Karlsruhe Institute of Technology

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Measurements of sodium flow rates in the high temperature SOLTEC-2 facility

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Institute for Neutron Physics and Reactor Technology

LIMTECH Alliance

HEMCP:Helmholtz Energy Materials Characterization Platform

HAC
HEMCP AMTEC CENTER

Introduction

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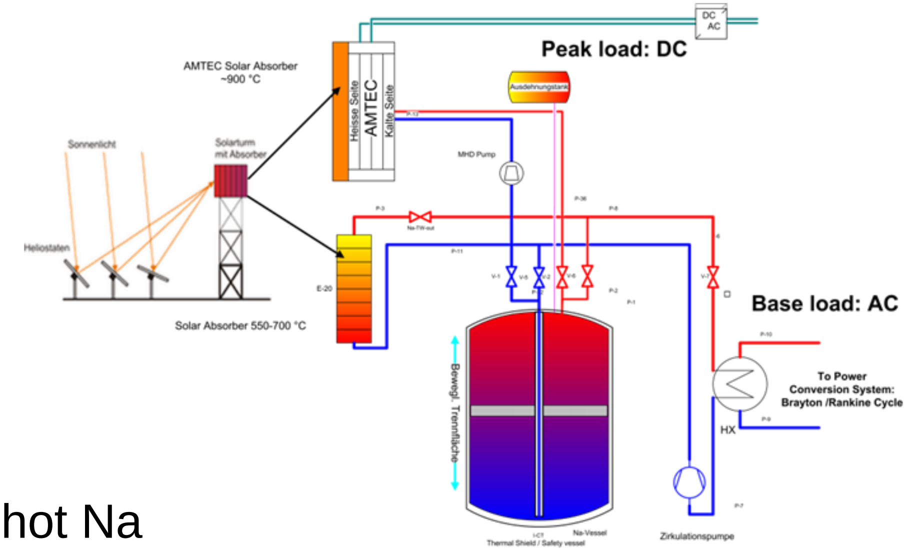
HEMCP:Helmholtz Energy Materials Characterization Platform

- "Energiewende" at KIT-INR: CSP concept[1] of solar tower plant with Na as HTF and AMTEC[2] direct thermoelectric convertes → R&D on materials and components



- Main tasks for the SOLTEC* ** family:
  - *Material development and qualification* for high temperature applications
  - *Experimental investigation of HT components and instrumentation*
  - *Creep fatigue* tests (SOLTEC-1) and *corrosion/erosion* tests (SOLTEC-2) of conventional and innovative materials in hot Na
- ESFR-smart EU program: ECFM investigation in high temperature sodium (KIT Germany & HZDR Germany)
  - This study focuses on flow measurements and test of innovative flow sensor at high temperature

[1] W. Hering et al. – Europ. Ph. J. 33, 03003 (2012)
[2] AMTEC: Alkali Metal Thermal-to-Electric Converter

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

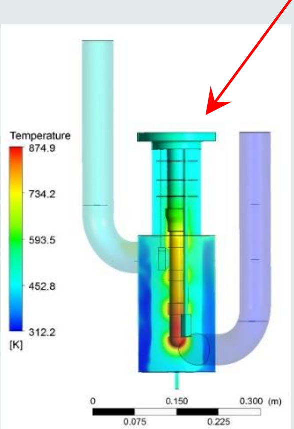
** Funded by HEMCP (Helmholtz Energy Materials Characterization Platform)

Na – Facilities @ KIT-INR: Operating, Qualifying

Basic physics (Electro-chemistry)

AMTEC

ATEFA →



Na inventory: ~3 L

System level (Materials)

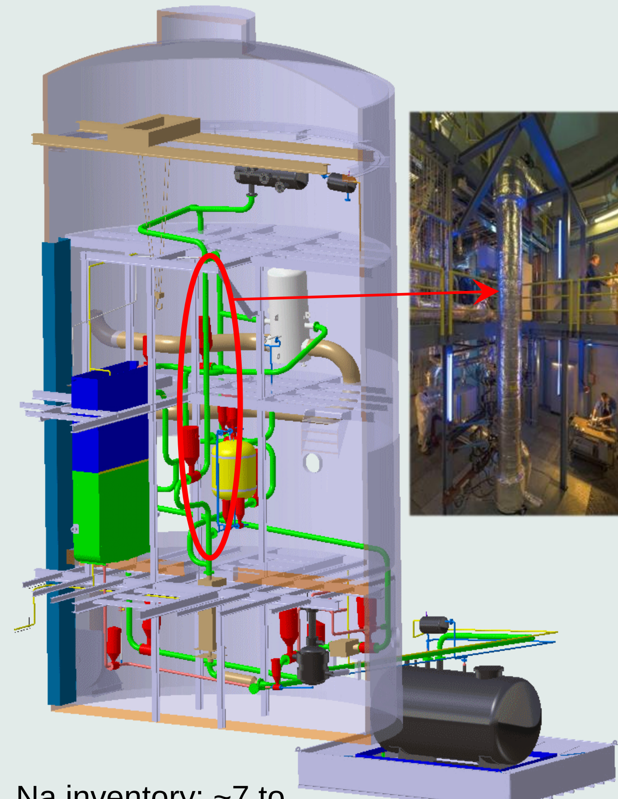
„Energy“ - materials

SOLTEC $1_{INR/AWP}$ – 2_{IHM}

Na inventory: ~14 L

Medium Scale / Demonstrator

Thermal storage: KASOLA facility



Na inventory: ~7 to

SOLTEC - Technical data

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- SOLTEC: SOdium Loop to TEst materials and Corrosion, developed at KIT-INR, Germany
- Na mass flow rate: 300 kg/h
  - Vel: 1.0 m/s in test sample (Re = 28600, 300°C)
  - Up to ~ 4.8 m/s depending on size of the sample
- Temperature: cold side 450°C; hot side 720°C
- Max. pressure: 3.5 bar g
- Na inventory: ~ 14 L
- Dimensions: 1.2 × 1.6 × 1.9 m^3
- Main components:
  - Na-pump (permanent magnet pump)
  - Storage tank = expansion tank (particular feature)
  - KIT-INR design: Na-air HX (7.5 kW) & Na-Na heat recuperator (27 kW)
  - KIT-INR design high temperature heater (6.7 kW)

SOLTEC-2

SOLTEC – SOdium Loop to TEst materials and Corrosion

Traction facility

Material test chamber

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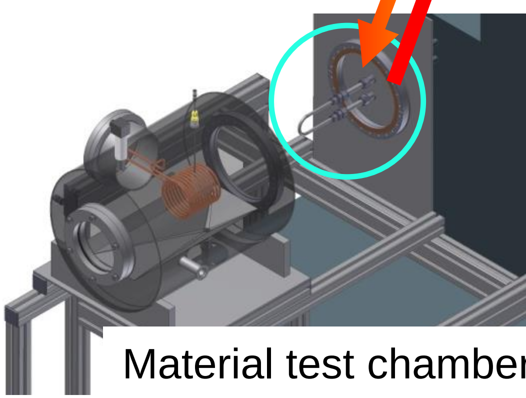
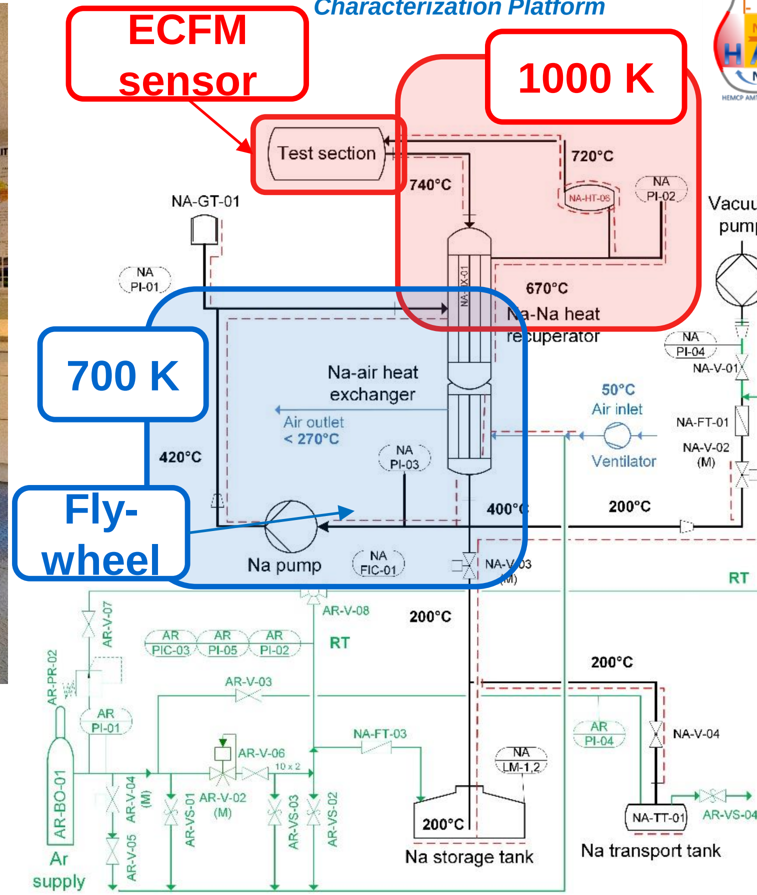
SOLTEC-1

SOLTEC-2

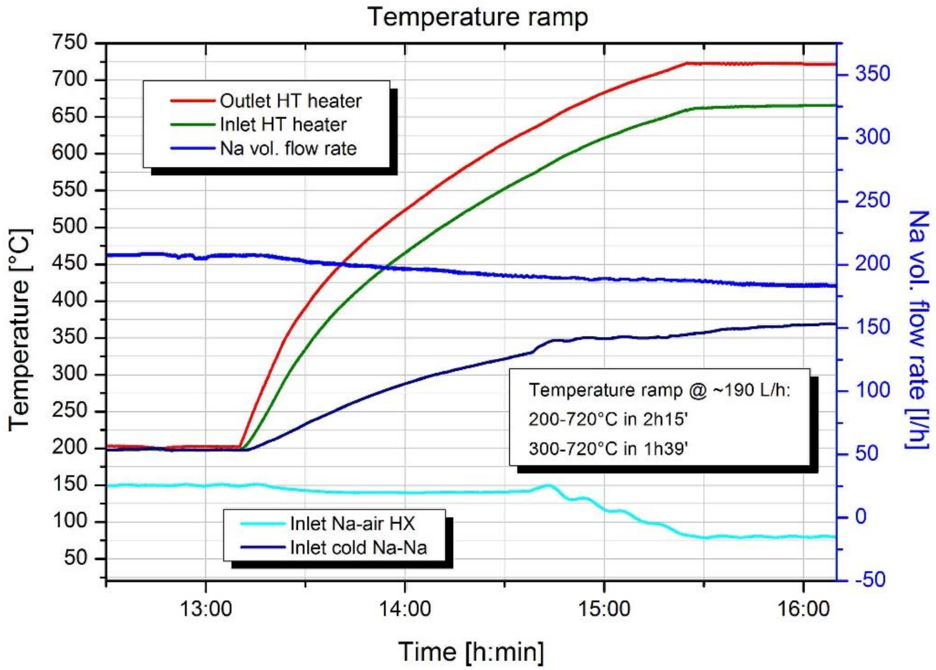


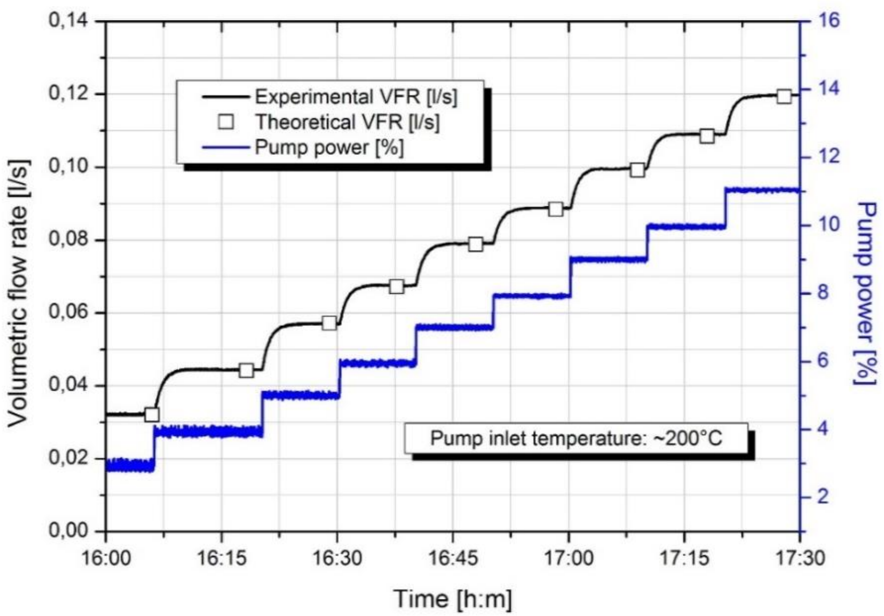
Material test chamber



P&I diagram

SOLTEC – Experimental data

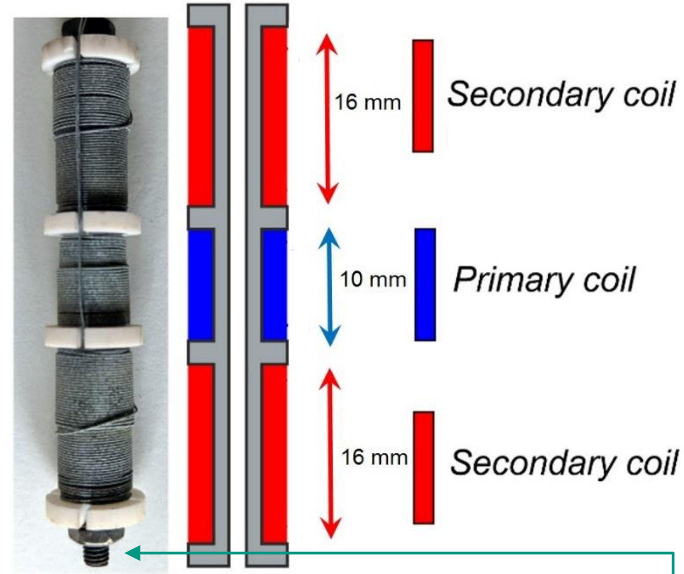


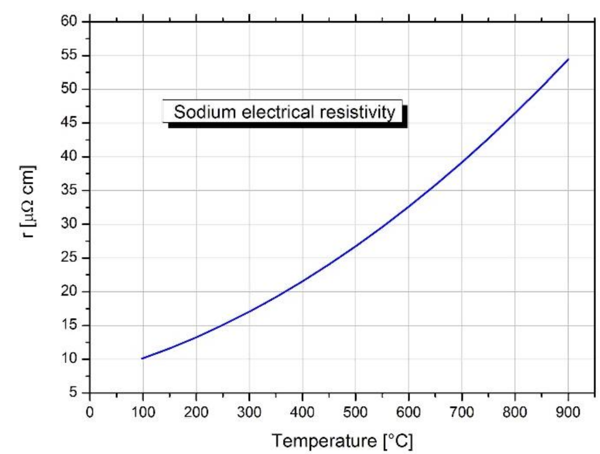


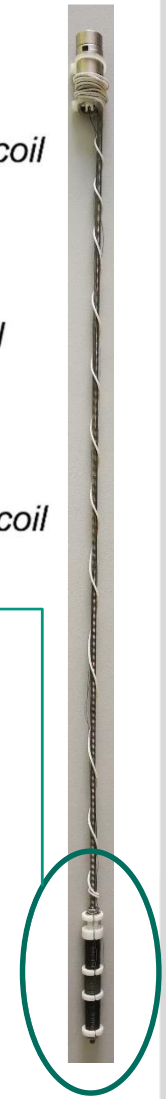
- Temperature ramp @ 190 L/h
  - 200 – 720°C in 2h 15’
  - 300 – 720°C in 1h 39’
- SOLTEC-2 operated @720°C for > 10h

Eddy current flow sensor

- Developed at HZDR, Germany
- Inductive sensor consisting of 3 coils placed vertically above each other:
  - Primary coil: magnetic field generation to induce eddy currents in the fluid
  - Secondary coils: quantification of the changes in the excitation field of the primary coil
- Coils: ceramic insulated Ni-Cu wires
- Coils mounted on ceramic holder
- Sensor placed in HT casing
- Calibration required due to the strong variation of the sodium electrical conductivity with the temperature*







*Kirillov – *Thermophysical Prop. of Mat. for Nuclear Eng.*, 2008

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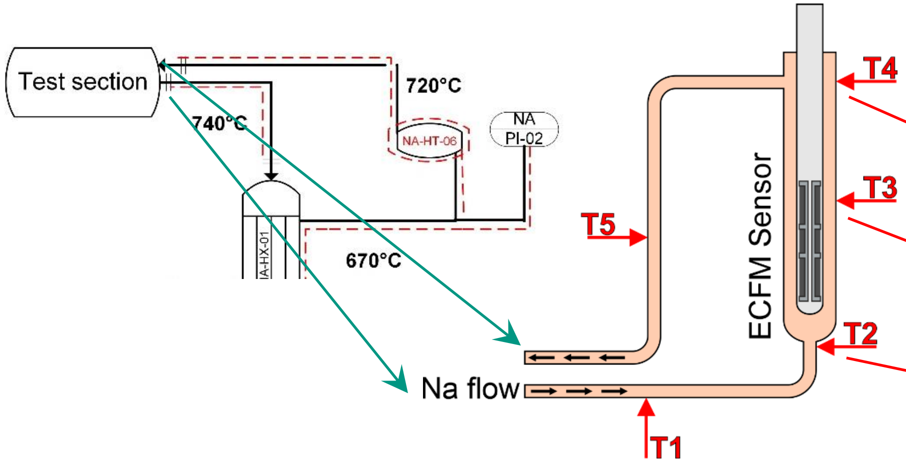
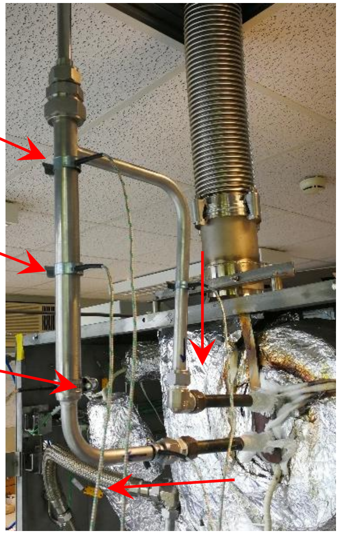
Experimental mock-up and integration in SOLTEC



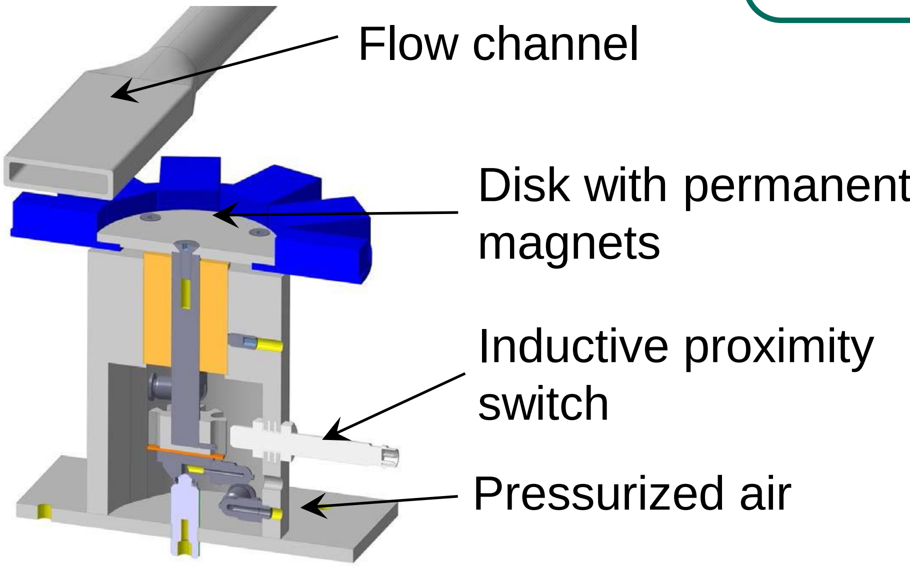


- Test track connected to the SOLTEC-2 loop at the outlet of the HT heater
- Casing for the ECFM sensor: AISI 314 (1.4841)
- Trace heating installed on the test track
- Instrumentation: TCs
- ECFM: excitation current: 200-500 mA rms; frequency: 500 Hz-2kHz.

Magnetic fly-wheel flow meter

- MFW: inductive sensor consisting of a rotating disk equipped with permanent magnets
- The flowing sodium induces the rotation of the disk, which is quantified
- Flow range: 0.05 – 2 m/s
- Calibrated in InGaSn test track
- Fluid temperature: < 500°C

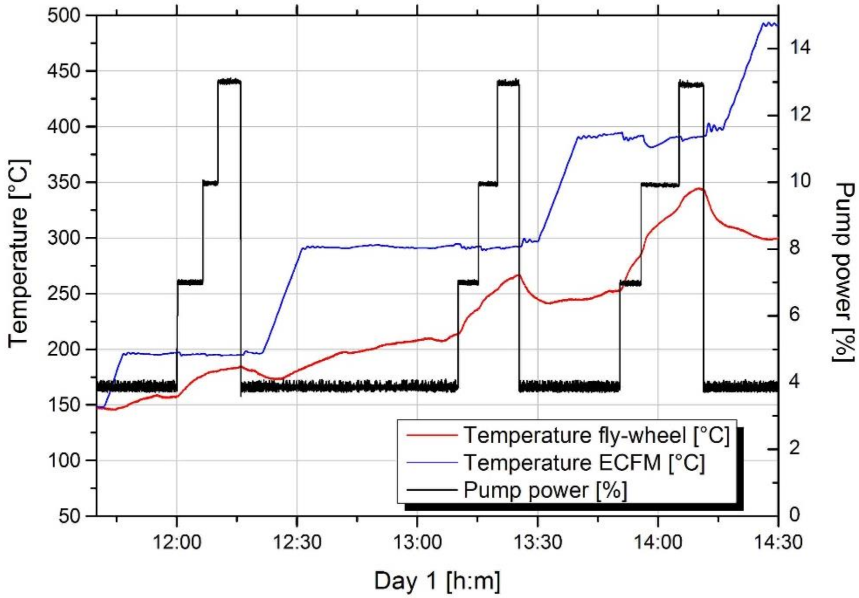
Drawbacks:
- Sensitive to external magnetic disturbances
- Delay of the response signal by flow changes

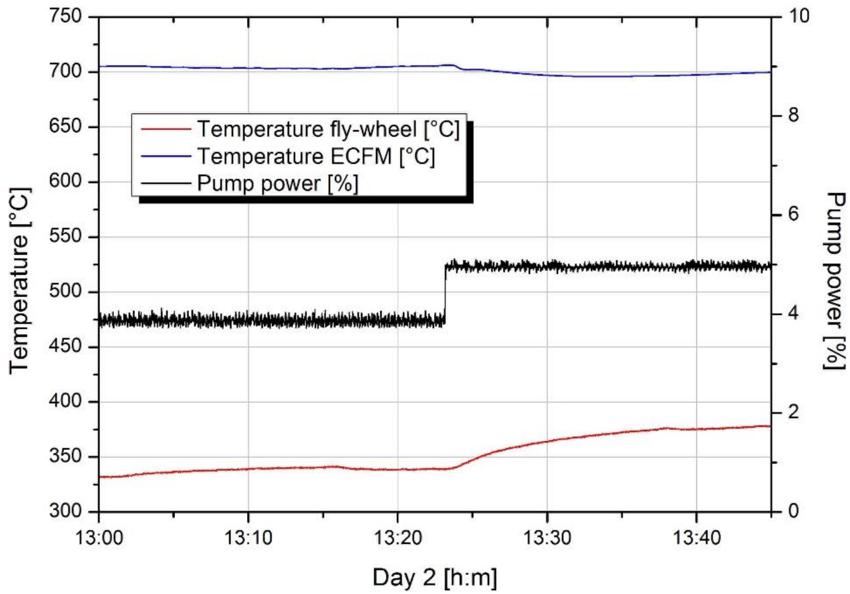


Magnetic fly-wheel model

Fly-wheel integrated in SOLTEC-2

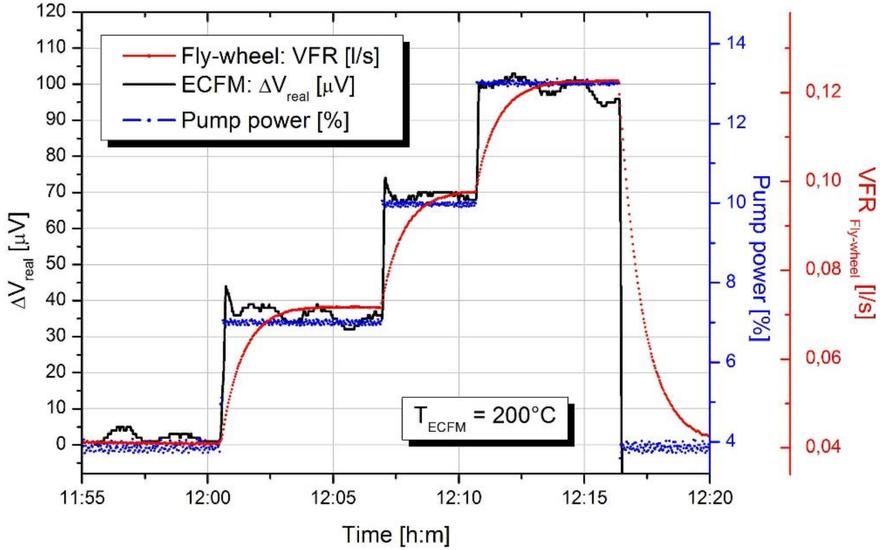
Temperature distribution at the flow sensors

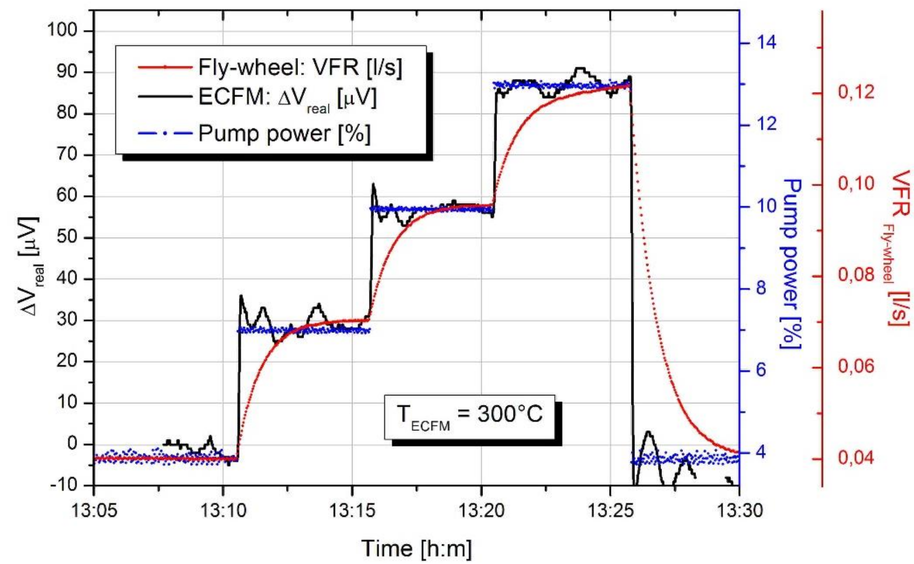




- MFW sensor: placed in the low temperature side of the loop (< 450°C).
- ECFM sensor: wetting of the sensor casing has a positive effect on the signal.

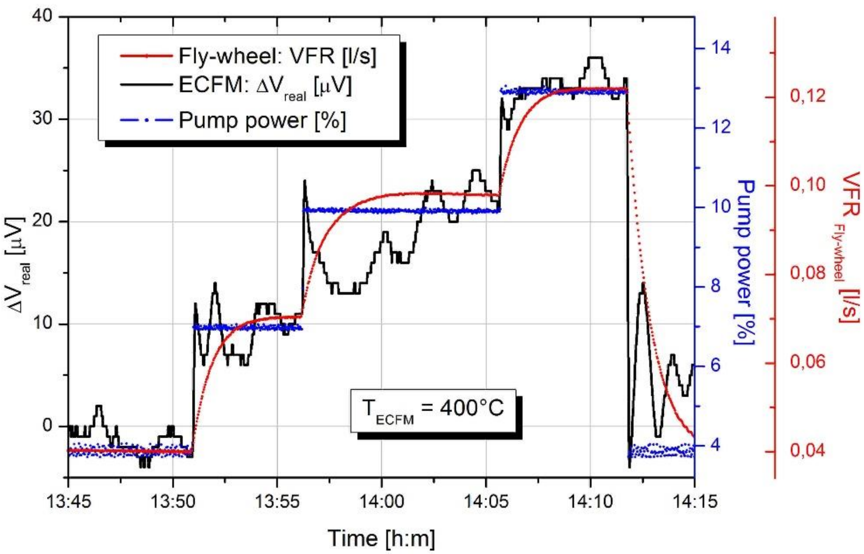
Experimental results

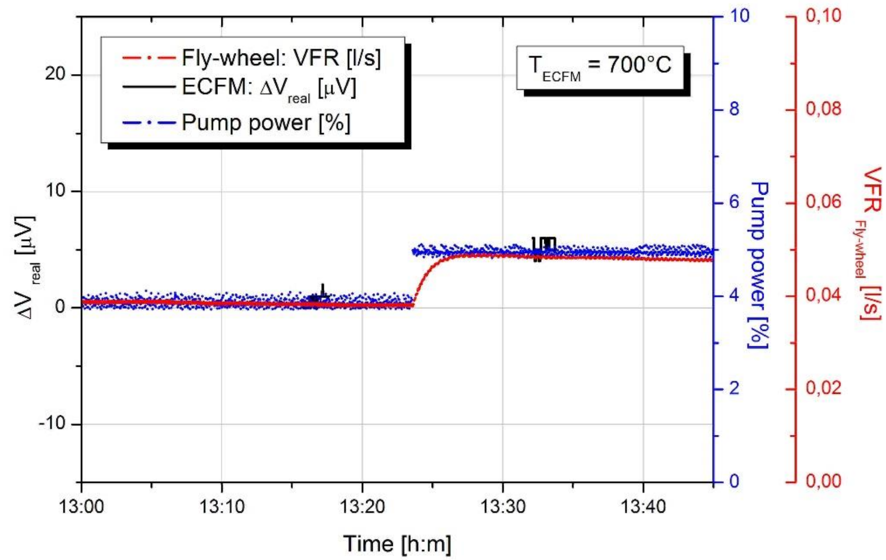




- Calibration of the ECFM sensor required due to the strong variation of the sodium electrical conductivity (factor 3.4 for 150-700 °C range). Performed in SOLTEC.
- Good agreement obtained between signals of ECFM, MFW and Na-pump power level.
- MFW: inertial behaviour (few minutes) followed by asymptotic approach
- ECFM: instantaneous response and sharp sensitivity of the signal

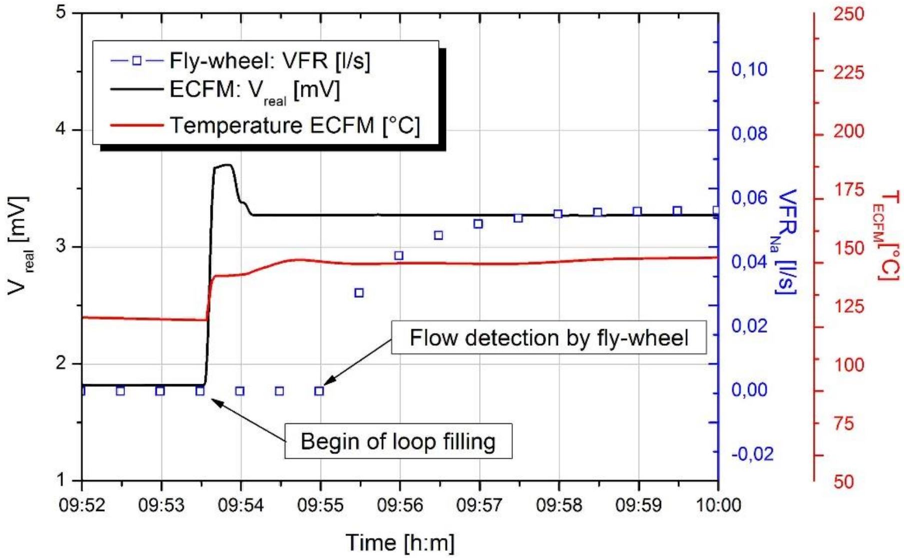
Experimental results (2)

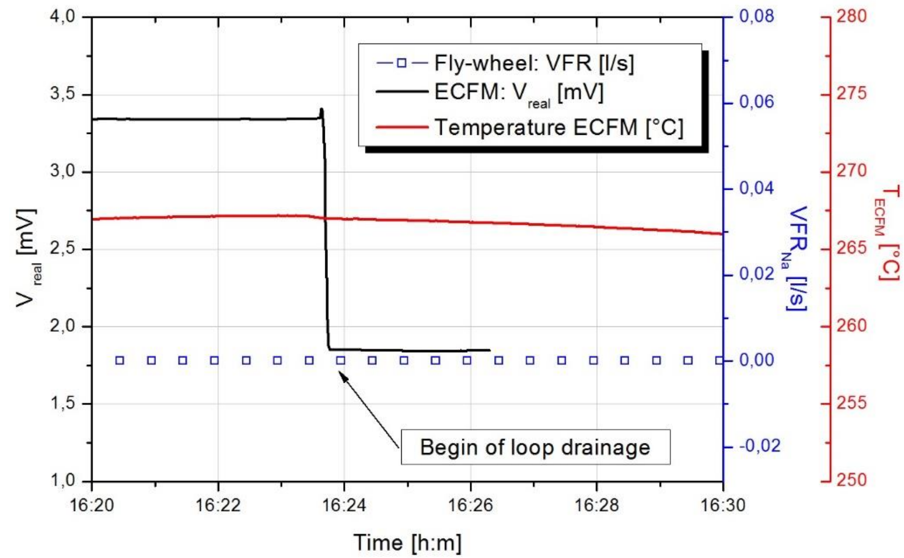




- Above the Curie temperature of nickel (358 °C) the inductivity of the ECFM sensor is reduced and the output voltage amplitude decreases.
- No reliable measurements around the Curie temperature: 345 °C ± 15 °C
- Challenges at higher temperatures for the ECFM sensor:
  - Nickel migration
  - Increased wire resistance
- Successful measurements at 700 °C (low magnitude of the output voltage)

Detection of filling/drainage of the loop



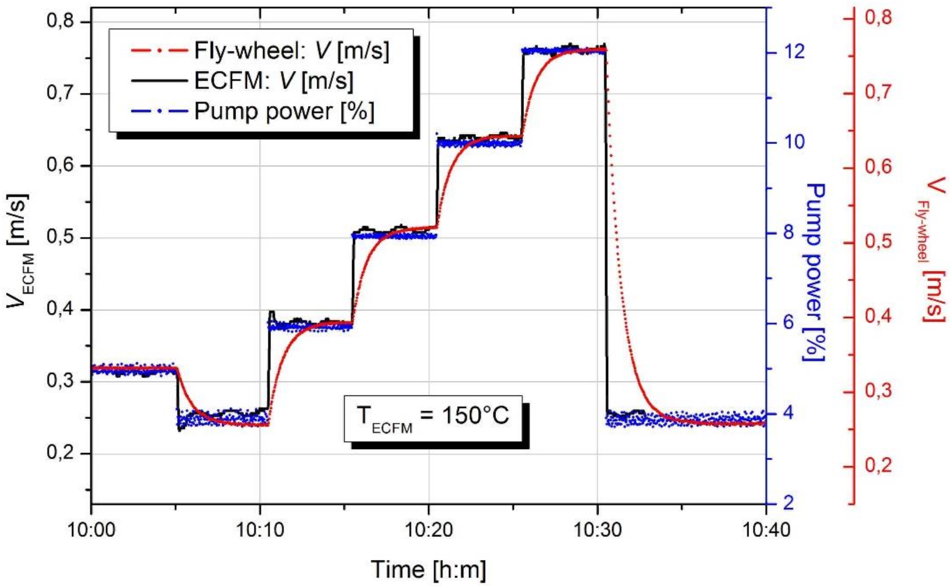


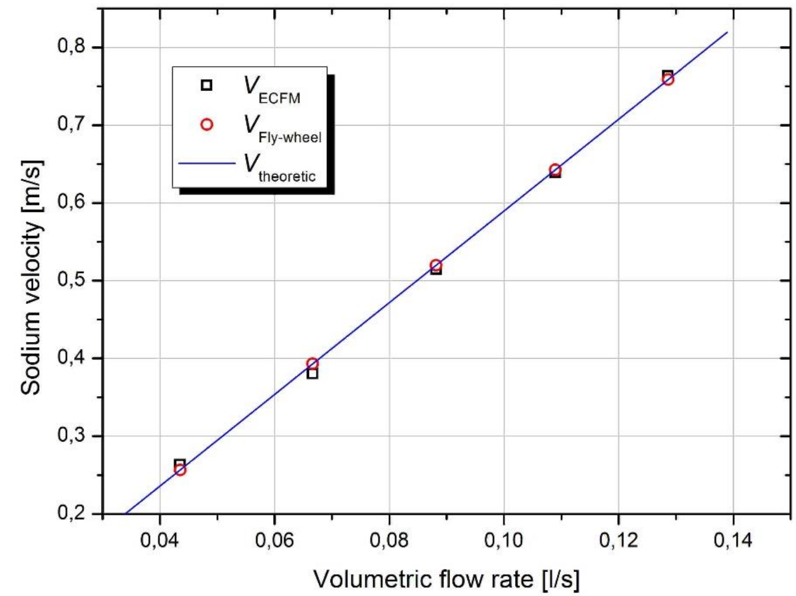
Signals during loop filling

Signals during loop drainage

- ECFM: instantaneous response and typical „overshooting“ behaviour
- Fly-wheel sensor: delay of ~1’26‘‘

ECFM calibration - Velocity values





Calibration equation for the ECFM sensor:

v[m/s] = -3.4473 × V_{real}[mV] + 11.584

Percent error: < 3%

Theoretic sodium velocity:

$$v_{theoretic} = \dot{Q}/A$$

Conclusions (1)

- Successful measurements are reported in this study in sodium up to 700 °C for the ECFM sensor.
- ECFM:
  - Sensitive to the flow changes (overshooting effect, oscillations), it follows instantaneous the flow changes. It can be recommended for tracking fast transient flows.
  - With increasing temperature and the nickel migration effect the wire resistance increases also, impacting the output voltage. The effect can be counteracted by appropriate adjustments of the frequency or amplitude of the excitation current.
  - Calibration of the ECFM: percentage error achieved < 3%.
  - Due to the Curie temperature the use of the ECFM sensor in the temperature regime 345 ± 15 °C will produce unreliable measurements.

Conclusions (2)

- Fly-wheel sensor:
  - Exhibits an inertial behaviour and a delay of several minutes by sudden flow changes.
  - It can be applied for steady-state flows, but is not recommended for fast transient flows.
  - Is restricted to an upper temperature level of 500 °C for the fluid.

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Thank you for your attention!

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