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Numerical investigations of temperature distribution in an AMTEC test cell and comparison with experimental data

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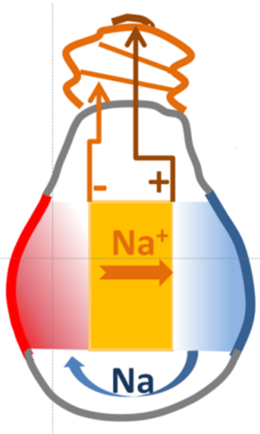
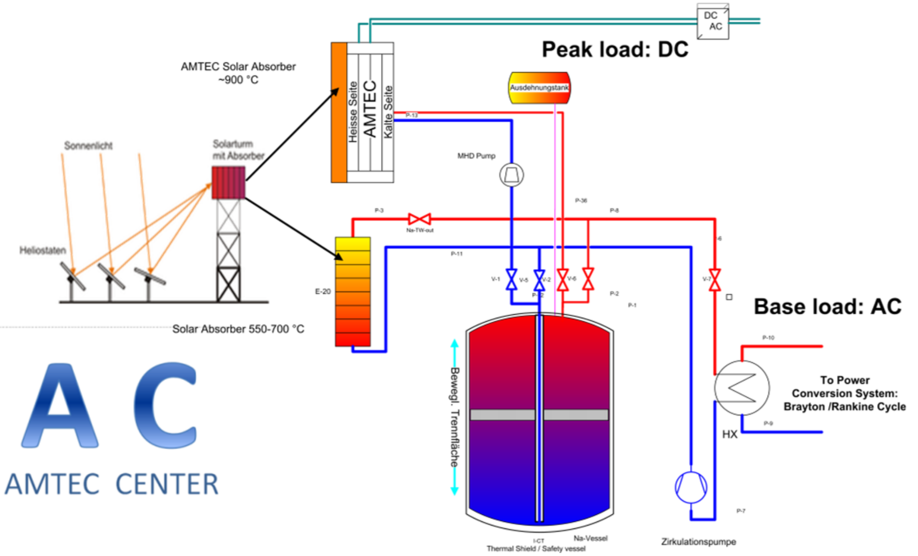
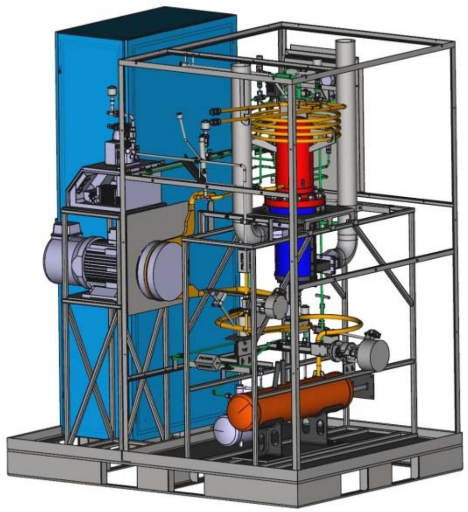
Institute for Neutron Physics and Reactor Technology



HAC
HEMCP AMTEC CENTER



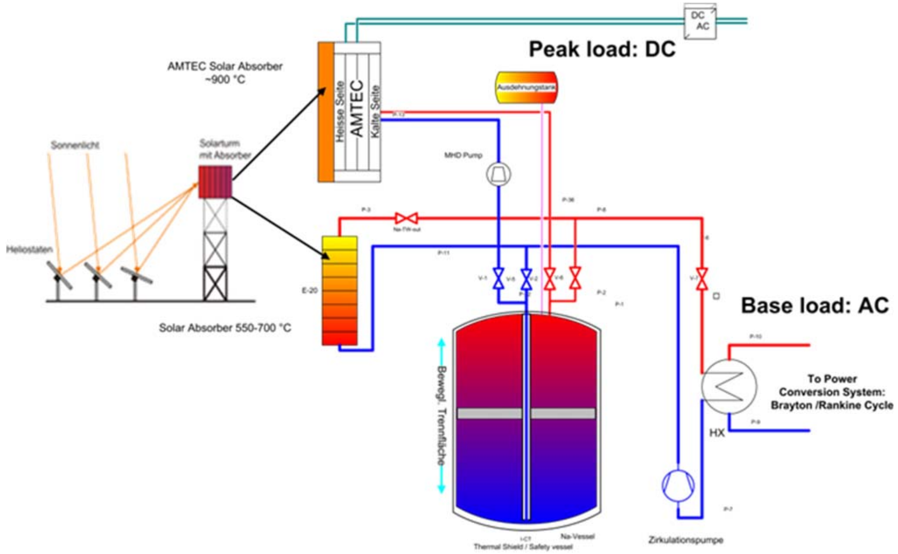


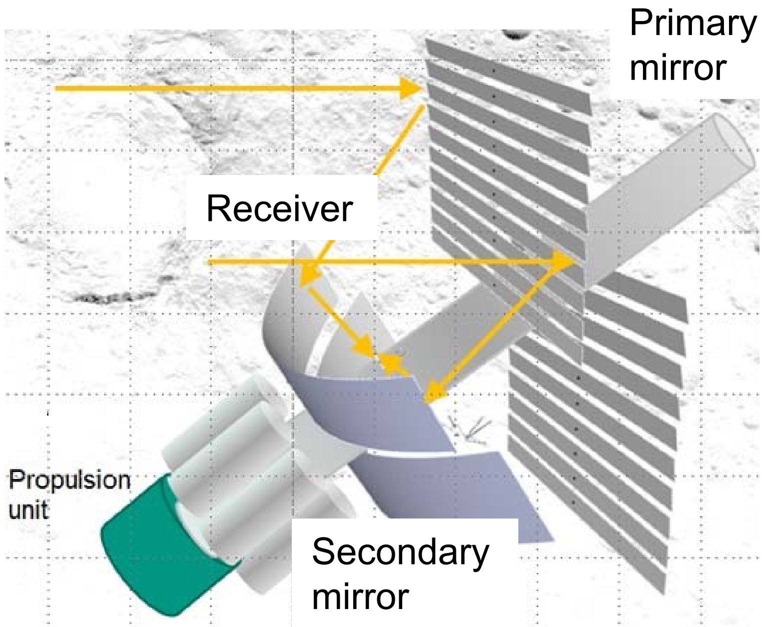
Outline

- Introduction
- AMTEC test cell
- Numerical model (ANSYS CFX)
- Numerical results and comparison with experimental data
- Conclusions

Introduction

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





- ATEFA (AMTEC TEst FAcility)*** successfully operated up to 700°C -> experimental data (T) available

***Developed in the frame of the Helmholtz Energy Material Characterization Platform (HEMCP) and Helmholtz Alliance on Liquid Metal Technology (LIMTECH)

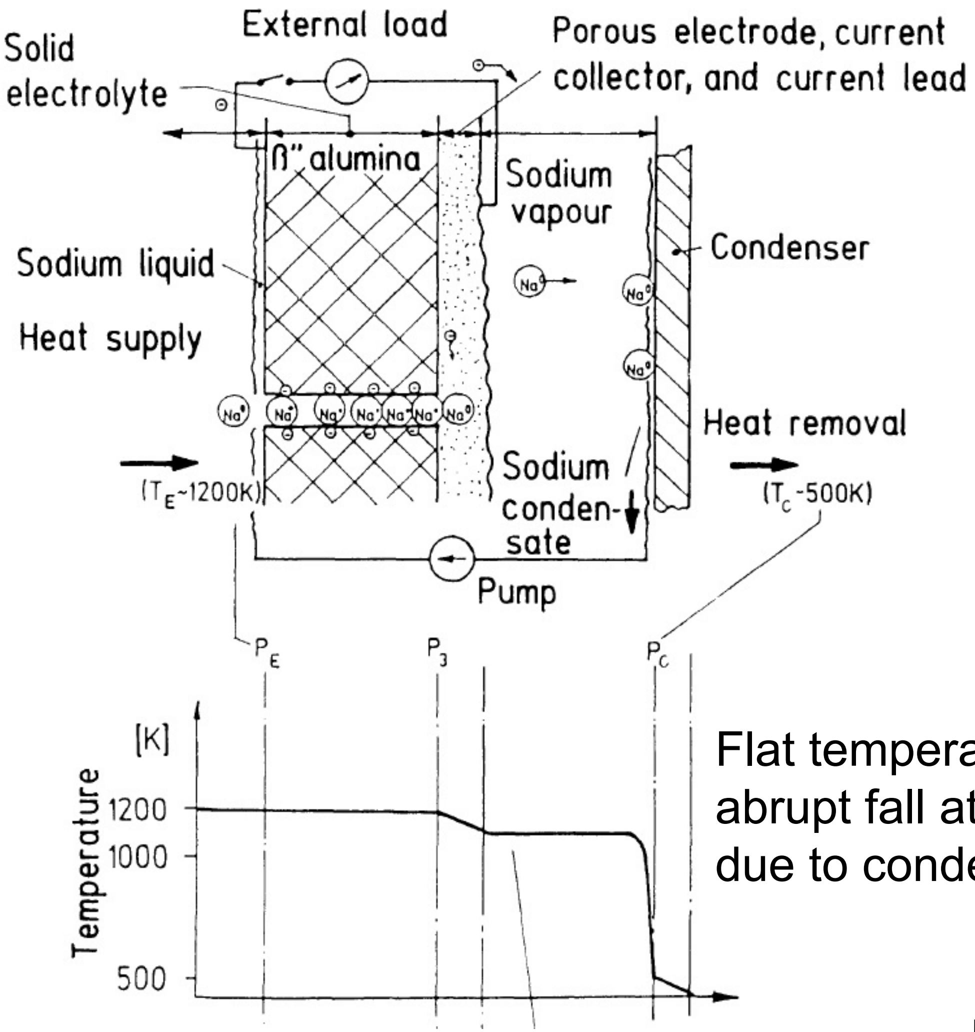
*W. Hering et al. – Europ. Ph. J. 33, 03003 (2012)
** Hering et al., PAMIR 2016
***N. Diez, PhD KIT, 2018

Motivation

- CFD model: Only one study reported so far#
- Development of a CFD model for AMTEC cell
  - thermodynamics
  - thermal radiation in sodium vapor
  - (later): sodium condensation model
  - (later): electrical model
- Validation of CFD data with the experimental data from ATEFA
- Studies for AMTEC power improvement
  - Decrease parasitic losses (thermal radiation)
  - Investigation of new cell configurations
- Models for calculation of AMTEC
  - Thermal model*
  - Electric model** (2D)
  - Pressure loss model***
  - Electrochemical model***

* Tournier et al. – CONF 970115 (1997)
** Tournier, El-Genk – J.A.Electrochem. 29 (1999)
*** Tournier, El-Genk – JTHT 13 (1999)
# Lee et al., HMT 53 (2017)

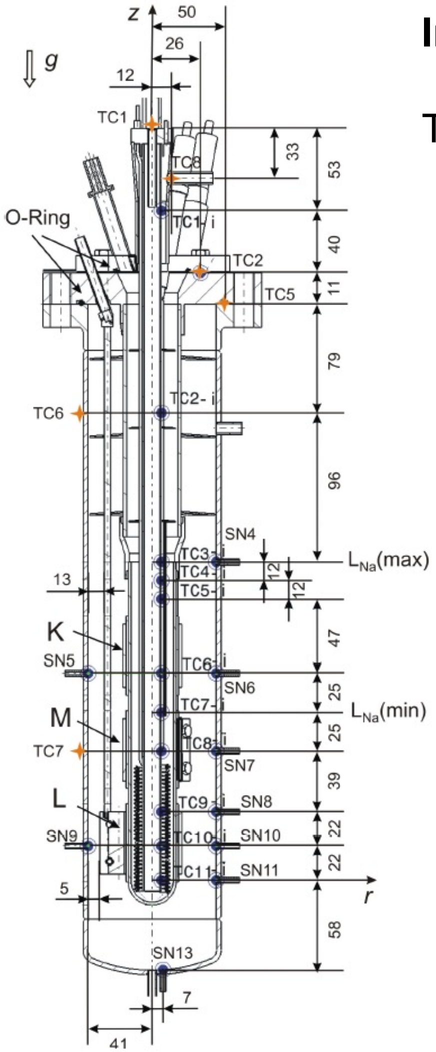
AMTEC (Alkali metal-to-energy converter)



Flat temperature profile with abrupt fall at the condenser wall due to condensation

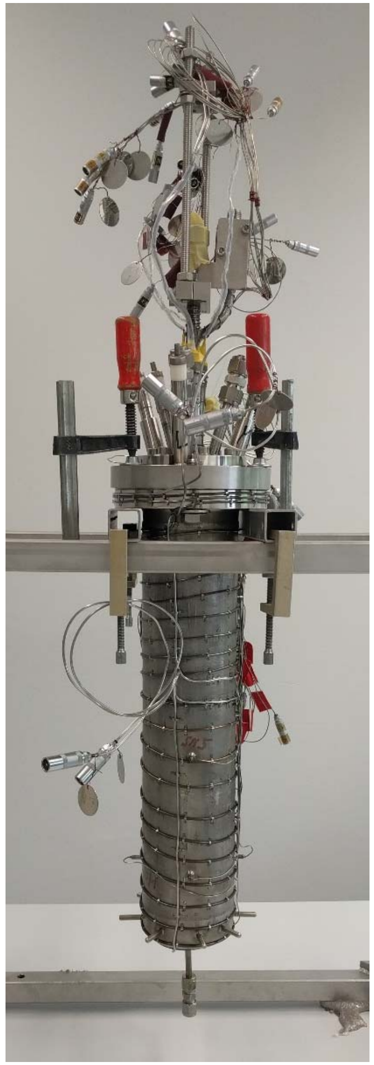
Heinzel et al., KEM 59, 1991

AMTEC test cell



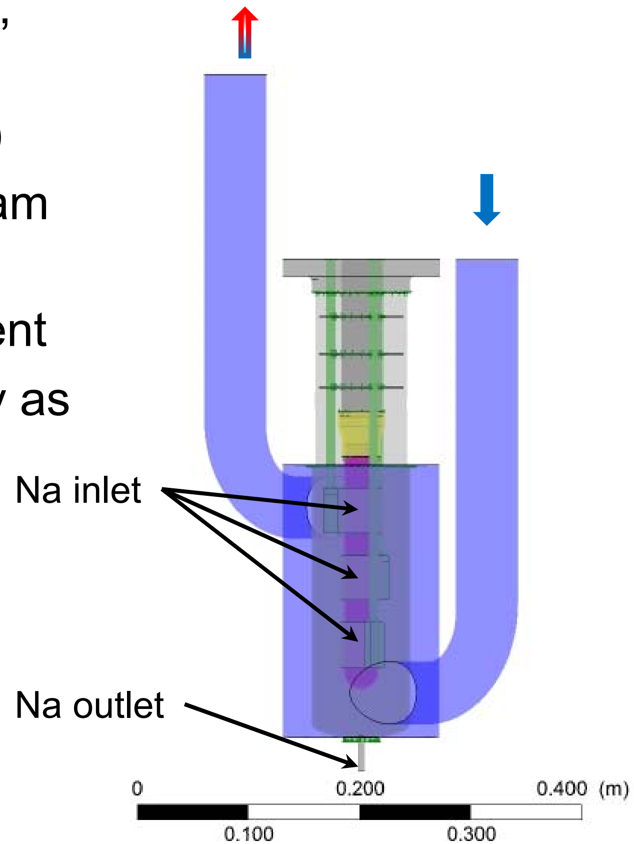
Instrumentation:

Type K thermocouples (up to 1000°C)
- BASE: max. error: ± 3.5 °C
- Condenser: max. error: ± 3.7 °C



Numerical model (ANSYS CFX)

- **BASE**: solid domain, **CC**: porous and solid domains, **sodium side**: vapor, **condenser**: solid domain (SS), **air**: gas
- Grid: ~ 5.3 Mio cells (Hexa: ~2 Mio., Tetra ~2.6 Mio)
- Na vapor (data from SAS-SFR*) defined as gas/steam with temperature dependent properties
- Air properties implemented as temperature dependent
- Steel specific heat capacity and thermal conductivity as temperature dependent**
- Na: laminar flow, MFR = 1 g/h
- Air: turbulent flow (SST TM), Re number: ~3300
- Temperature field at BASE implemented from experimental data from ATEFA



- No sodium condensation
- Location of the inner BASE/feedthroughs and cooling system implemented as "best approximate"

*P. Breton - 3rd S.M. Sodium/fuel interaction FR ,1976
** F. Richter - The Physical Properties of Steels

Numerical model (ANSYS CFX)

- Heat transfer by radiation and conduction dominant vs. convective HT
- All inner surfaces considered gray and diffuse
- Heat transfer:
  - Thermal energy model
  - Monte Carlo radiation model
  - Spectral model: Gray
  - Scattering model: isotropic
  - Histories: 100000-500000
- Components (walls, ceramic) emissivities implemented from literature as temperature dependent
- Sodium vapor radiation data (absorption, scattering) from Hattori et al.
- Surfaces: diffuse emitters
- Imbalances << 1 %
- Residuals: ~ 10^{-4} - 10^{-5}

Numerical results

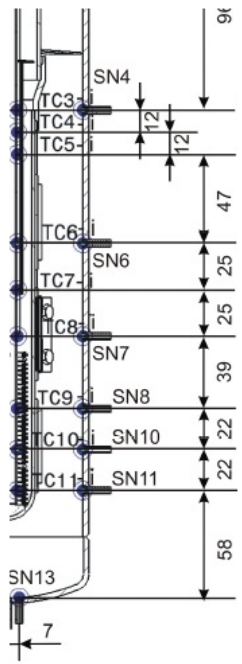
- Temperature distribution along the height of the condenser

T_{BASE} = 500°C 5mm 10mm

TE	SN04	SN06	SN07	SN08	SN10	SN11	SN10 A	SN10 B
Exp.	197	167.1	166.7	161.6	151.6	138.1	181.1	213.3
CFD	220.3	196.4	180.7	165.7	164.5	163.1	186.9	214.9
PD[%]	11.8	17.5	8.4	2.5	8.5	18.1	3.2	1

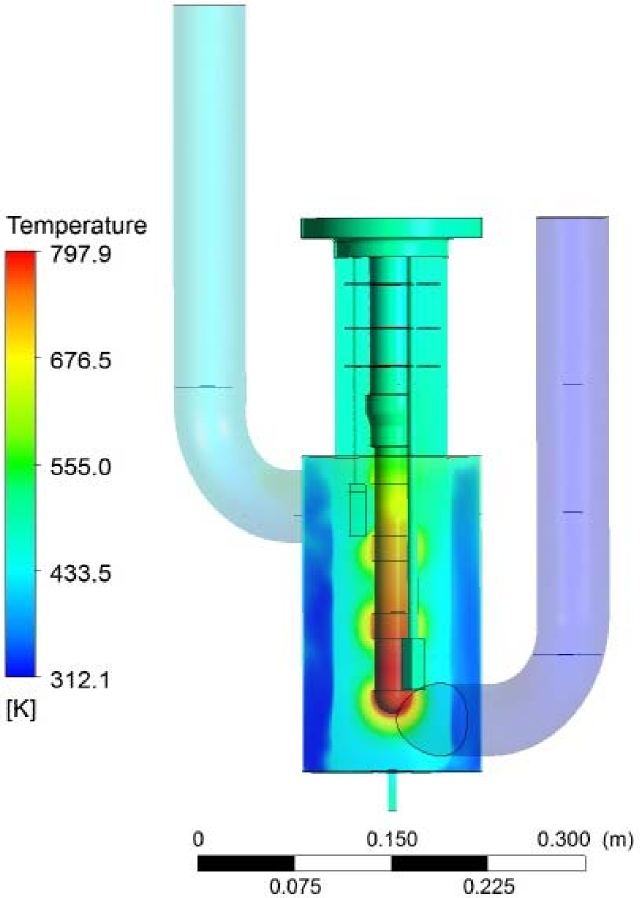
T_{BASE} = 600°C

TE	SN04	SN06	SN07	SN08	SN10	SN11	SN10 A	SN10 B
Exp.	222	176.1	174.8	175.8	163.6	137.8	206.6	236.3
CFD	207.9	209.9	198.3	186	184.2	185.6	203	242
PD[%]	6.3	19.1	13.4	5.8	12.6	34.7	1.7	2.4

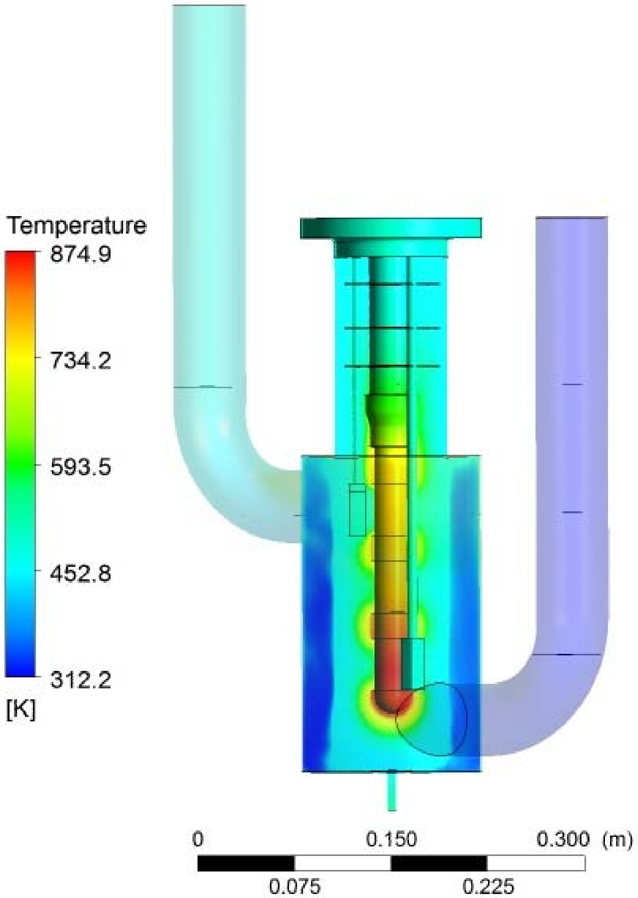


*N. Diez, PhD KIT, 2018

Temperature distribution

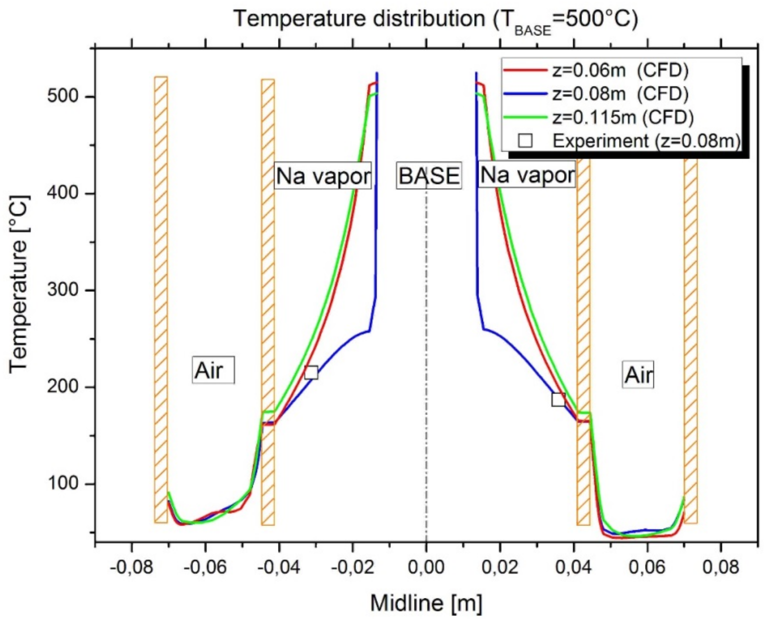


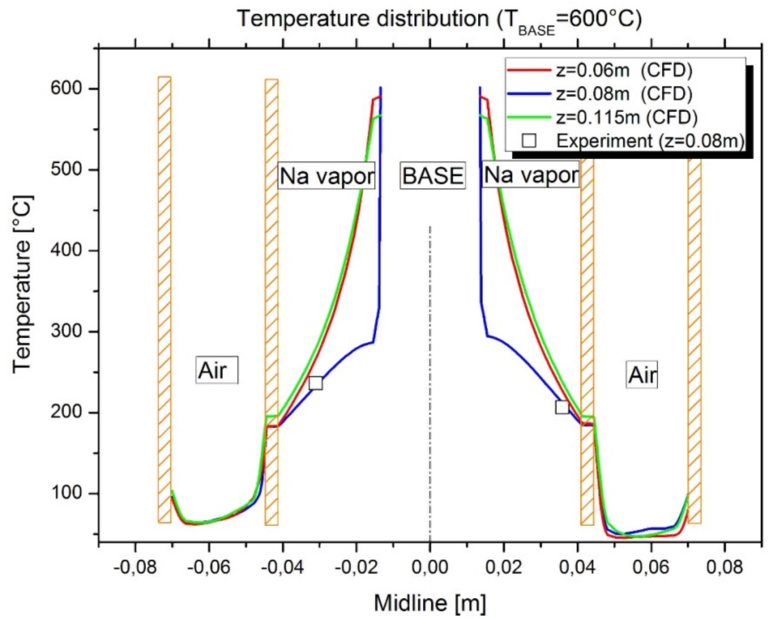
T_{BASE} = 500°C



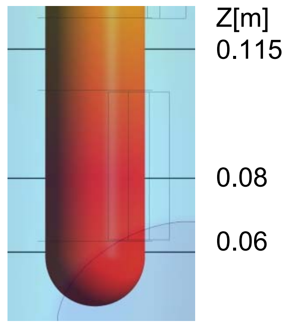
T_{BASE} = 600°C

Temperature distribution in the cell





- Linear temperature decrease in the vapor domain, but no temperature decay at the wall
- Significantly lower temperature in the current collector (mesh in CC and flow)
- Good agreement between experiment and numerical model in the bulk vapor region



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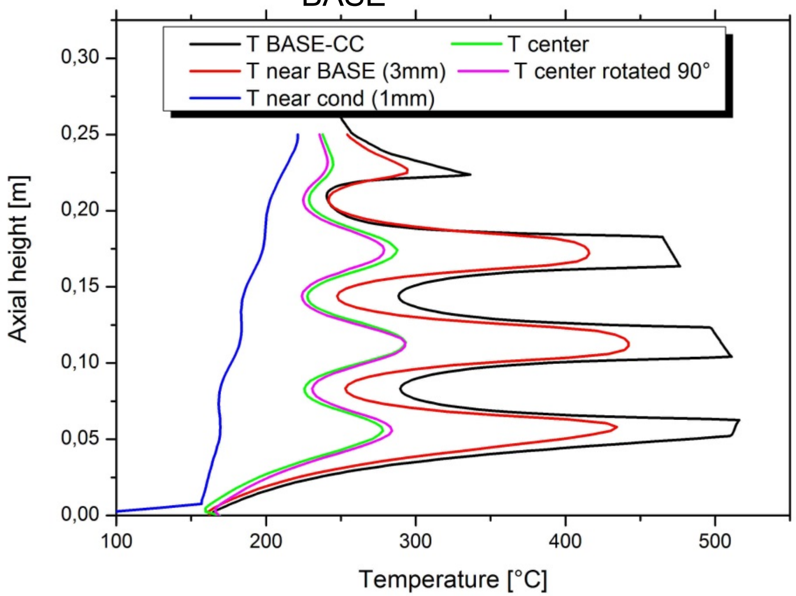
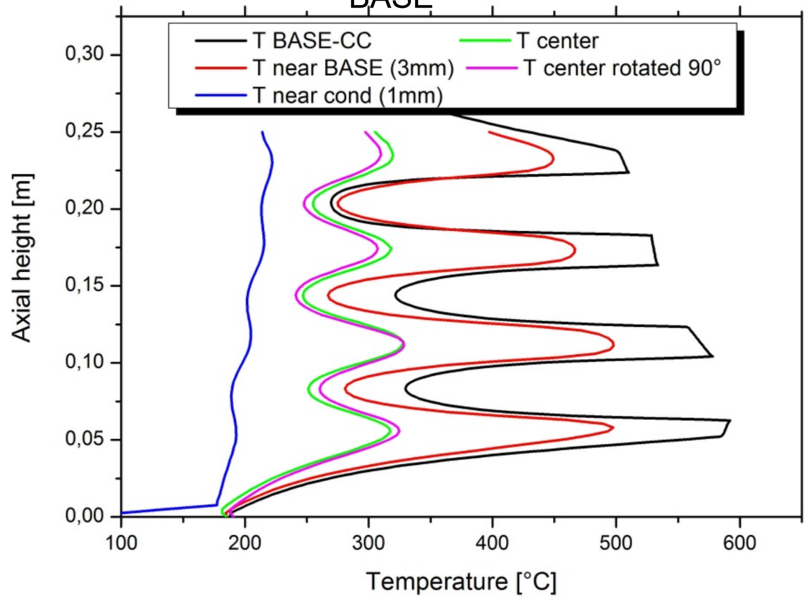
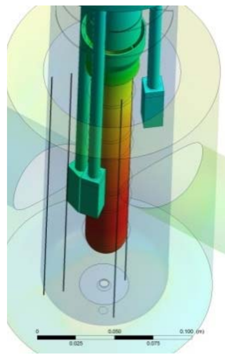
Axial temperature distribution

T_{BASE} = 500°C



T_{BASE} = 600°C





- The pattern of the axial temperature distribution at the BASE is extending through the BASE-condenser space (quasi no convective effect)
- The pattern is continuously smoothed while approaching the wall -> discontinuous sodium film occuring on the condenser wall
- Significant influence of the CC and current feedthroughs on temperature

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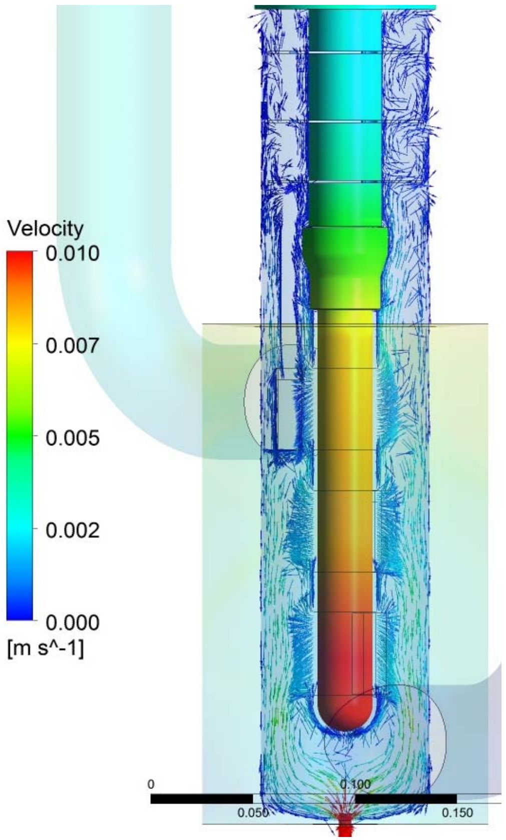
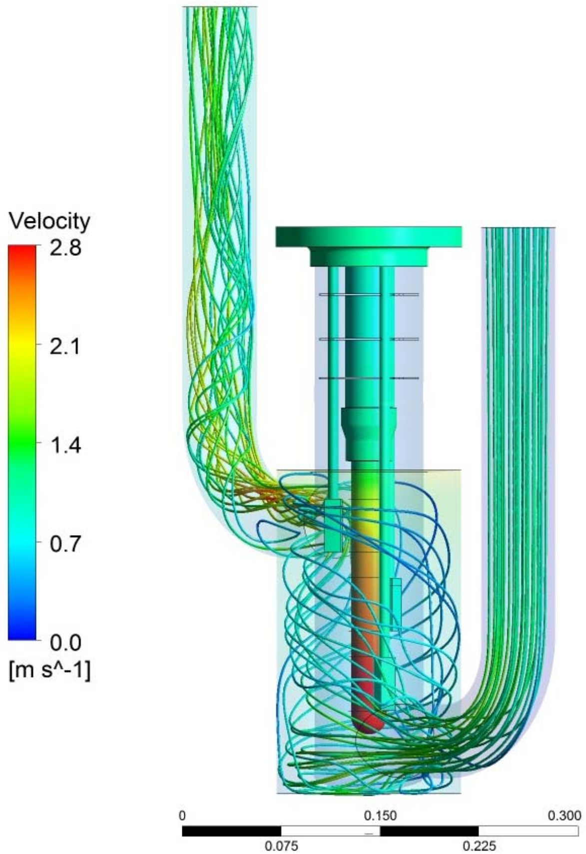
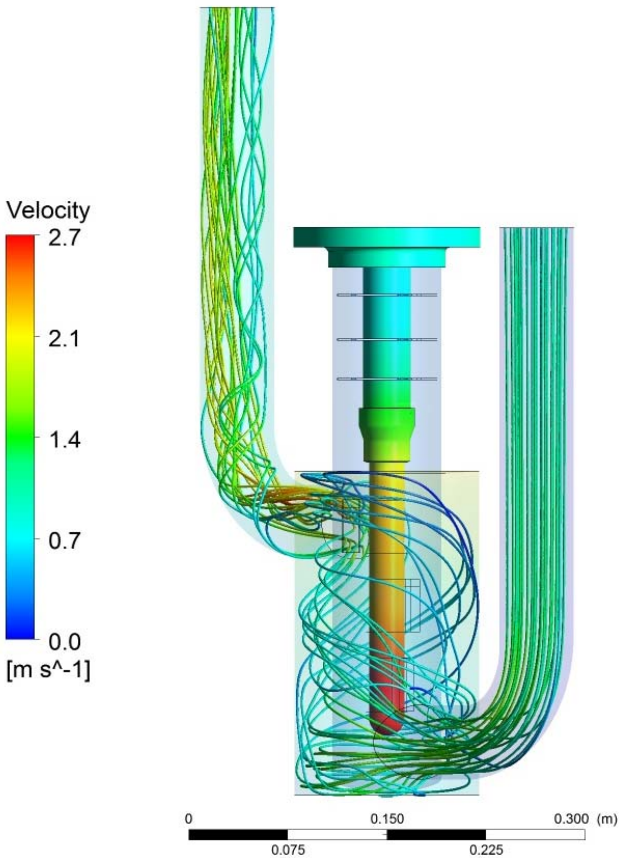
Velocity field in Na and air



T_{BASE} = 600°C



T_{BASE} = 500°C



T_{BASE} = 600°C

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Conclusions

- CFD model developed for sodium vapor flow considering thermal radiation within an AMTEC cell
- Good agreement obtained between experimental data and numerical data in the bulk vapor domain.
- CFD model overpredicts up to 20% the experimental data observed at the condenser due to the lack of consideration of a sodium condensation model in the numerical approach and to the fact that the position of the inner cell and of the cooling system are „best approximate“
- The differences observed at the wall are not constant, due to the fact that the condensation film is probably disrupted and not uniform
- The sodium temperature distribution in the vapor has a linear decay up to the condenser
- The current collector and current feedthroughs have a significant influence on the temperature profile in the BASE-condenser region

Thank you for your attention!