Thermocycling tests by inductively heated sodium in the high temperature SOLTEC-2 facility

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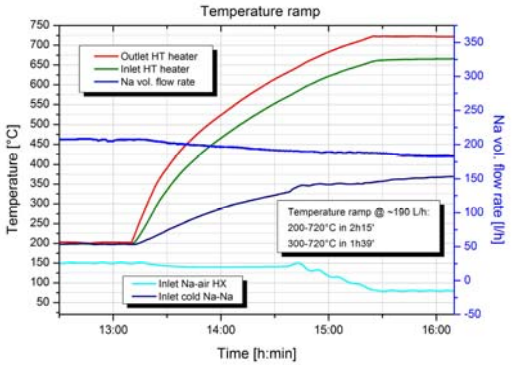
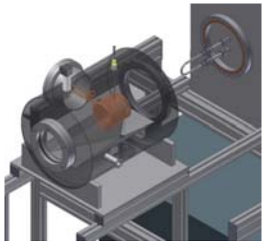
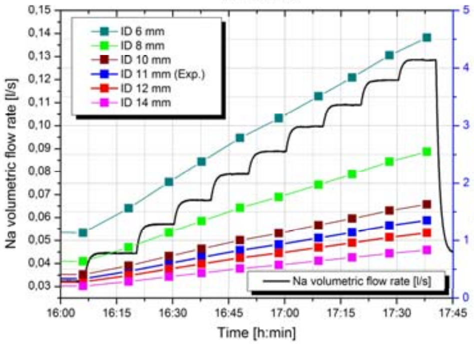
SOLTEC facilities

- 1000K sodium loops SOLTEC (SOdium Loop for TEst materials and Corrosion): Material investigation and qualification for high temperature applications in CSP field
- SOLTEC-1: Steady-state/transient investigation of creep fatigue in circulating Na
- SOLTEC-2: Experimental investigation of steel erosion and corrosion
- Main technical data:
  SOLTEC -1, -2: cold side 450°C, hot side 720°C @ 3.5 bar, ~14L Na, ~300 kg/h



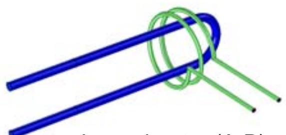


Test chamber SOLTEC-2



Inductive heater

- frequency range: 150-400 kHz;
- maximum voltage: 300 Vrms;
- maximum active power: 6 kW;
- maximum reactive current: 500 Arms



Large heater (A-B)

Small heater (C-F)

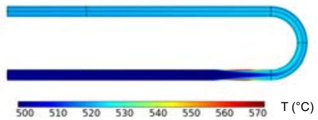
COMSOL simulation

- Calculation of electromagnetic field and induced currents for test tube and inductor (cases A to F) inside vacuum chamber → selection of case F
- CFD calculation of Na flow using SST turbulence model
- Calculation of transient heat transfer

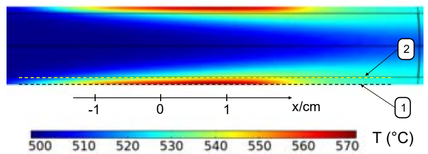
Case	Coil parameters				Operational parameters				Heat load
	input			output	input		output		output
	R_c, mm	N	a, mm	L, µH	f, kHz	U, Vrms	I_q, Arms	P, kW	Q_m, MW/m²
A	50	5	21	1.75	150	300	180	5.2	0.03
B	50	2	21	0.61	150	221	385	6.0	0.07
C	15	2	11	0.22	150	104	500	2.3	0.49
D	15	5	11	0.44	150	195	472	6.0	0.84
E	15	5	11	0.42	400	274	256	6.0	0.59
F	15	5	8	0.45	150	200	472	6.0	1.04

Results for $\dot{V} = 200$ L/h and $T_{in} = 500$ °C

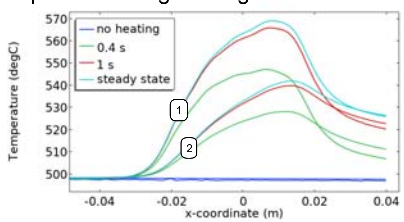
temperature distribution in stationary stage:



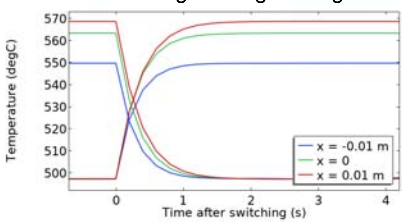
zoom to heated section:



T profiles during heating:



T evolution during heating/cooling:



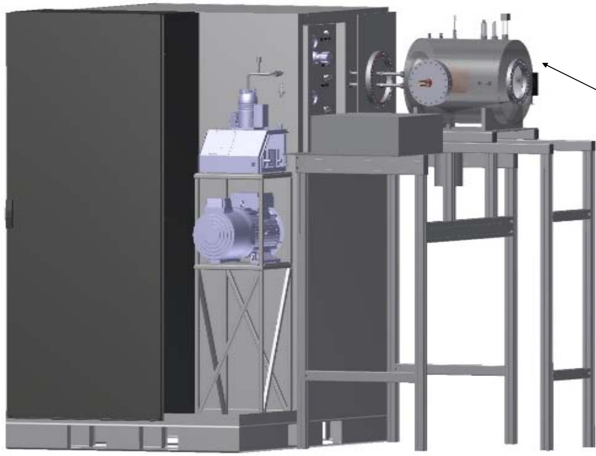
Input parameters		Results			
$\dot{V}$	T_{in}	T_{max}	T_{out}	$\Delta T/\Delta r$	$\partial T/\partial t$
400 L/h	500 °C	557 °C	510 °C	~30,000 K/m	~145 K/s
200 L/h	500 °C	569 °C	519 °C	~30,000 K/m	~155 K/s
200 L/h	700 °C	767 °C	713 °C	~25,000 K/m	~150 K/s

Conclusions

- Simulation campaign performed for the optimization of the setup of the inductive heater
- SOLTEC-2 loop with inductive heater is promising for fast thermocycling tests of receiver materials and designs under relevant conditions

SOLTEC-1/2 Description

- Soltec-1: *Creep fatigue* tests of new materials in hot Na
- Soltec-2: *Corrosion/erosion* tests for conventional and new steels in hot Na
- Sodium flow rate: 300 kg/h
  - S1: ~ 5 m/s (test sample)
  - S2: ~ 1 m/s (test sample Re ~28600, 300°C)
- Temperature: cold side 450°C; hot side 720°C
- Max. pressure: 3.5 bar g
- Compact configuration: 1.2 × 1.6 × 1.9 m^3
- Main components:
  - 3kW permanent Na magnet pump
  - 7.5 kW Na-air HX and 27 kW Na-Na heat recuperator
  - Na storage tank (15 L) used also as expansion tank
  - 6.7 kW high temperature heater
- Manufacturer: SAAS GmbH, SOWEC GmbH



Soltec-2

SOLTEC-2 Experimental results

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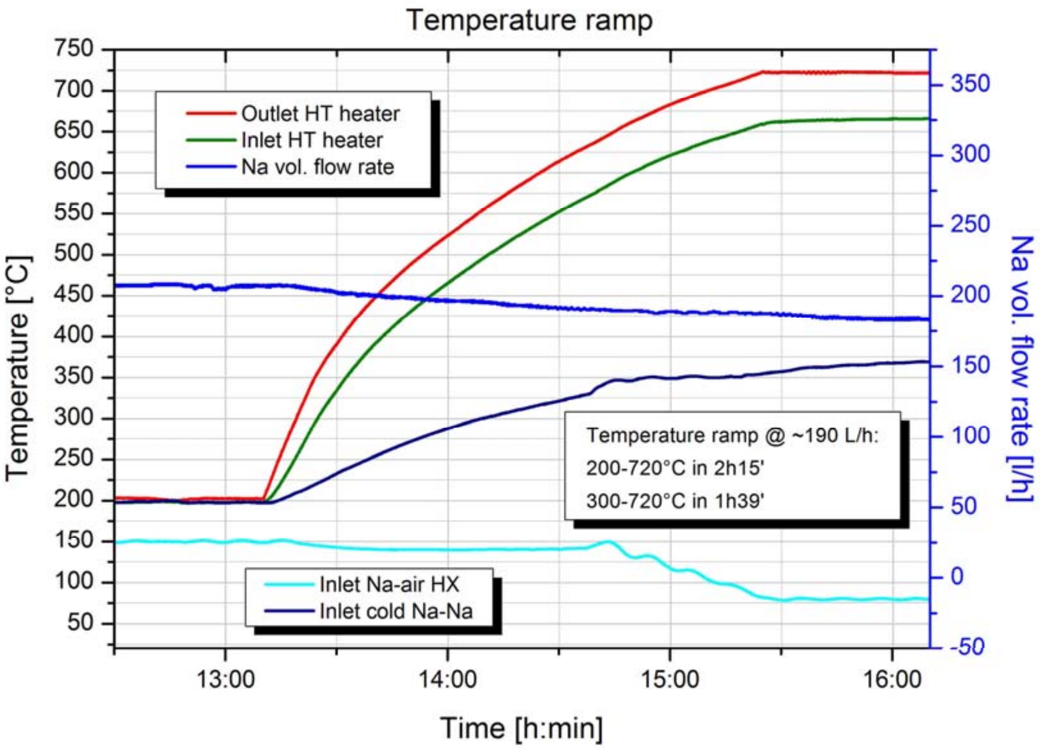
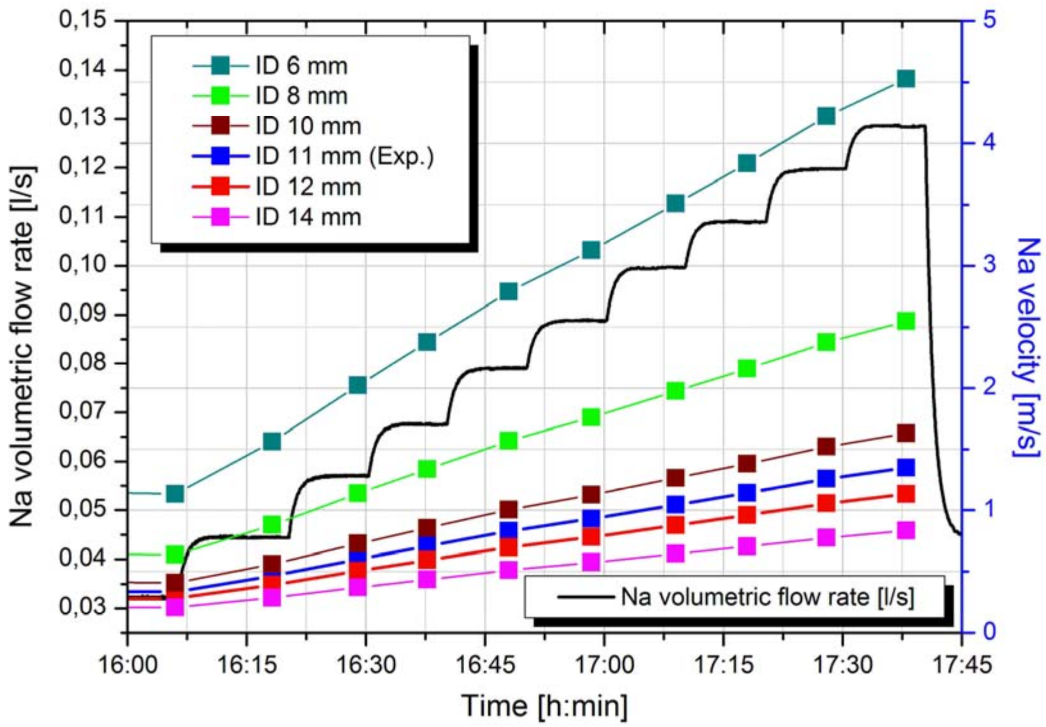
- Several experimental campaigns performed up to 720°C
- Significant operation experience gained with the loop and also in handling/cleaning components covered with Na
- No unsafe state/operation is to be reported

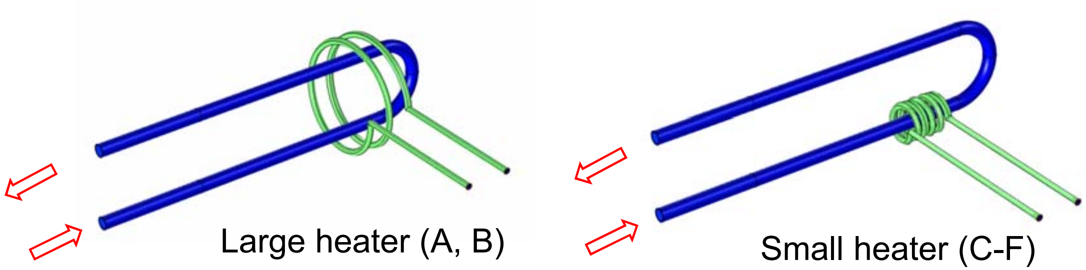




COMSOL simulations

Karlsruhe Institute of Technology

- Two main designs for the inductive heater considered
- Parametric study performed
- Grid: ~1.3 Mio. cells
- Wall resolution y+: ~1
- SST turbulence model (Re < 50000)
- Turb. Prandtl number: Kays-Crawford



Case	Coil parameters				Operational parameters				Heat load
	input			output	input		output		output
	R_c, mm	N	a, mm	L, μH	f, kHz	U, Vrms	I_q, Arms	P, kW	Q_m, MW/m²
A	50	5	21	1.75	150	300	180	5.2	0.03
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R_c - inductor radius,
N - number of turns,
a - pitch,

L – inductance,
f - frequency,
U - voltage,

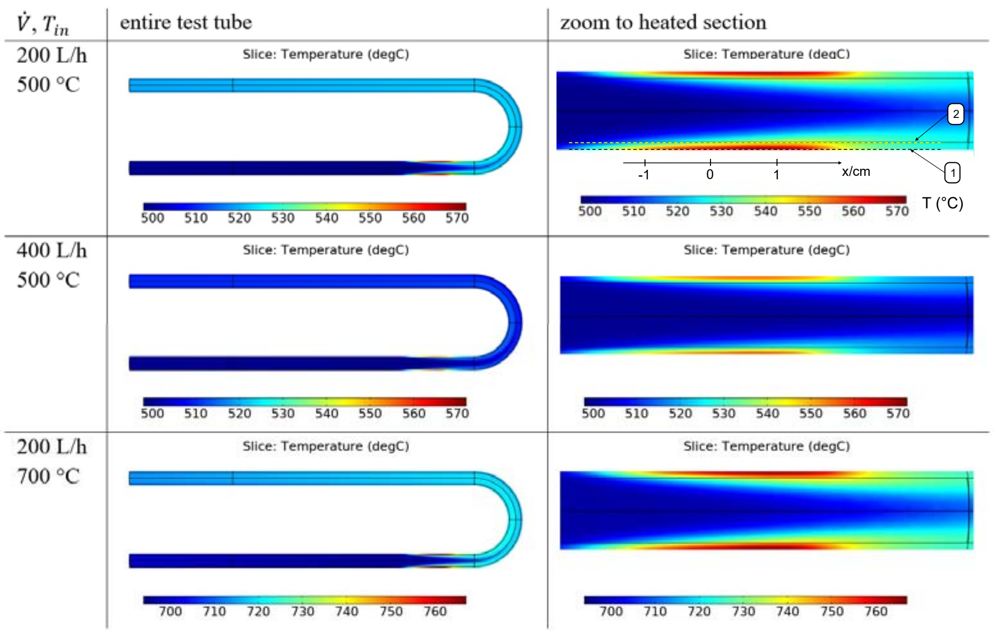
I_q - reactive current,
P - active power,
Q_m - maximum heat load in test tube

- Influence of nr. of turns N (A-D):
  - Large heater: larger N → larger inductance → smaller active power due to **voltage limit** → smaller heat load
  - Small heater: larger N → larger inductance → larger active power → larger heat load
- Influence of frequency f (D, E):
  - Larger frequency → smaller current at same active power → smaller heat load
- Influence of coil pitch a (D, F):
  - Smaller pitch → same active power, but larger heat load **density**

➢ Selection of heater F

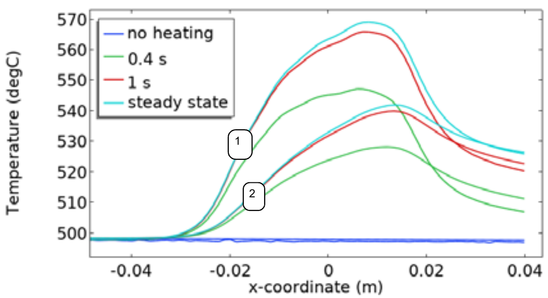
Expected temperature evolution (1 MW/m² heater)

- Maximum achievable temperature and heating/cooling rates as function of
  - Sodium flow rate $\dot{V}$
  - Sodium inlet temperature T_{in}

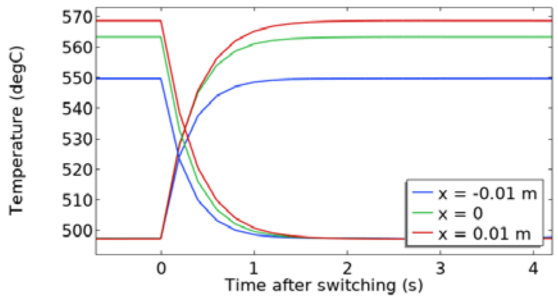


Steady-state temperature distribution (midplane)

Results for $\dot{V} = 200$ L/h and $T_{in} = 500$ °C



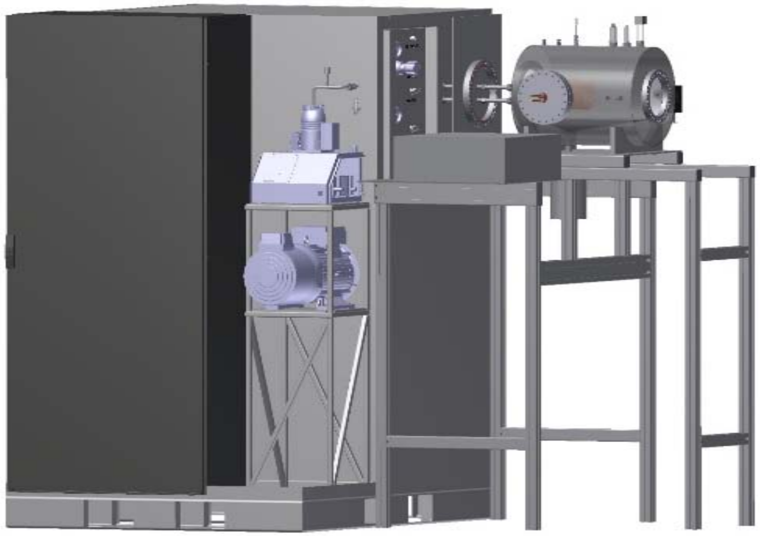
Temperature profile along outer respectively inner side of lower wall of test tube



Temperature evolution at different positions on outer wall after switching on/off

Input parameters		Results			
$\dot{V}$	T_{in}	T_{max}	T_{out}	$\Delta T/\Delta r$	$\partial T/\partial t$
400 L/h	**500 °C**	557 °C	510 °C	~30,000 K/m	~145 K/s
200 L/h	**500 °C**	569 °C	519 °C	~30,000 K/m	~155 K/s
200 L/h	**700 °C**	767 °C	713 °C	~25,000 K/m	~150 K/s

T_{max} - maximum temperature,
T_{out} - temperature at outlet,
$\Delta T/\Delta r$ - average radial temperature gradient during heating,
$\partial T/\partial t$ - maximum heating rate



Thank you for your attention!

See also:

J. Fuchs, F. Arbeiter, M. Böttcher, W. Hering, H. Neuberger, R. Stieglitz –
„Computational Fluid Dynamic Investigations on a Small Scale Liquid Sodium Loop"