High Temperature Direct Energy Conversion for Concentrated Solar Power

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Long time perspective (motivation)
Hybrid system **CSP + AMTEC** (toping system)

- HTF + storage fluid: Na
- $T_{\text{receiver}} \sim 550 – 700 \, ^\circ\text{C}$
- AMTEC as topping system
  - $T \sim 900 \, ^\circ\text{C}$
- AMTEC excess energy reused in TS
- Increase system efficiency*
  - ($\eta \sim 25 \%$)
- Compensation of fluctuations from source
- Longer and more flexible operation
- Increase lifetime of PCS

**Research projects (milestones)**

- AMTEC prototype
- Material characterization in Na
- High temperature thermal storage device
- A&CP $\rightarrow$ integration of small prototype in Karlsruhe Sodium Laboratory
Liquid metals as HTF for CSP

<table>
<thead>
<tr>
<th>Heat transfer fluid (HTF)</th>
<th>Therminol VP-1</th>
<th>Solar Salt (60% NaN03/ 40% KNO3)</th>
<th>Steam@ 10bar</th>
<th>Liquid Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point</td>
<td>400 °C</td>
<td>~ 585 °C</td>
<td>-</td>
<td>873 °C</td>
</tr>
<tr>
<td>Therm. Cond. 600 °C</td>
<td>0.0956 W/mK</td>
<td>≥ 0.58 W/mK</td>
<td>0.09 W/mK</td>
<td>60 W/mK</td>
</tr>
<tr>
<td>Melting Point</td>
<td>12 °C</td>
<td>228 °C</td>
<td>-</td>
<td>97.7 °C</td>
</tr>
<tr>
<td>Density 600 °C</td>
<td>696 kg/m³</td>
<td>1867 kg/m³</td>
<td>2.5 kg/m³</td>
<td>810 kg/m³</td>
</tr>
<tr>
<td>Spec. Heat 600 °C</td>
<td>~ 2,5 kJ/kgK</td>
<td>1,5 kJ/kgK</td>
<td>2.2 kJ/kgK</td>
<td>1,25 kJ/kgK</td>
</tr>
</tbody>
</table>

- Comparison of HTFs *:
  Na identified as the best HTF for CSP-TS

- Disadvantage of Na
  Reactive with air and water

Sodium good candidate as a HTF in CSP systems

- Safety oriented design and maintenance

* Liu et al. SE 101, 220-231, 2014
AMTEC – direct heat to electricity conversion

Alkali Metal Thermal to Electric Converter

Main advantages
- High theoretical efficiency (40 %)
- Flexible regarding the heat source
- Suitable for modular design
- No moving components

Issues
- Real efficiency of 20 %
  - Heat losses (10 – 15 %)
  - Electrical losses (12 – 15 %)
- Power degradation over time
  - Degradation of BASE
  - Electrode sintering (grain growth)

Key component:
β”-Alumina Solid Electrolyte (BASE)

Key process: Na-ionization
ΔP across BASE → Δ(sodium activity)

Na → Na⁺ + e⁻
AMTEC TEst FAcility (ATEFA)

- **Na-side** includes:
  - Two storage tanks (~ 4,5 l)
  - AMTEC test cell
    \[ T_{\text{Na}} = 600 – 800 \, ^\circ\text{C} \]
  - Air-cooled condenser
    \[ T_{\text{Na}} \sim 300 \, ^\circ\text{C} \]
  - Heating trace, \( T_{\text{Na}} \sim 150 \, ^\circ\text{C} \)
- **Ar-side** controls Na-flow and pressure in cell and tank

**Safe design**

- Enclosed in a metallic box
- Possibility to float with Ar
- Small Vol_{\text{Na}} \sim 0.4 \, \text{l in cell}
- Max. p = 1.5 bar
AMTEC test cell

- Single BASE tube (D=3 cm, L=22 cm, wall thickness 1 mm)
- Na-liquid anode
- Sputtered cathodes (~ 5 μm)

<table>
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<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open voltage</td>
<td>~ 1.2 V</td>
</tr>
<tr>
<td>Power density</td>
<td>0.5 – 1 W/cm²</td>
</tr>
<tr>
<td>Efficiency</td>
<td>15 – 20 %</td>
</tr>
</tbody>
</table>

Tests*

- Influence of ΔT
- Electrode composition (Mo, TiN, TiC)
- Electrode-wire interface
- BASE (thickness, chemical stability)
- Ceramic-metal brazing

*in collaboration with other institutes in KIT
Summary and outlook

- New CSP concept using Na and AMTEC technology
- Experimental infrastructure (ATEFA facility, AMTEC prototype) to be set into operation by end of summer 2015

- Experimental campaign focused on:
  - BASE and electrode improvement
  - Performance evaluation

- Long term tests:
  - Material qualification (low cycle fatigue)
  - Corrosion/erosion in structure materials
  - AMTEC long term tests

- Feasibility study of an AMTEC cluster for CSP plants as a topping system:
  - Solar receiver
  - Scaled AMTEC demonstrator
  - Na storage tank
Thank you for your attention

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