Karlsruhe Institute of Technology

Numerical investigations of a prototype monolithic channel receiver in the SOLTEC-1 high temperature sodium loop

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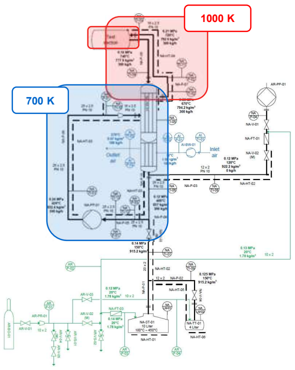
Background, motivation and tasks

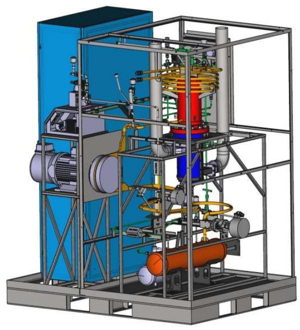
- 1000 K SOLTEC-1 (SOdium Loop to TEst Corrosion and materials) facility
- Developed in the frame of the Helmholtz Energy Material Characterization Platform (HEMCP) and Helmholtz Alliance on Liquid Metal Technology (LIMTECH) at KIT-INR.
- SOLTEC-2: Similar construction; Facility is presently used for corrosion investigations of high temperature steels.
- Monolithic channel receiver (Inconel 718) to be integrated in SOLTEC-1 facility and qualified at sodium temperatures > 700°C.
- Task 1: Numerical investigations of the thermo-dynamic behavior of the test monolithic channel.
- Task 2: Assessment of the required heat energy throughput for the preparation of the experimental campaign in SOLTEC-1.

Technical specifications SOLTEC-1

- Mass flow rate: 300 kg/h (3kW permanent magnet pump)
- Velocities: up to ~ 4.8 m/s in test sample (Re: 114 824)
- Pressure loss: S-1: ~ 1.6 bar; S-2: ~ 0.45 bar
- Temperature: cold loop 700 K; hot loop 1000 K
- Max. pressure: 3.5 bar g
- Compact configuration: 1.2 × 1.6 × 1.9 m^3
- Na inventory: ~ 14 L
- Main components: Na-pump, Na-air HX coupled to a Na-Na heat recuperator (with integrated flow distributor), storage tank (expansion vessel)
- Ar is used as cover gas to fill/drain the facility and pressure monitoring



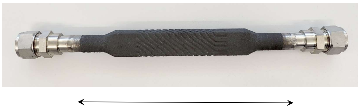
SOLTEC -1: Piping and instrumentation diagram



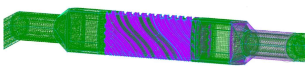
SOLTEC -1 facility (CAD model)

Additive manufactured receiver prototype

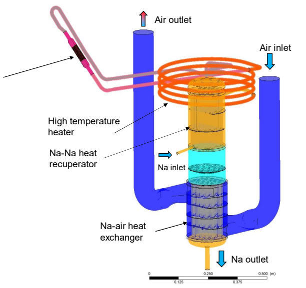
- 3D printed monolithic channel receiver manufactured using the Selective Laser Melting method and the Cold Spray metal powder deposition.
- Prototype manufactured at KIT from Inconel 718 powder.
- Inner and outer spiral rectangular channels and feed hoppers at the ends.
- Internal flow channels are integrated for improved mixing and heat transfer.



Additive manufactured monolithic channel receiver prototype (L = 195 mm)



Numerical grid of the monolithic channel



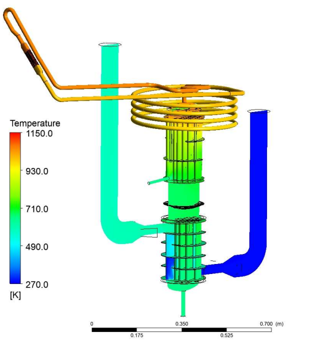
SOLTEC-1: CFD model and numerical results

- ANSYS CFX 2023: Conjugate heat transfer model (Na, air, stainless steel, Inconel).
- Numerical grid: 41.2 mio. cells (49% hexagonal, 45% tetrahedral, 3% pyramids, 3% prisms); y+ < 1 (regions of interest).
- Heat transfer model: thermal energy.
- Turbulence modelling: ω-RS (Na) and SST (air).
- Air, Na and material properties implemented as temperature dependent.
- Turbulent Prandtl number: Pr_{turb} (air) = 0.85;

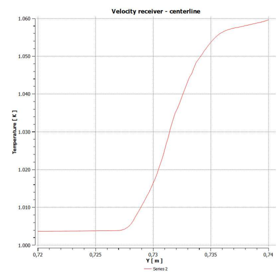
  $Pr^{-1}_{tb}(Na)=0.014\ Re^{0.045}\ Pr^{0.2}\ \{1-\exp[-1/(0.014\ Re^{0.045}\ Pr^{0.2})]\}$ [Aoki, 1963]
- Thermal losses based on experimental data from SOLTEC-2.
- Thermal effectiveness of the Na-Na heat recuperator:

  $\epsilon = c_h\ (t_{h1} - t_{h2})\ /\ c_{min}\ (t_{h1} - t_{c1})$

Sodium flow rate [kg/h]	Air flow rate [kg/h]	Thermal energy heater [kW]	Heat flux test receiver [MW/m²]	Temperature inlet receiver [°C]	Temperature outlet receiver [°C]	Temperature gradient receiver [°C]	Mean velocity inlet receiver [m/s]	Therm. effectiveness [%]
300	67.4	2.97	1.0	730.6	788.9	58.3	0.49	78.0
300	67.4	2.97	1.5	795.7	881.3	85.6	0.51	79.4
300	67.4	0	2	749.7	863.9	114.2	0.50	77.9



Temperature distribution @ $q_{receiver}$ = 1MW/m^2, m_{Na} = 300 kg/h



Temperature distribution in test receiver (centerline) @ $q_{receiver}$ = 1MW/m^2, m_{Na} = 300 kg/h

Conclusions

- Developed numerical model of the SOLTEC-1 facility integrating a monolithic channel design, proposed as material for a CSP receiver.
- Optimized heat transfer in the heat recuperator (flow distributor): uniform temperature distribution and increased efficiency of the heat recuperator.
- Operating range of the facility investigated for preparation of the experimental campaign.
- Numerical investigation of the monolithic channel design performed up to 2 MW/m^2.

References:

S. Aoki, Bull. Tokyo Inst. Tech. 54, 63–73, 1963.
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