Initial tests of the high temperature SOLTEC facility for corrosion analyses

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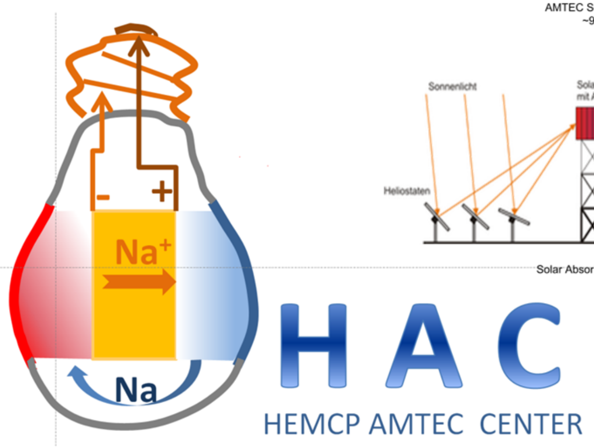
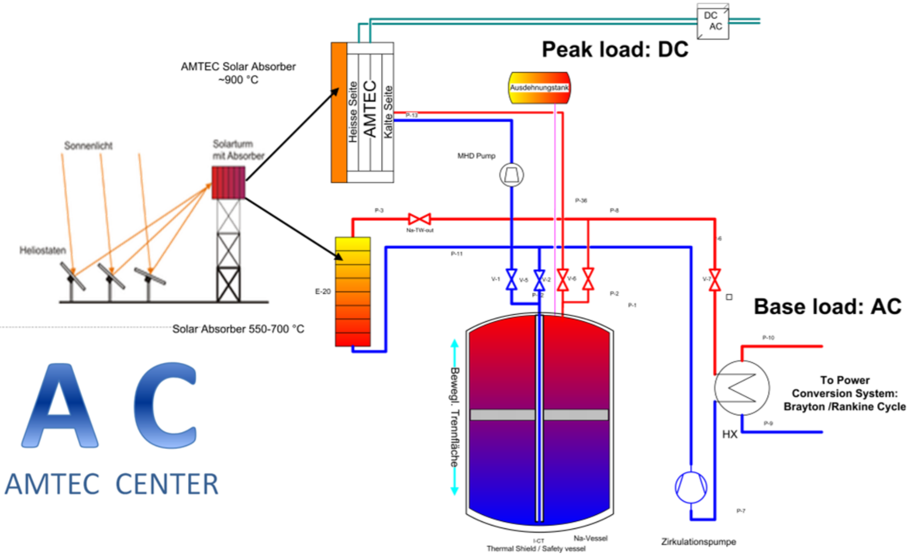
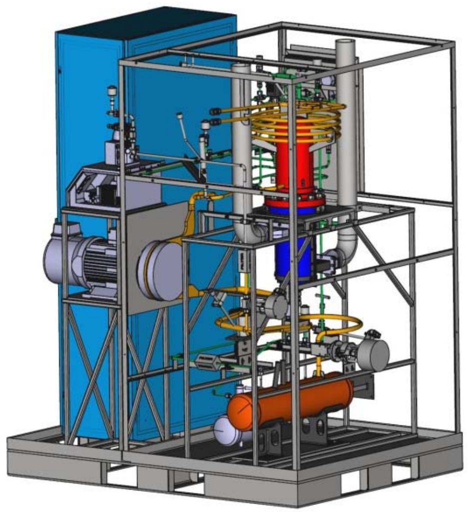
Institute for Neutron Physics and Reactor Technology







Outline

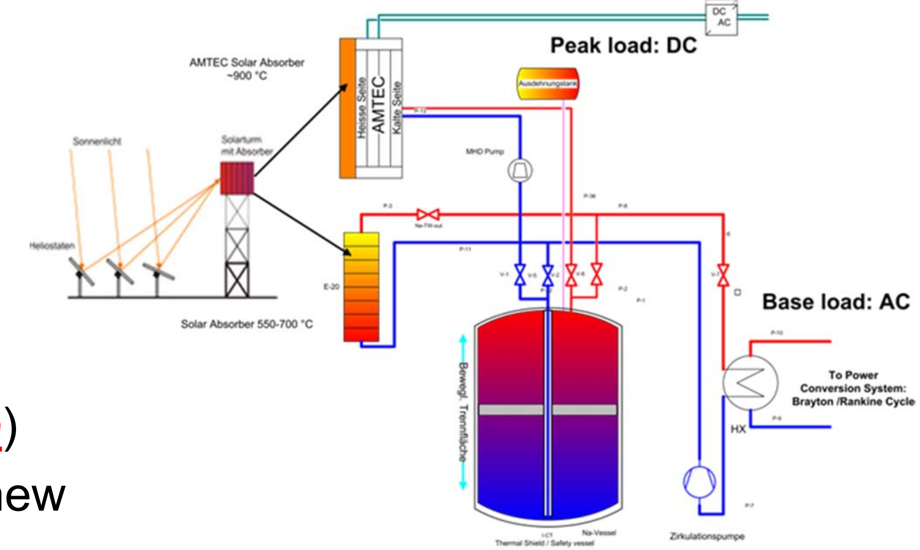
- Introduction
- Liquid metals facilities at KIT-INR
- SOLTEC family (SOdium Loop to TEst Corrosion and materials):
  - Objectives
  - Main technical data
  - Safety issues
  - P&I diagramm
  - Test sections
- Numerical analyses and experimental tests
- Operational experience

Introduction

LIMTECH Alliance

HEMCP:Helmholtz Energy Materials Characterization Platform

- 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



*W. Hering et al. – Europ. Ph. J. 33, 03003 (2012)

**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

Basic physics (Electro-chemistry)	System level (Materials)	Medium Scale / Demonstrator

AMTEC

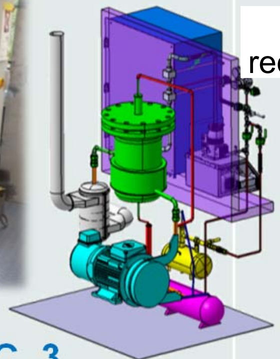
ATEFA →

← DITEFA

KARIFA

„Energy“ - materials

SOLTEC 1_{AWP} – 2_{IHM}



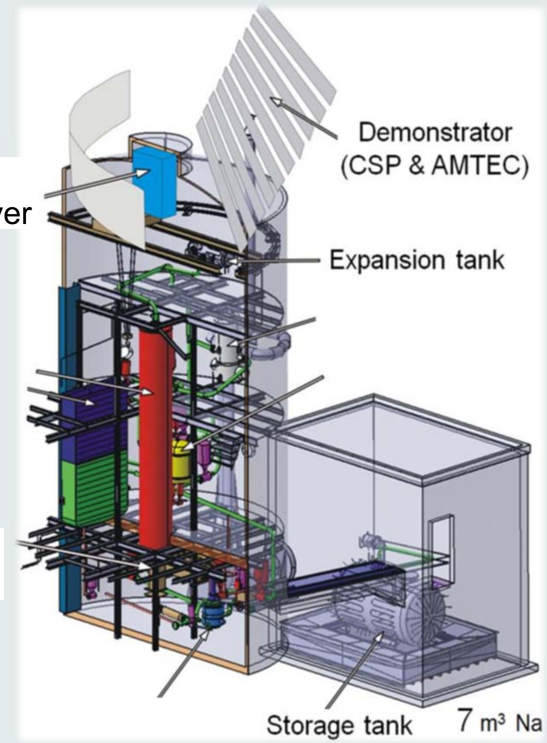
SOLTEC 3_{INR}

←CORTINA$_{AWP}$

Thermal storage: KASOLA facility

Na-receiver

MHD Pump



Status of HAC / KASOLA facilities

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

Operating, Qualifying, Preparation, Design

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
  - → S1: 4.8 m/s in test sample
  - → 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)

LIMTECH Alliance

HEMCP:Helmholtz Energy Materials Characterization Platform

- Compact configuration: 1.2 × 1.6 × 1.9 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: ~40 kW
- PLS: Siemens Simantec S7
- Instrumentation: Na/Ar – pressure, temperature, Na-level meter, Na flowmeter

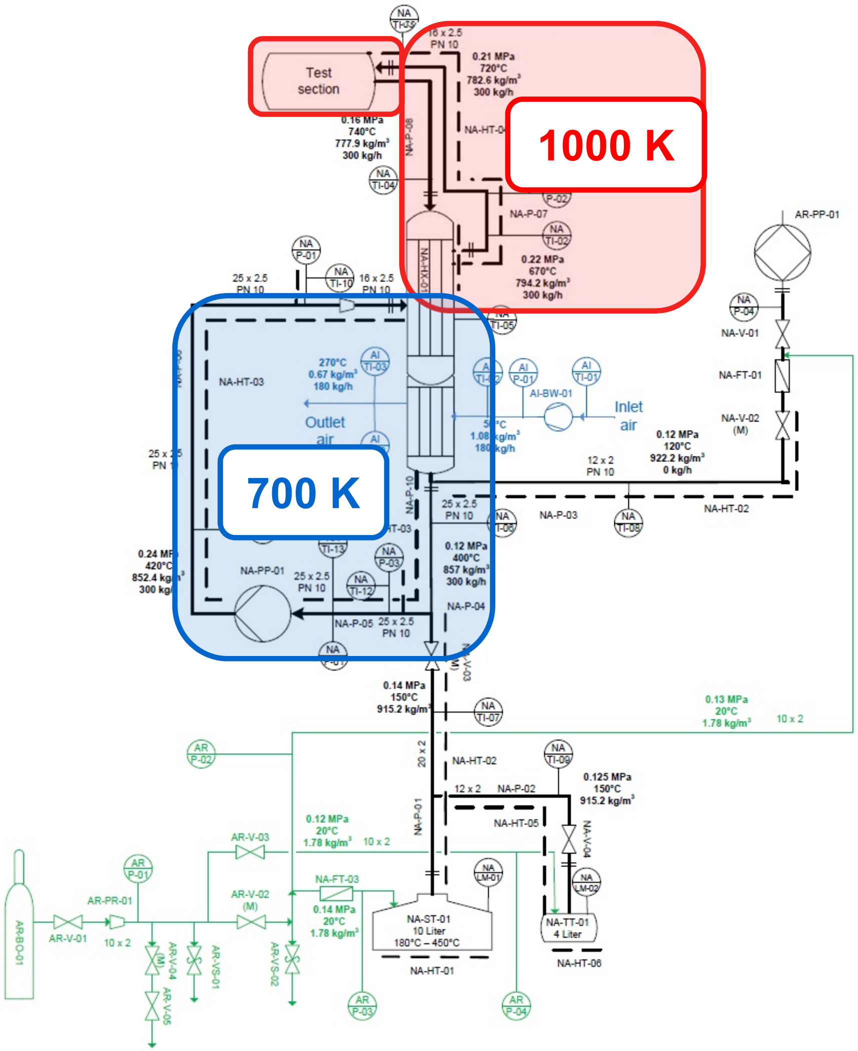
Manufacturing: SAAS GmbH, SOWEC GmbH

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

Piping and instrumentation diagram



,2 m

Na storage tanks (15 L)

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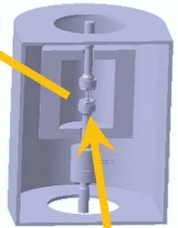
SOLTEC – SOdium Loop to TEst materials and Corrosion

Test sections:

SOLTEC - 1

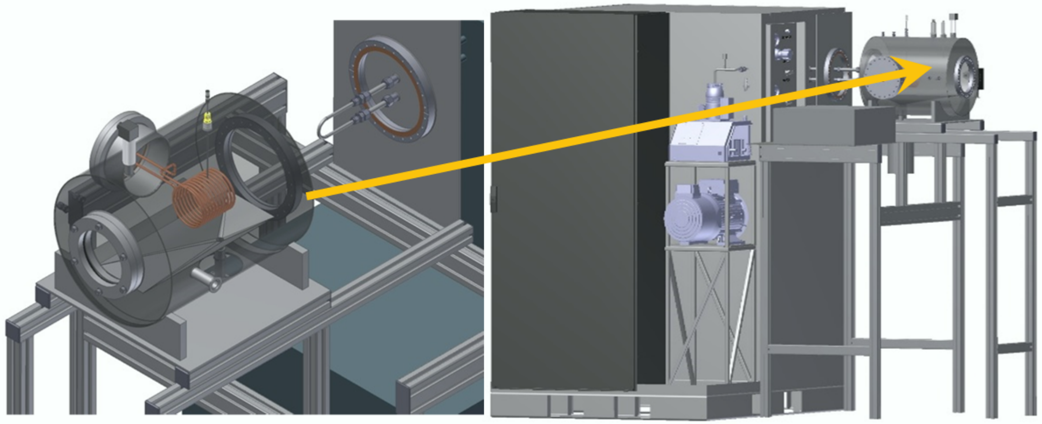


Zwick/Roell Z100 universal traction facility (Low cycle fatigue tests)

Innovative W-Cu compounds*

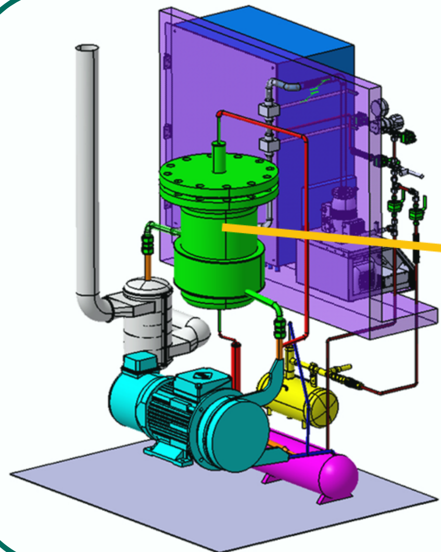
*J. Reiser et al. - Advanced Eng. Mat. 17, 491 (2015)

SOLTEC - 2

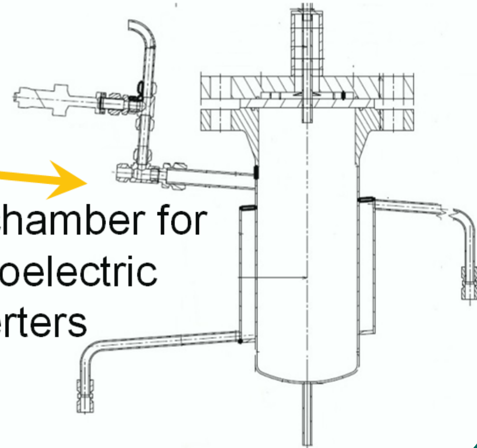


Material test chamber

SOLTEC - 3

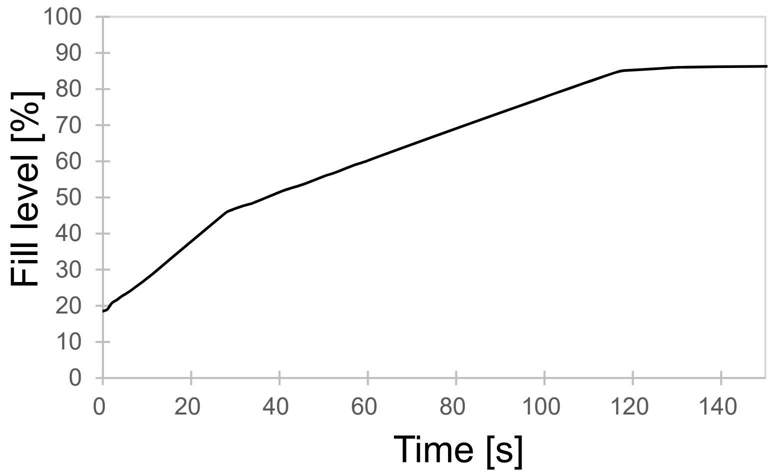


Test chamber for thermoelectric converters



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



Numerical analyses and experimental tests

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

Ansatz	S-1 Δp / Pa	$\lvert\Delta p\rvert$ / %
Prandtl-Kármán	1,62E+5	2,47
Ghanbari	1,67E+5	5,39
TRACE	1,58E+5	/

Location	Temperature [°C] FEM	Temperature [°C] TRACE	ΔT	$\lvert\Delta T\rvert$ / %
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	ΔT	$\lvert\Delta T\rvert$ [%]
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

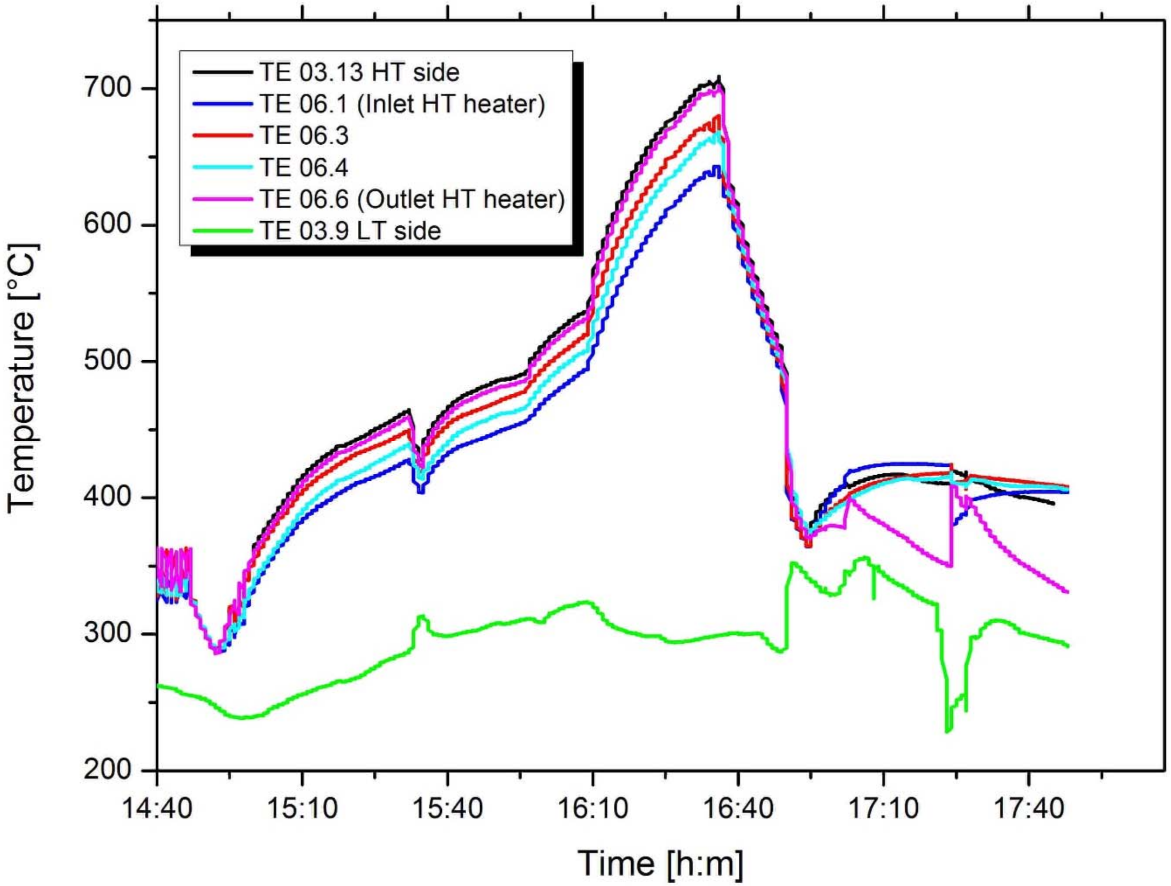
D. Fischer – TRACE simulation SOLTEC-1, -2, KIT

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

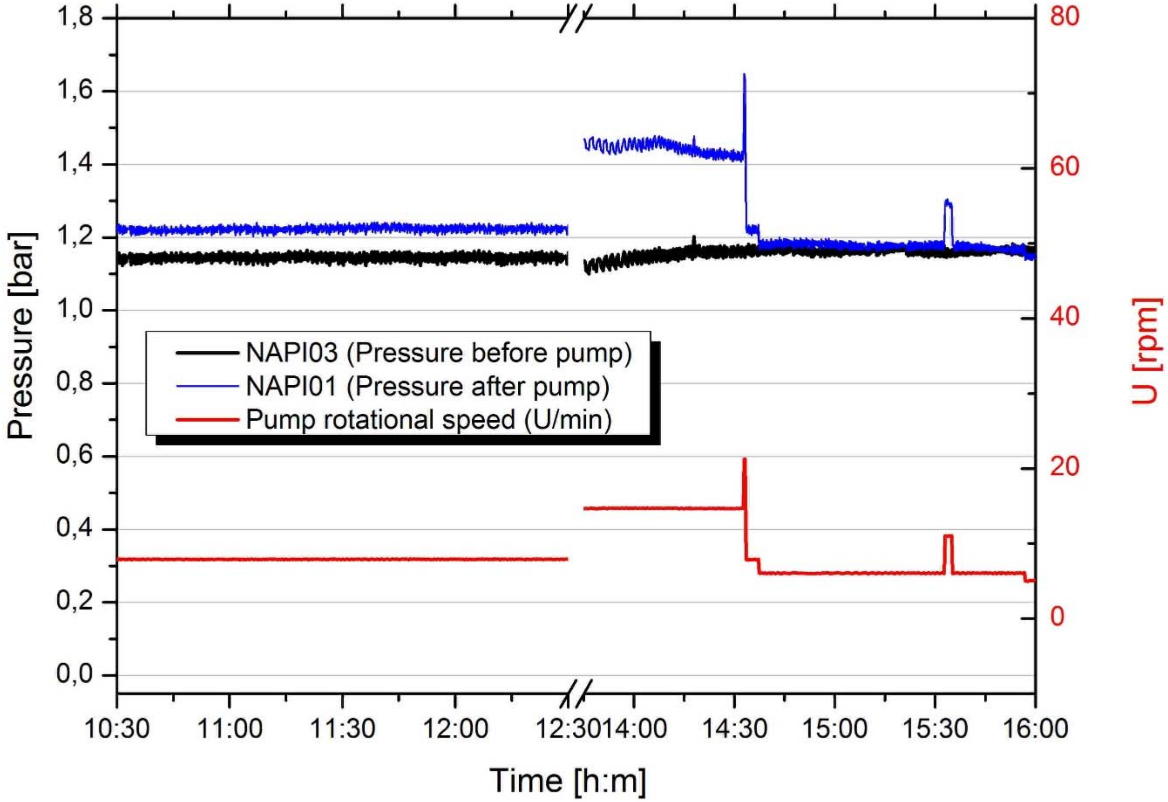
- No leakage / fire
- However, one Na valve exchanged due to plugging (replacement under Ar atmosphere and at RT)

Temperature distibution



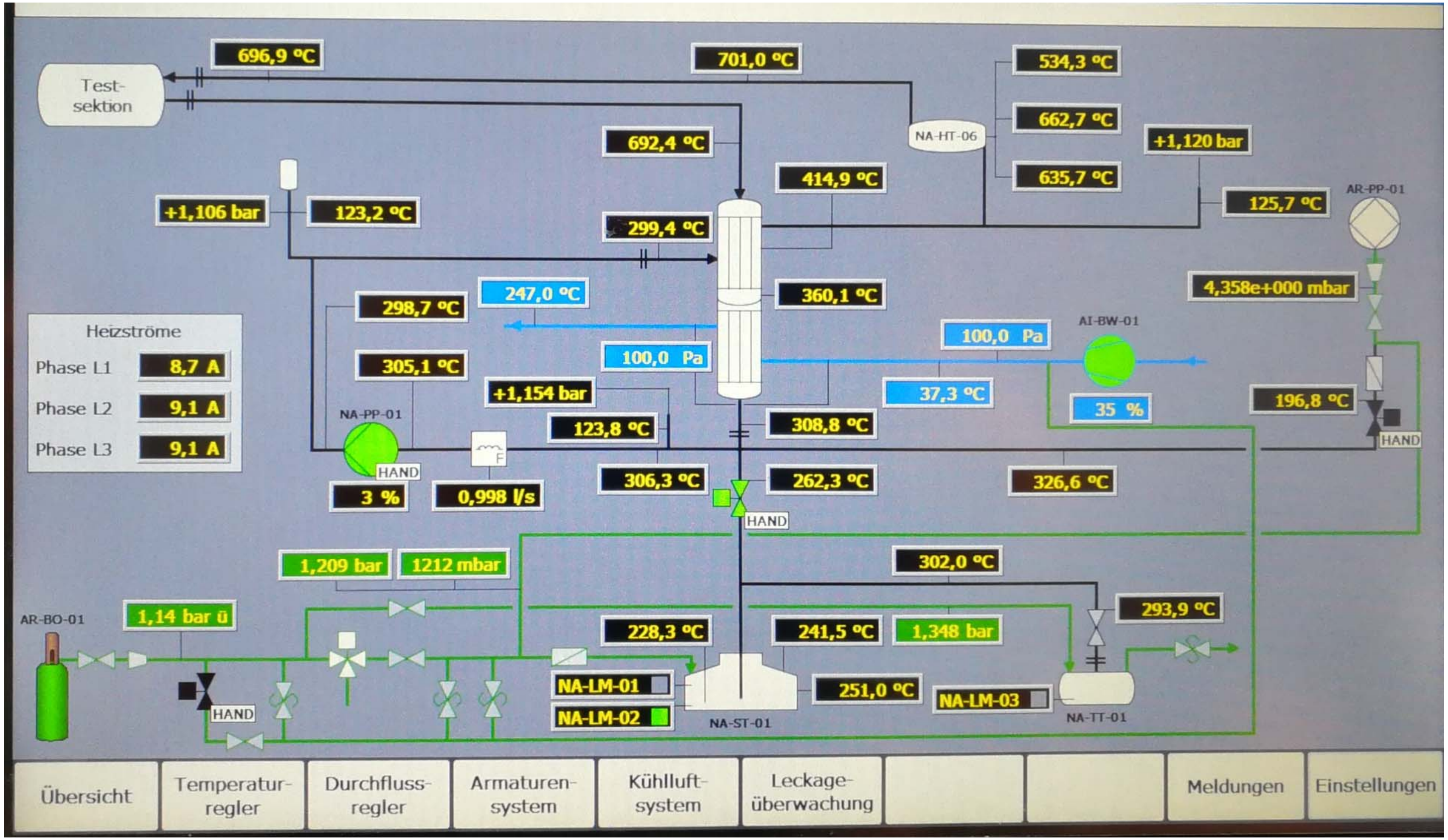
- Temperature in LT region < 550°C
- Fast thermal transients

Pressure distribution



- Low pressure difference across the pump
- Low pressure levels < 3.5 bar g

Set-into-operation



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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