Initial tests of the high temperature SOLTEC facility for corrosion analyses

A. Onea, W. Hering, A. Weisenburger, S. Vielhaber, O. Albrecht, U. Häfner, R. Stieglitz
Outline

- Introduction
- Liquid metals facilities at KIT-INR
- SOLTEC family (SOdium Loop to TEst Corrosion and materials):
  - Objectives
  - Main technical data
  - Safety issues
  - P&I diagramm
  - Test sections
- Numerical analyses and experimental tests
- Operational experience
Introduction

- CSP concept* of solar tower plant with Na as HTF and AMTEC technology as topping cycle → R&D on materials and components

- Main tasks for the SOLTEC family:
  - Development of the 1000 K sodium SOLTEC test facilities (INR)**
  - Material qualification for high temperature applications (collaborations with IAM-AWP, IHM)
  - Soltec-1: Creep fatigue tests of innovative materials in hot Na (*unique*)
  - Soltec-2: Corrosion/erosion tests for new steels in hot Na
  - Soltec-3: Long term tests for new thermoelectrical converters

**Developed in the frame of the Helmholtz Energy Material Characterization Platform (HEMCP) and Helmholtz Alliance on Liquid Metal Technology (LIMTECH)
**Na – Facilities: Operating, Qualifying, Preparation, Design**

<table>
<thead>
<tr>
<th>Basic physics (Electro-chemistry)</th>
<th>System level (Materials)</th>
<th>Medium Scale / Demonstrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMTEC</td>
<td>„Energy“ - materials</td>
<td>Thermal storage: KASOLA facility</td>
</tr>
<tr>
<td>ATEFA →</td>
<td>SOLTEC 1\text{AWP} – 2\text{iHM}</td>
<td>Na-receiver</td>
</tr>
<tr>
<td>DITEFA ←</td>
<td>SOLTEC 3\text{INR}</td>
<td></td>
</tr>
<tr>
<td>KARIFA ←</td>
<td>CORTINA\text{AWP}</td>
<td></td>
</tr>
</tbody>
</table>

**Thermal storage: KASOLA facility**

- Na-receiver
- Expansion tank
- Storage tank: 7 m³ Na
## Status of HAC / KASOLA facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Fluid</th>
<th>Max. temp. [°C]</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>KASOLA</td>
<td>Na; ~7 to 550</td>
<td>In HT qualification phase</td>
<td></td>
</tr>
<tr>
<td>ATEFA</td>
<td>Na ~3 L 1000</td>
<td>Successfully operated up to 700°C; PhD finished.</td>
<td></td>
</tr>
<tr>
<td>SOLTEC-2</td>
<td>Na ~14 L 720</td>
<td>Qualification phase with sodium up to 700°C</td>
<td></td>
</tr>
<tr>
<td>SOLTEC-1</td>
<td>Na ~14 L 720</td>
<td>In final assembly phase</td>
<td></td>
</tr>
<tr>
<td>SOLTEC-3</td>
<td>Na ~14 L 950</td>
<td>Finalization postponed until Q4/19; Commissioning in Q1/20</td>
<td></td>
</tr>
<tr>
<td>DITEFA</td>
<td>InGaSn</td>
<td>In construction</td>
<td></td>
</tr>
<tr>
<td>KARIFA</td>
<td>Na 1000</td>
<td>Concept finished &amp; fixed → detail design</td>
<td></td>
</tr>
</tbody>
</table>
R&D objectives SOLTEC-2

- Material development, qualification & durability at high temp. in contact with flowing liquid metals (Na, design complying also with PbBi, Sn), since no experimental data for steel corrosion in Na above 650°C is reported
- Simulation of real operation condition (rapid temperature transients - Thermal cycling tests at high temperature DT: 650 – 900°C, LCF, safety & operational aspects (LOFA, LOHS)
- Development, qualification & demonstration of Long term stability of protective surface coatings (in/outer surface) (using pulsed electron beams – Surface Optimization facility with Fast In-situ diagnostic Equipment- GESA-SOFIE)
- Planned materials: austenitic steels with different chrome composition, nickel-based superalloys, Inconel-based superalloys, W-Cu laminates.

Technical data

- Na inventory: ~ 14 L
- Mass flow rate: 300 kg/h
  - $\rightarrow$ S1: 4.8 m/s in test sample
  - $\rightarrow$ S2: 1.1 m/s in test sample
- Temperature: cold loop 700 K; hot loop 1000 K
- Max. pressure: 3.5 bar g
- Pressure loss: S-1: ~ 1.6 bar; S-2: ~ 0.45 bar
Technical data (2)

- Compact configuration: $1.2 \times 1.6 \times 1.9 \text{ m}^3$
- Main components:
  - Na-pump (3kW permanent magnet pump)
  - 7.5 kW Na-air HX coupled to a 27 kW Na-Na heat recuperator,
  - Storage tank (15 L) used as expansion tank (particular feature)
  - 6.7 kW HT heater
- Materials: Inconel (HT side), 316Ti (LT side)
- Ar is used as cover gas to fill/drain the facility and pressure monitoring
- Heating power: $\sim 40 \text{ kW}$
- PLS: Siemens Simantec S7
- Instrumentation: Na/Ar – pressure, temperature, Na-level meter, Na flowmeter

Manufacturing: SAAS GmbH, SOWEC GmbH
Safety issues

- Dedicated infrastructure for LM facilities (KASOLA facility, LM lab)
- Fail safe design:
  - Fast drainage is to be made at any malfunction
  - Sample rupture: vacuum monitored in the test chamber
  - Heater and pump to be stopped either by the process control system (PCS) or by signals from sensors operating separately from the PCS
- Limited amount of Na
- Ar used as cover gas. All argon/sodium interfaces protected by filters
- All Na valves have a NO configuration
- Low overpressure in any operation state
- Any leackage to be detected by the leackage detection system
- Na collection tray integrated in the bottom part of the framework of the housing
- Any possible fire/smoke limited within the insulated metallic housing
SOLTEC – SOdium Loop to TEst materials and Corrosion

Main components:
- 1,2 m 6.3 kW heater
- 3kW Na pump
- Na storage tanks (15 L)

Piping and instrumentation diagram

1000 K
700 K
SOLTEC – SOdium Loop to TEst materials and Corrosion

Test sections:

SOLTEC - 1

Zwick/Roell Z100 universal traction facility (Low cycle fatigue tests)

Innovative W-Cu compounds*


SOLTEC - 2

Material test chamber

SOLTEC - 3

Test chamber for thermoelectric converters

Institute for Neutron Physics and Reactor Technology
Karlsruhe Institute of Technology
Numerical analyses and experimental tests

- **FEM analysis**: Na-Na heat recuperator, Na-air HX
- **CFD analysis**: Na-Na heat recuperator, Na-air HX.
  - Validation against heat balance analysis
- **TRACE analysis**:
  - SOLTEC-1-2 drainage: high temperature region drained in < 30 s
  - Transient and steady-state simulations: filling/drainage process, steady-state simulations
- **Experimental tests**:
  - Pressure tests of the main components successfully performed
  - Experimental tests of screw connections

![Graph showing fill level percentage over time]
Numerical analyses and experimental tests

- Theoretical analyses*:
  - Pressure loss: (good agreement with TRACE model)
  - Heat balance analysis

<table>
<thead>
<tr>
<th>Ansatz</th>
<th>S-1 (\Delta p) / Pa</th>
<th>(\Delta p) / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prandtl-Kármán</td>
<td>1,62E+5</td>
<td>2,47</td>
</tr>
<tr>
<td>Ghanbari</td>
<td>1,67E+5</td>
<td>5,39</td>
</tr>
<tr>
<td>TRACE</td>
<td>1,58E+5</td>
<td>/</td>
</tr>
</tbody>
</table>

| Location          | Temperature [°C] FEM | Temperature [°C] TRACE | \(\Delta T\) | \(|\Delta T|\) [%] |
|-------------------|----------------------|------------------------|---------------|-------------|
| Inlet Na-Na HX    | 420,00               | 419,94                 | -0,06         | 0,01        |
| Outlet Na-Na HX   | 689,80               | 715,56                 | +25,76        | 3,73        |
| Inlet Na-Air HX   | 740,00               | 740,20                 | +0,20         | 0,02        |
| Middle section Na-Air HX | 469,50        | 444,52                 | -24,98        | 5,32        |
| Outlet Na-Air HX  | 388,80               | 378,85                 | -9,95         | 2,55        |

SOLTEC-1

| Location          | Temperature [°C] FEM | Temperature [°C] TRACE | \(\Delta T\) | \(|\Delta T|\) [%] |
|-------------------|----------------------|------------------------|---------------|-------------|
| Inlet Na-Na HX    | 420,00               | 420,05                 | +0,05         | 0,01        |
| Outlet Na-Na HX   | 689,80               | 715,68                 | +25,9         | 3,75        |
| Inlet Na-Air HX   | 740,00               | 740,35                 | +0,35         | 0,05        |
| Middle section Na-Air HX | 469,50        | 444,64                 | -24,86        | 5,29        |
| Outlet Na-Air HX  | 388,80               | 378,95                 | -9,85         | 2,53        |

SOLTEC-2

D. Fischer – TRACE simulation SOLTEC-1, -2, KIT
Results and operational experience

- Loop evacuation prior to the loop filling
- Filling under low Ar pressure and vacuum
- HT heater set to operational temperature once the loop is filled
- Na thermal expansion compensated in the ST
- Temperature in the LT side < 450°C
- HT heater off / low power before drainage to avoid thermal shocks in the ST

- No leakage / fire
- However, one Na valve exchanged due to plugging (replacement under Ar atmosphere and at RT)
Temperature distribution

- Temperature in LT region < 550°C
- Fast thermal transients
Pressure distribution

- Low pressure difference across the pump
- Low pressure levels < 3.5 bar g
Set-into-operation
Looking forward for future collaborations!

Friday, Session 1, C2, 10:00: A. Onea, W. Hering, S. Perez Martin, et al. - Numerical and experimental investigations of temperature investigation in an AMTEC test cell