

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

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SOLTEC facilities

Main technical data:

Test chamber SOLTEC-2

Inductive heater

150

16:00

Temperature ramp @ ~190 L/t

Na volumetric flow rate []/s]

17:30

17:45

17:15

200-720°C in 2h15

15:00

300-720°C in 1h3

100 8

The second secon

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

COMSOL simulation

- Calculation of electromagnetic field and induced currents for test tube and inductor (cases A to F) inside vacuum 300 chamber → selection of case F 250 N CFD calculation of Na flow using SST 200 5
 - turbulence model
 - Calculation of transient heat transfer

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

temperature distribution in stationary stage:



zoom to heated section:

Input parame	ters	Results			
Υ	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



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Small heater (C-F
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ase	Coil para	ameters			Operatio		Heat load		
	input			output	input		output		output
	R _c , mm	Ν	a, mm	<i>L</i> , μΗ	f, kHz U, Vrms		I _q , Arms	P, kW	Q_m , MW/m ²
	50	5	21	1.75	150	300	180	5.2	0.03
	50	2	21	0.61	150	221	385	6.0	0.07
	15	2	11	0.22	150	104	500	2.3	0.49
	15	5	11	0.44	150	195	472	6.0	0.84
	15	5	11	0.42	400	274	256	6.0	0.59
	15	5	8	0.45	150	200	472	6.0	1.04







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1000K sodium loops SOLTEC (SOdium Loop for TEst materials and Corrosion):

SOLTEC-1: Steady-state/transient investigation of creep fatigue in circulating Na

700 -

650 -

600 -

550

500 -

400 -

350 -

300 -

250 -

200

150

100

0.15

0.14

0,13 -

0,12 -

0.11

0.09 0,08

0,07

0,06

0.04

16:00

[S]

rate 0,10

망 0.05 13:00

- ID 14 mm

16:30

16:15

16:45 17:00

Time [h:min]

[°] 450 -

SOLTEC-2: Experimental investigation of steel erosion and corrosion

Material investigation and qualification for high temperature applications in CSP field

SOLTEC -1, -2: cold side 450°C, hot side 720°C @ 3.5 bar, ~14L Na, ~300 kg/h

- Outlet HT heate

- Inlet HT heater - Na vol. flow rate

Inlet Na-air HX

niet cold Na.No

14:00

Time [h:min]

Temperature ramp



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 m³
- 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





- 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



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- 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	C	a lioC	arame	ters	Ope	rationa	l param	eters	Heat	Influence of nr. of turns N (A-D):
			input	:	output	in	put	out	put	load output	Large heater: larger N → larger inductance → smaller active power due to voltage limit → smaller heat load
		R _c , mm	Ν	a, mm	<i>L</i> , μΗ	<i>f</i> , kHz	<i>U</i> , Vrms	I _q , Arms	P, kW	Q _m , MW/m²	Small heater: larger N → larger inductance → larger active power → larger heat load
	Α	50	5	21	1.75	150	300	180	5.2	0.03	$\square \text{ Influence of frequency } f(D, E);$
	В	50	2	21	0.61	150	221	385	6.0	0.07	
	С	15	2	11	0.22	150	104	500	2.3	0.49	Larger frequency \rightarrow smaller current at same active power \rightarrow
	D	15	5	11	0.44	150	195	472	6.0	0.84	smaller heat load
	Е	15	5	11	0.42	400	274	256	6.0	0.59	Influence of coil pitch a (D, F):
	F	15	5	8	0.45	150	200	472	6.0	1.04	Smaller pitch \rightarrow same active power, but larger heat load density
R_c - inductor radius, L - in N - number of turns, f - fr a - pitch, U - ve				ductan equency oltage,	се, у,	$I_q - 1$ $P - a$ $Q_m - a$	reactive active po maxim	e current, ower, um heat le	Selection of heater F oad in test tube		

Large heater (A, B)

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Small heater (C-F)

Expected temperature evolution (1 MW/m² heater)

Maximum achievable temperature and heating/cooling rates as function of

- Sodium flow rate *V*
- Sodium inlet temperature T_{in}

	entire test tube							zoom to heated section							
	Slice: Ter	mperatu	ıre (deç	gC)					Sli	ce: Ten	nperatu	ure (de	aC)		
															2
								-1		0	1		→ x/cm		1
500 510	520 530	540	550	560	570	5	00	510	520	530	540	550	560	570	T (°C)
	Slice: Ter	mperatu	ure (deg	gC)					Sli	ce: Ten	nperatu	ure (de	gC)		
500 510	520 530	540	550	560	570	5	500	510	520	530	540	550	560	570	
	Slice: Ter	mperatu	ure (deg	gC)					Sli	ce: Ten	nperatu	ure (de	gC)		
700 71	0 720 7	30 74	40 75	50 7	60		70	0 71	0 72	20 73	10 74	10 7:	50 70	60	
	500 510	500 510 520 530 Slice: Ter 500 510 520 530 Slice: Ter 200 710 720 7	500 510 520 530 540 Silce: Temperatu 500 510 520 530 540 Silce: Temperatu	500 510 520 530 540 550 Slice: Temperature (de 500 510 520 530 540 550 Slice: Temperature (de 500 510 520 530 540 550	500 510 520 530 540 550 560 Slice: Temperature (degC) 500 510 520 530 540 550 560 Slice: Temperature (degC)	500 510 520 530 540 550 560 570 Slice: Temperature (degC) 500 510 520 530 540 550 560 570 Slice: Temperature (degC) Slice: Temperature (degC) Slice: Temperature (degC)	500 510 520 530 540 550 560 570 5 Slice: Temperature (degC) 500 510 520 530 540 550 560 570 5 Slice: Temperature (degC) 700 710 720 730 740 750 760	500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 Silice: Temperature (degC) 700 710 720 740 750 760 70	500 510 520 530 540 550 560 570 500 510 520 530 540 550 500 510 Slice: Temperature (degC) 500 510 520 530 540 550 500 510 Slice: Temperature (degC) Slice: Temperature (degC) Top 710 700 710 700 710 700 710 700 710 700 710 700 710 700 710 700 710 700 710 <	500 510 520 530 540 550 560 570 Slice: Temperature (degC) Slice: Temperature (degC)	500 510 520 530 540 550 570 500 510 520 530 540 550 570 500 510 520 530 540 550 510 500 510 520 530 540 550 560 500 510 520 530 540 550 560 500 510 520 530 540 550 560 500 510 520 530 540 550 560 500 510 520 530 540 550 560 500 510 520 530 510 520 530 500 510 520 530 560 570 500 500 510 520 530 510 520 530 500 510 520 530 510 520 530 500 510 520 530 500 510 520 530 500 510 520 530 560 570 500 510 520 530 700 710 720 730 740	Junce: 1 cmpcradue (degc) Junce: 1 cmpcradue (degc) -1 0 500 510 520 530 540 Slice: Temperature (degC) Slice: Temperature Slice: Temperature 500 510 520 530 540 500 510 520 530 540 500 510 520 530 540 500 510 520 530 540 500 510 520 530 540 500 510 520 530 540 Slice: Temperature (degC) Slice: Temperature (degC) Slice: Temperature (degC) 700 710 720 730 740	Since: Temperature (degc) -1 0 1 500 510 520 530 540 550 Silice: Temperature (degC) Silice: Temperature (degC) Silice: Temperature (degC) 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510 520 530 540 550 500 510	Sile: 1000000000000000000000000000000000000	Silice: Temperature (degC) 500 510 520 530 540 550 570 Silice: Temperature (degC) Silice: Temperature (degC) Silice: Temperature (degC) 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560 570 500 510 520 530 540 550 560<

570 no heating 560 emperature (degC) 0.4 s 550 1 s steady state 540 530 520 510 500 -0.04 -0.02 2 0 x-coordinate (m) 0.02 0.04 Temperature profile along outer respectively inner side of lower wall of test tube



positior	is on outer wall after
switchi	na on/off
e triterini	ig en, en

\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	nput param	neters	Results			
400 L/h 500 °C 557 °C 510 °C ~30,000 K/m ~145 K/s	<i></i> <i>V</i>	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
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200 L/h 700 °C 767 °C 713 °C ~25,000 K/m ~150 K/s	200 L/h	700 °C	767 °C	713 °C	~25,000 K/m	~150 K/s

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

 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"

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