)

- ATEFA in last phase of construction

Preliminary tests*

- First successful ceramic-metal joint (10^{-5} mbar)

- TiC, TiN, Mo electrodes achieved

- Analysis of electrode ongoing

*together with other institutes in KIT

AMTEC cell

Na – Tanks

Nb - BASE - Cathodes

Analysis of former measurement data (1993)

Basic equation system

- Open circuit (oc) voltage, Nernst equation:

$$E_{cell}{}^{oc} = \frac{RT_B}{F} \ln \frac{p_a}{p_c}$$

- Closed circuit (cc) voltage:

$$E_{cell}{}^{cc} = E_{cell}{}^{oc} - \underbrace{(\xi_a - \xi_c)}_{\text{Polarization losses}} - \underbrace{\xi_r}_{\text{Ohmic losses}}$$

(with $(\xi_a - \xi_c) \to 0$ indicated)

Applying Butler-Volmer equation for overvoltage:

$$E_{cell}{}^{cc} = \frac{2RT_B}{F} \ln \left[\frac{p_a}{2(p_c{}^T + (K_f + m_i)i)} \left\{ -\frac{i}{i^{ex}} + \sqrt{\left(\frac{i}{i^{ex}}\right)^2 + \frac{4(p_c{}^T + (K_f + m_i)i)}{p_a}} \right\} \right] - i\, R_\Omega{}^{cell}$$

Analysis of former measurement data (1993)

Overvoltage losses
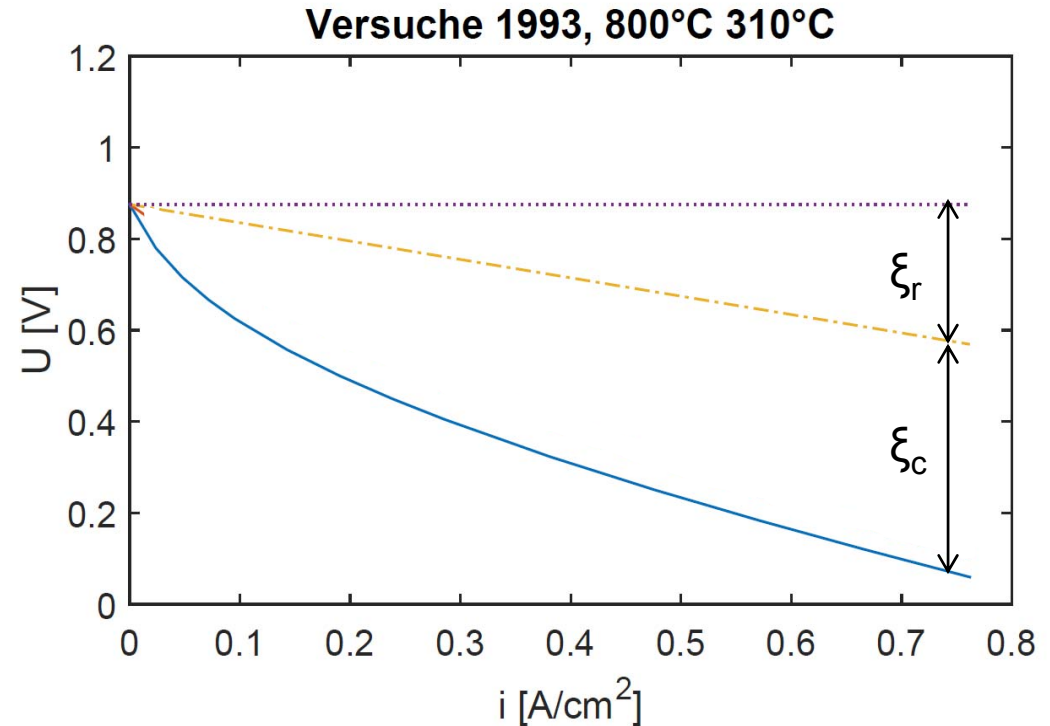
Voltage drop:

- Ohmic losses:
  $$\xi_r = i\, R_\Omega{}^{cell}$$
  (~ 20 %)

- Polarization losses: ξ_c
  (~ 80 %)

  - Grain size
  - Porosity
  - Thickness
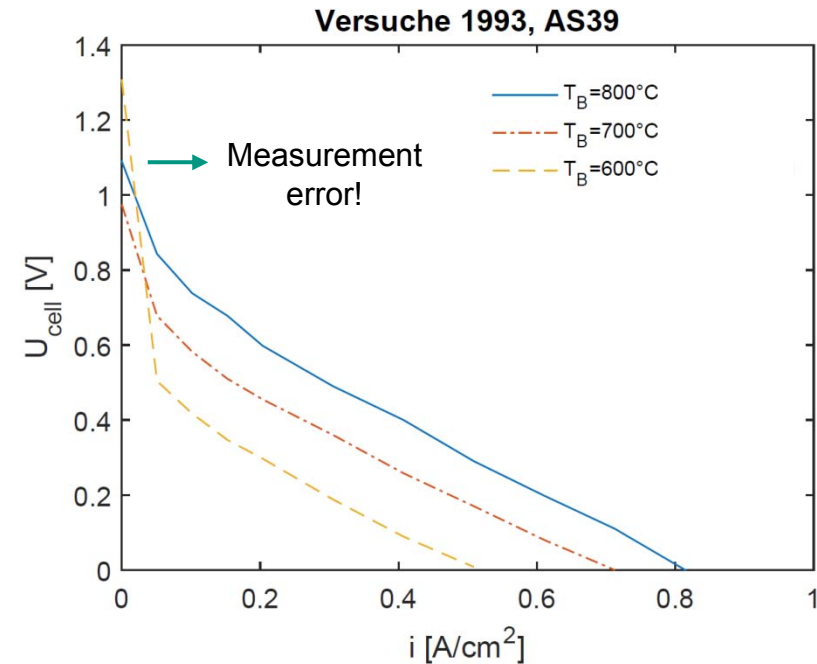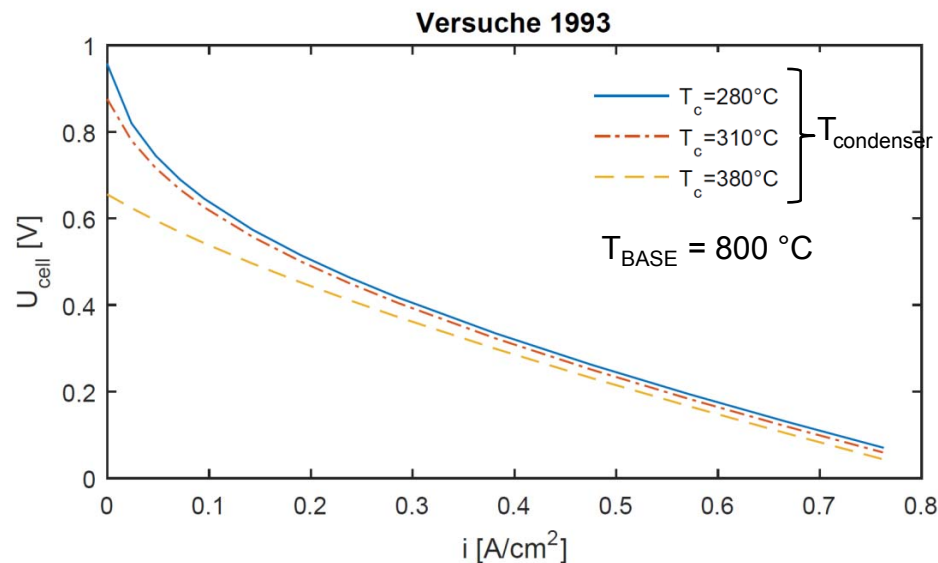 - Current collector structure
  - Material properties

Versuche 1993, 800°C 310°C

Heinzel et al. 1993

Analysis of former measurement data (1993)

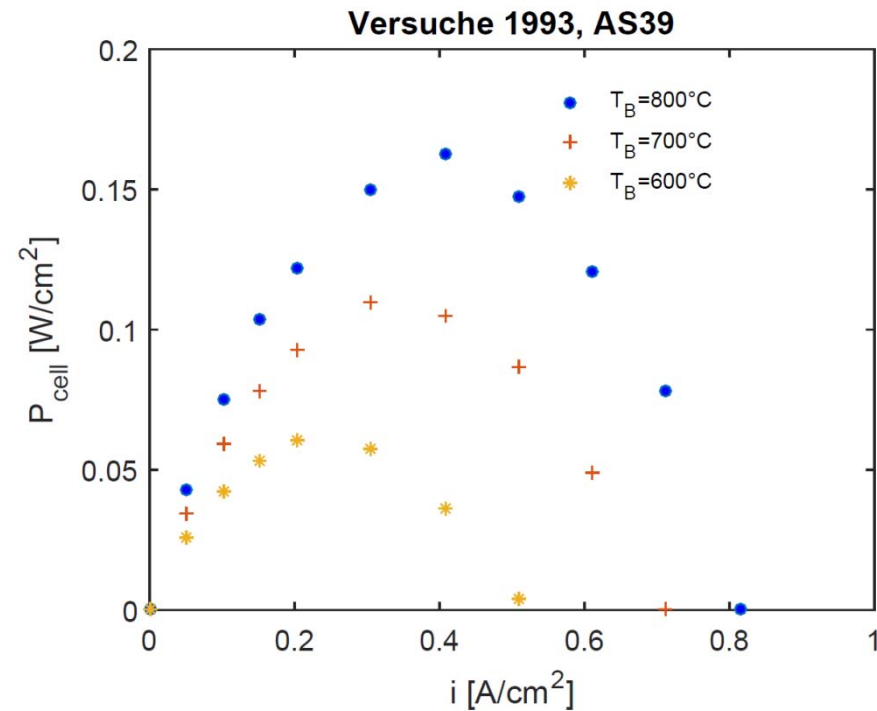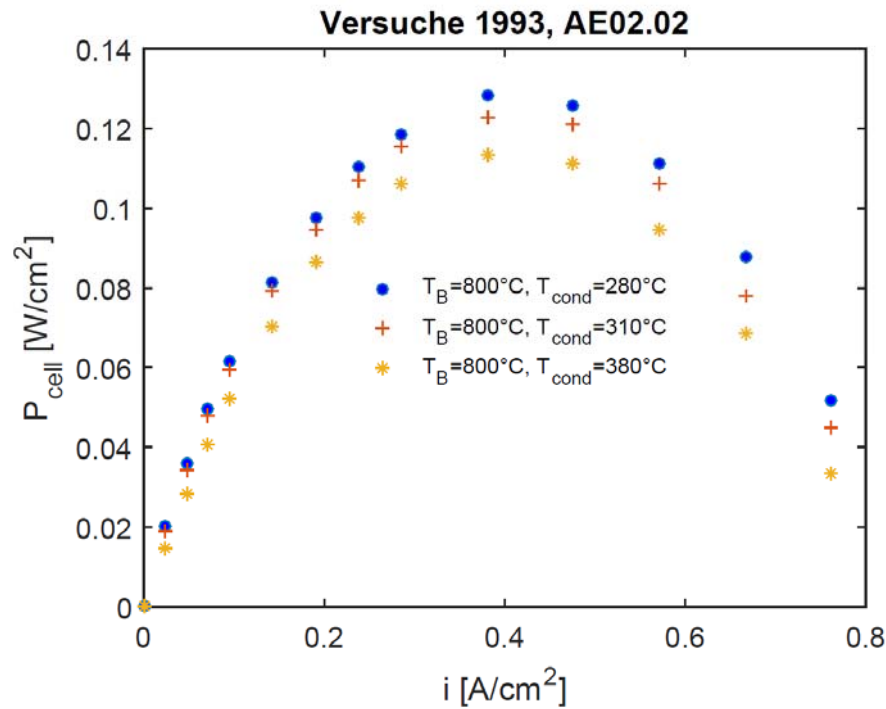## Effect of the temperature

- **Characteristic curve (IV)**

Versuche 1993

$T_{BASE} = 800\ °C$

Versuche 1993, AS39

Heinzel et al. 1993

- **Decreasing T_{cond} increases U_{cell}**
- **Increasing T_{BASE} increases U_{cell}**
- **Effect of T_{BASE} >> effect of T_{cond}**

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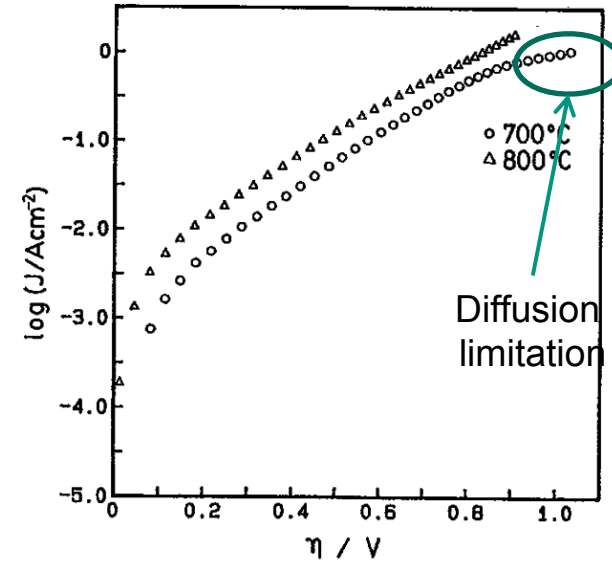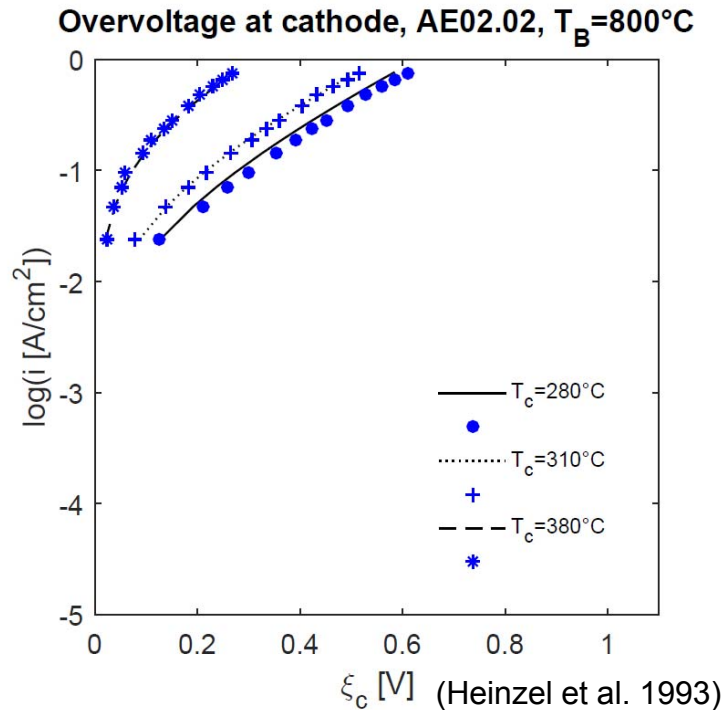
Analysis of former measurement data (1993)

Effect of the temperature

Heinzel et al. 1993

Analysis of former measurement data (1993)

Effect of the polarization - overvoltage

Overvoltage at cathode, AE02.02, T_B=800°C

T_c=280°C

T_c=310°C

T_c=380°C

(Heinzel et al. 1993)

○ 700°C
△ 800°C

Diffusion limitation

(Kato et al., 1992)

Fig. 9 Relation between overvoltage and logarithm of current density of AMTEC with TiC–A2 electrode.

- Overvoltage increases with current
- Overvoltage increases with decrease of T_{BASE} & T_{cond}
- No diffusion limitation is at T_{BASE}>800 °C for i<1.1 A/cm²

Summary and Outlook

- ATEFA waiting for TESTCELL
- Preliminary tests in ceramic-metal joining finished
- Analysis of the electrode ongoing
- Data acquisition and control system finished (test phase ongoing)
- Programed data-analysis (evaluation) system in Matlab finished
- Former measurement data analyzed

- Set into operation of ATEFA (Sept. 2016)
- Start measurement campaign (Oct. 2016)

THANK YOU
QUESTIONS?