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Experimental investigations and qualification of innovative flow sensors in the 1000 K SOLTEC-2 sodium loop

Alexandru Onea[1], Nico Krauter[2], Wolfgang Hering[1], Stephan Lenk[3], Sebastian Ruck[1], Robert Stieglitz[1] and Gunter Gerbeth[2]

[1]Karlsruhe Institute of Technology Germany, [2]HZDR Germany, [3]SAAS GmbH, Germany

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HEMCP:Helmholtz Energy Materials Characterization Platform

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Outline

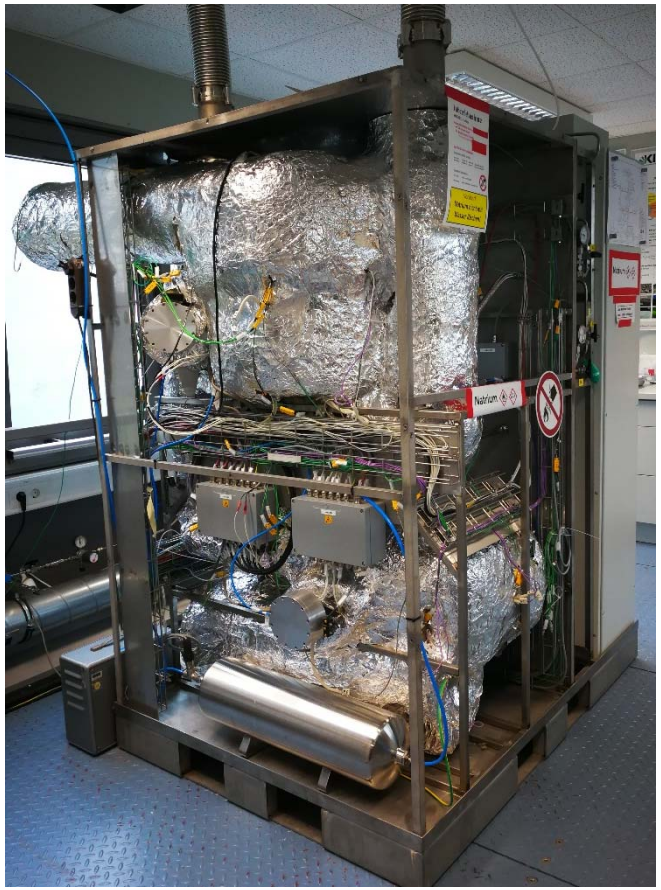
- Introduction
- 1000 K SOLTEC sodium loop
- Eddy curent flow meter and test mock-up
- Magnetic fly-wheel
- Experimental results
- Conclusions

Introduction

- SOLTEC-2 is a 1000 K sodium loop developed at KIT, Germany for component/material investigations and qualifications for high temperature applications in the CSP field.
- ESFR-smart 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

SOLTEC - Technical data

- Na mass flow rate: 300 kg/h
  - S1: 4.8 m/s in test sample
  - S2: 1.0 m/s in test sample (Re = 28600, 300°C)
- Temperature: cold loop 450°C; hot loop 720°C
- Max. pressure: 3.5 bar g
- Dimensions: 1.2 × 1.6 × 1.9 m^3
- Na inventory: ~ 14 L
- Main components:
  - 3kW Na-pump (permanent magnet pump)
  - 7.5 kW Na-air HX & 27 kW Na-Na heat recuperator,
  - Storage tank (15 L) = expansion tank (particular feature)
  - 6.7 kW high temperature heater



SOLTEC-2

SOLTEC – SOdium Loop to TEst materials and Corrosion

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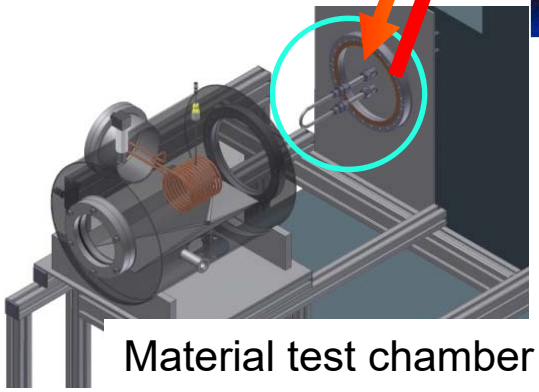
Traction facility

1000 K

Material test chamber

SOLTEC-2



Material test chamber

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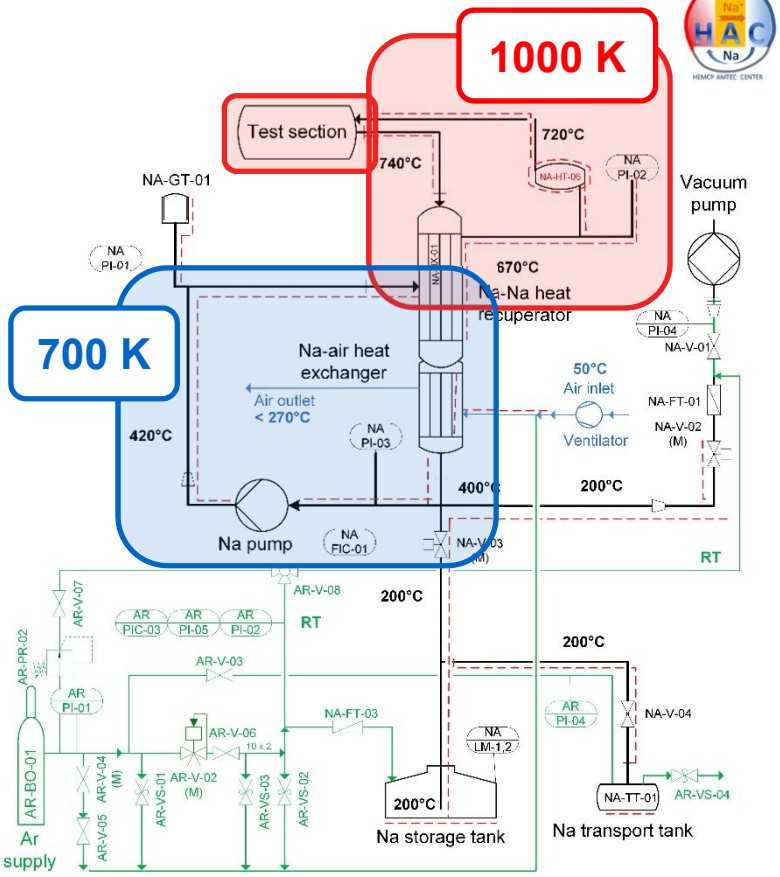

P&I diagram

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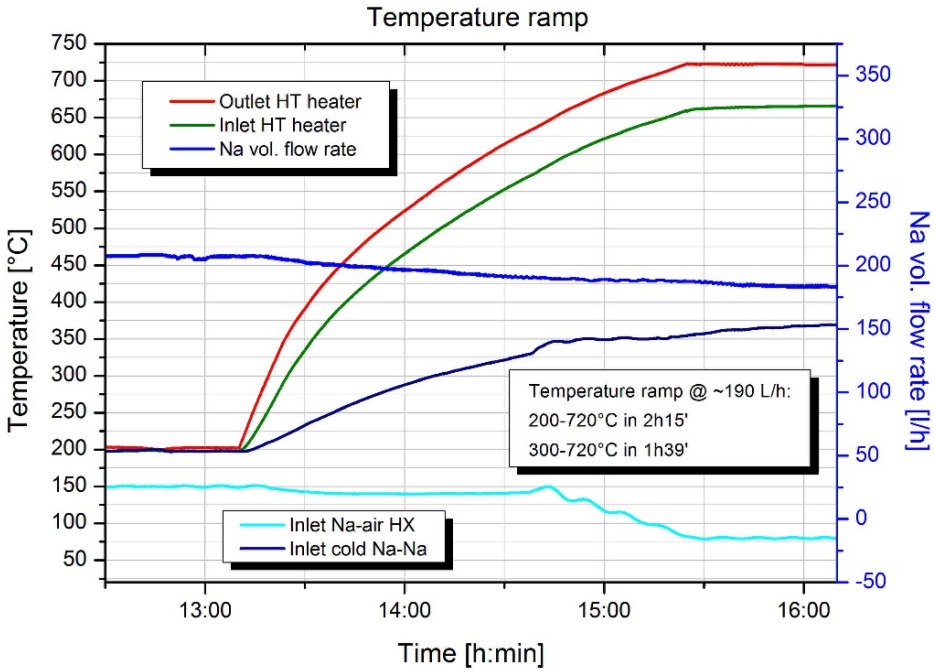
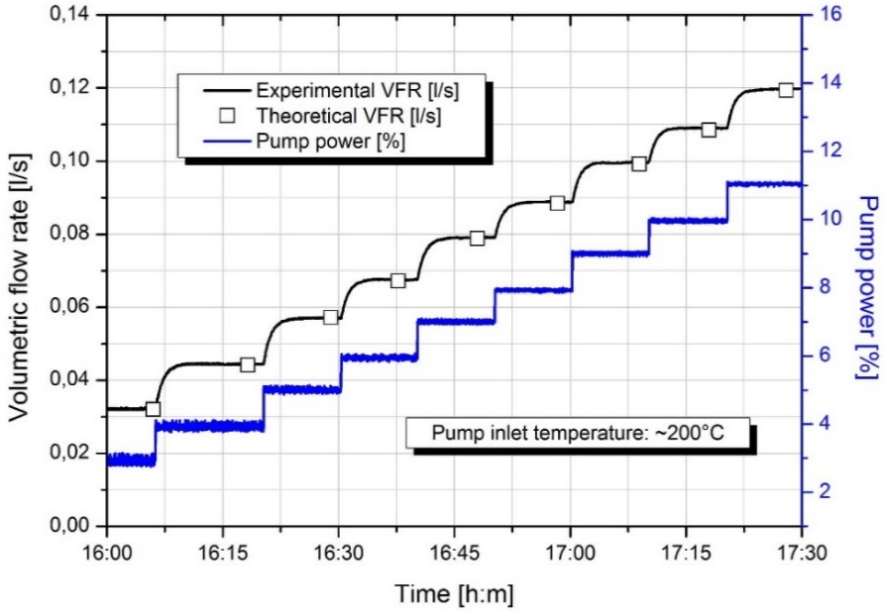
SOLTEC – Experimental data





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

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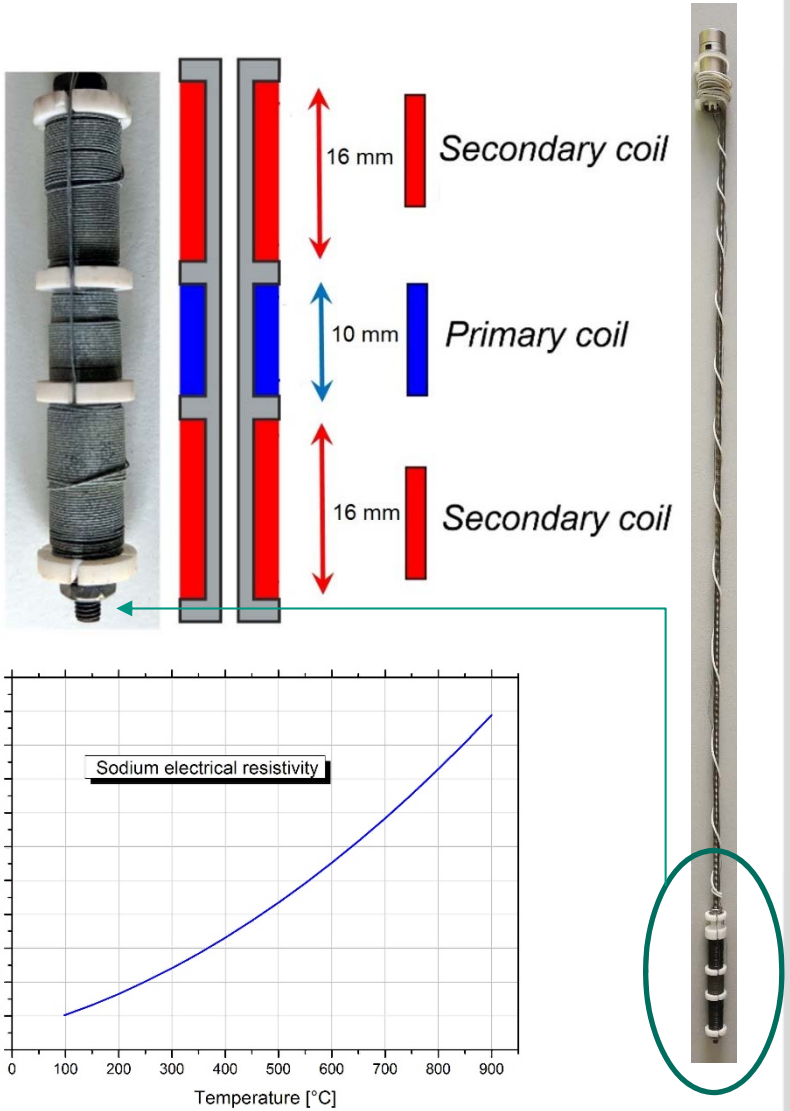
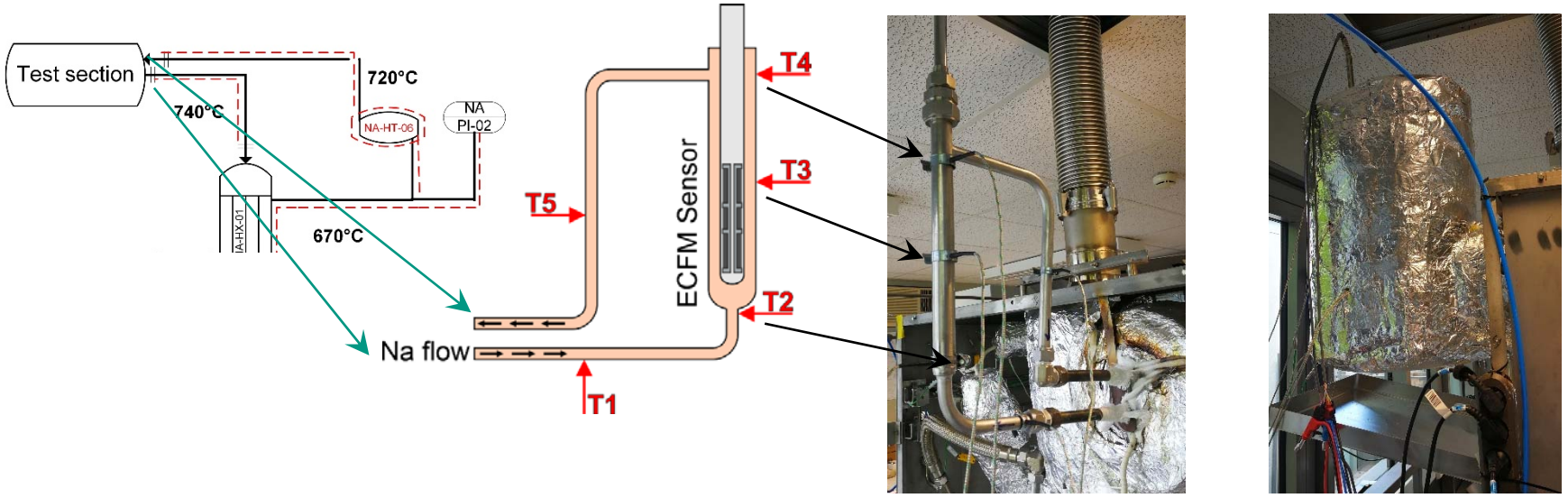
Eddy current flow sensor - HZDR

- Developed at HZDR, Germany
- Inductive sensor consisting of 3 magnetic 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
- Sensor placed in HT casing
- Coils mounted on ceramic holder
- Calibration required due to the strong variation of the sodium electrical conductivity with the temperature*

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



Experimental mock-up and integration in SOLTEC

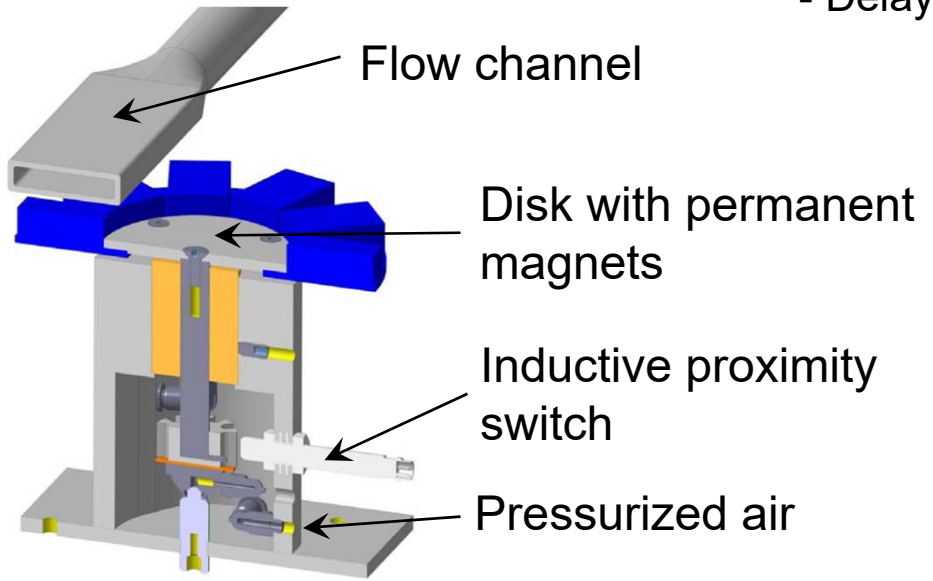


- Test track connected to the SOLTEC loop at the outlet of the HT heater
- Casing for the ECFM sensor: AISI 314
- Trace heating installed on the test track
- Instrumentation: TCs
- ECFM: excitation current: 200-500 mA rms; frequency: 500 Hz-2kHz.

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

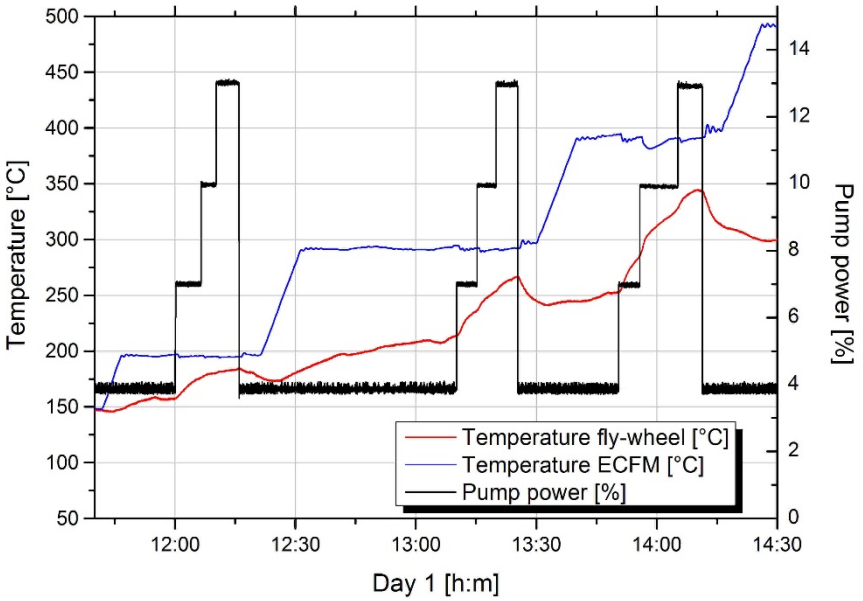
Drawbacks:
- Sensitive to external magnetic disturbances
- Delay of the response signal by flow changes

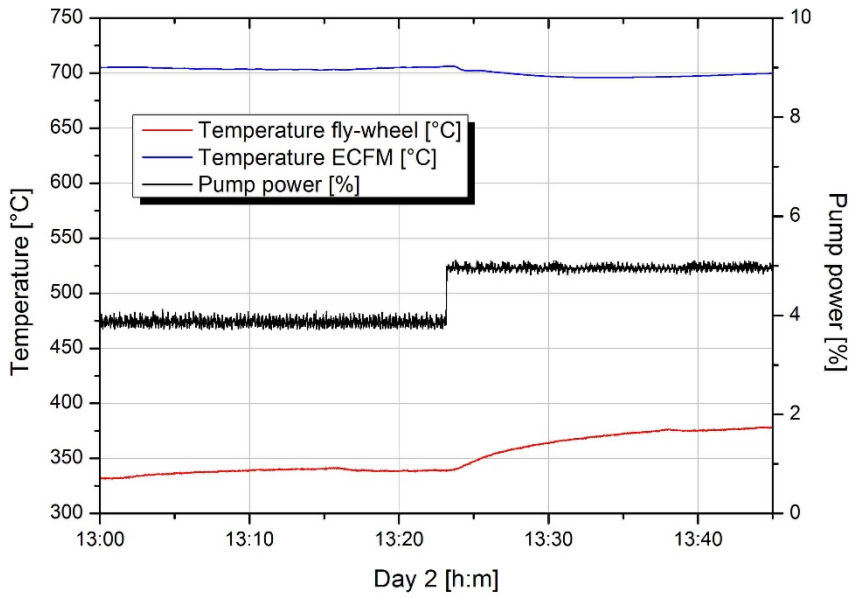


Magnetic fly-wheel model

Fly-wheel integrated in SOLTEC

Temperature distribution at the flow sensors





- MFW sensor: placed in the low temperature side of the loop.
- ECFM sensor: wetting of the sensor casing has a positive effect on the signal.

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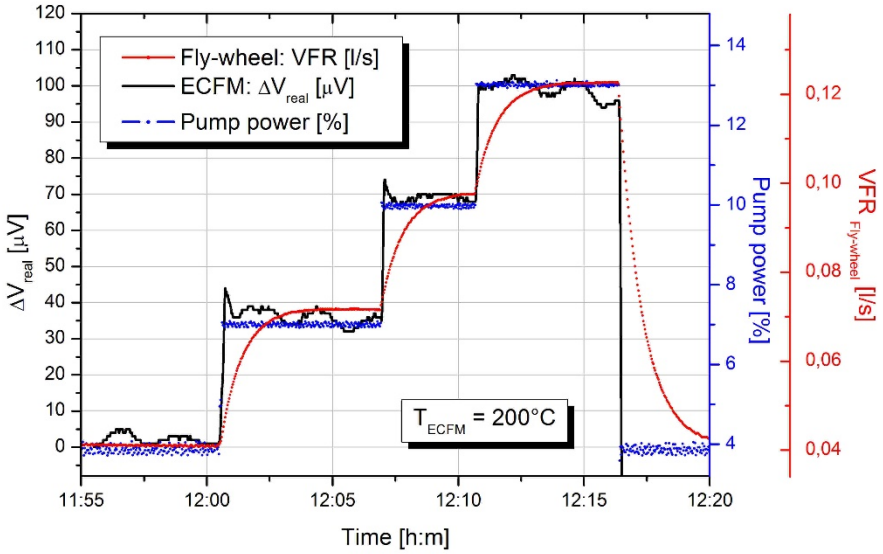
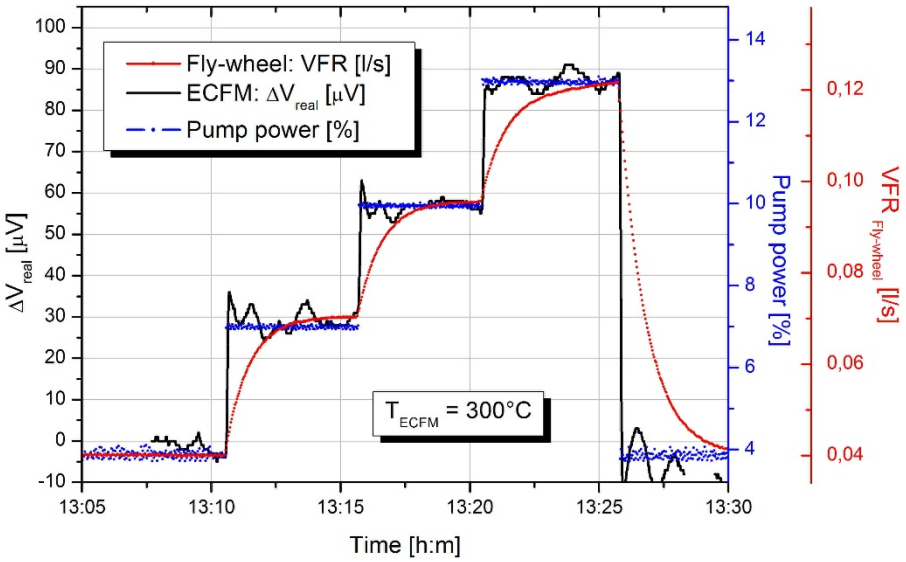
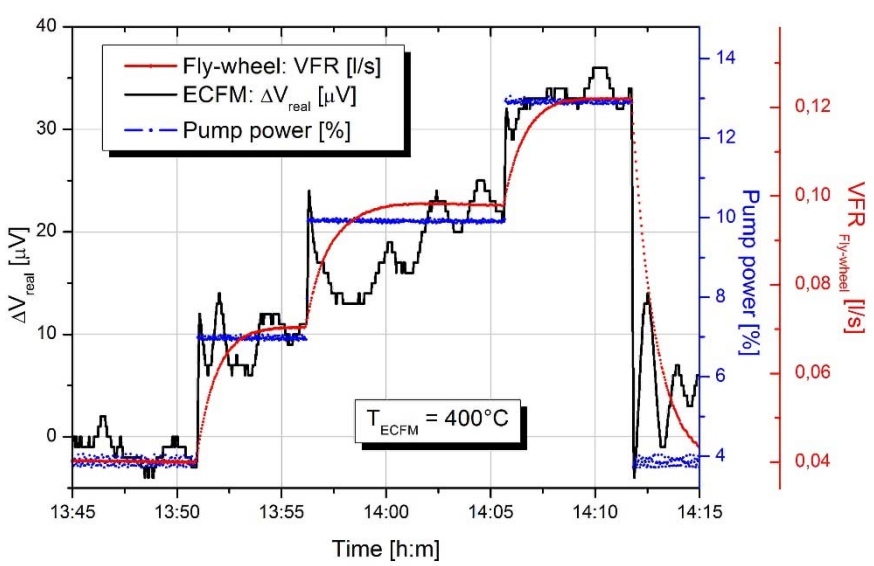
Experimental results

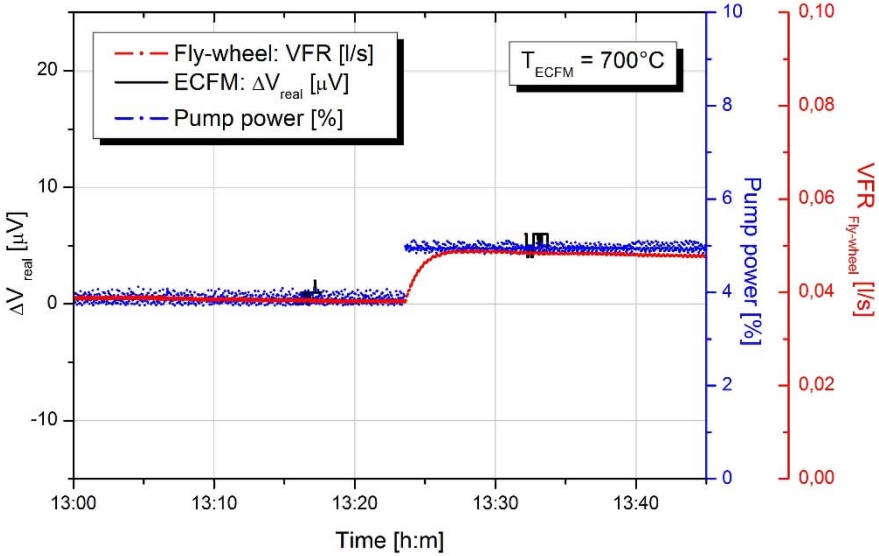




- Calibration of the ECFM sensor required due to the strong variation of the sodium electrical conductivity. Performed in SOLTEC.
- Good agreement obtained between signals of ECFM, MFW and Na-pump power level.
- MFW: inertial behaviour (few minutes) followed by asymptotic approach
- ECFM: instantaneous 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 ± 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)

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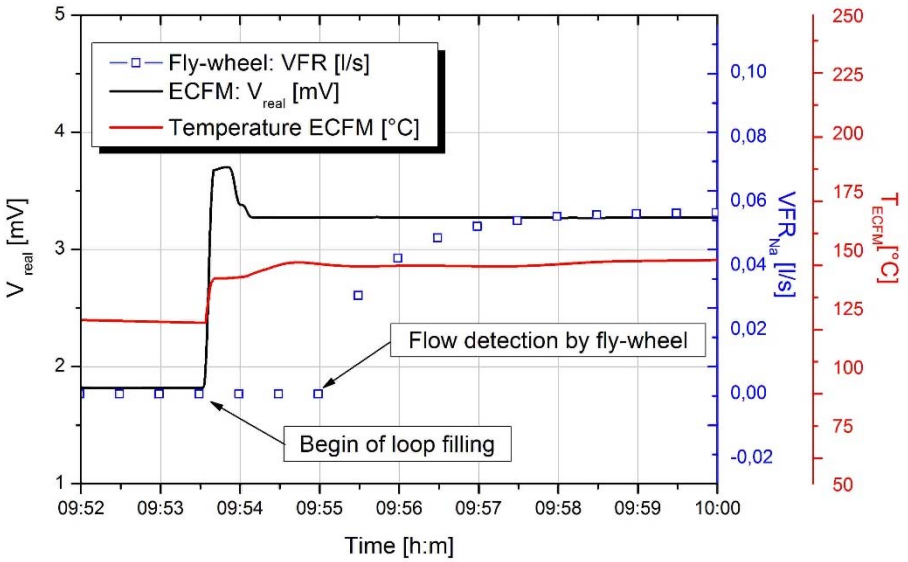
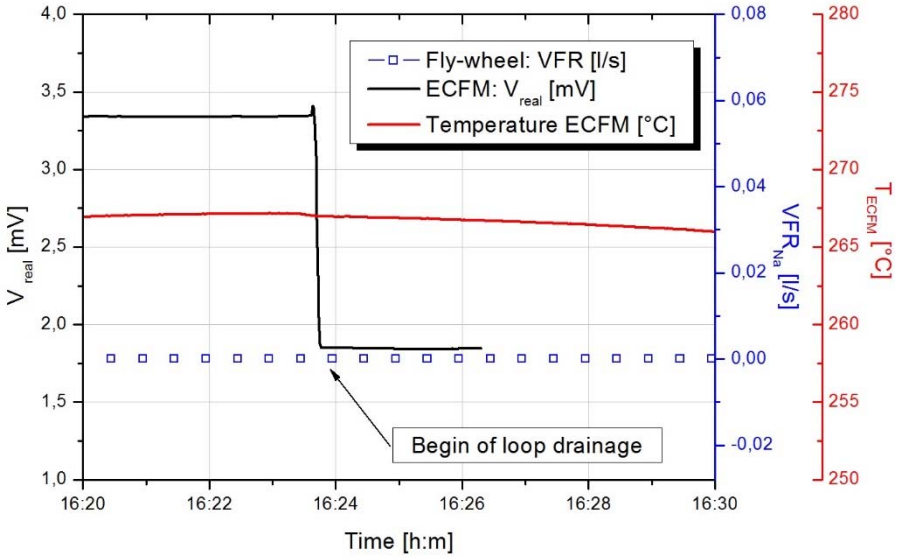
Detection of filling/drainage of the loop



Signals during loop filling



Signals during loop drainage

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

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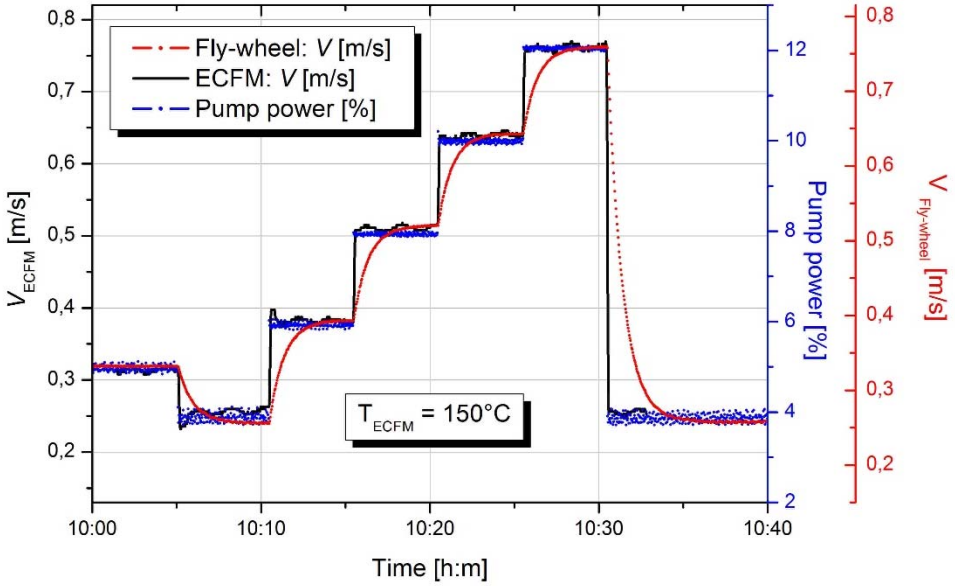
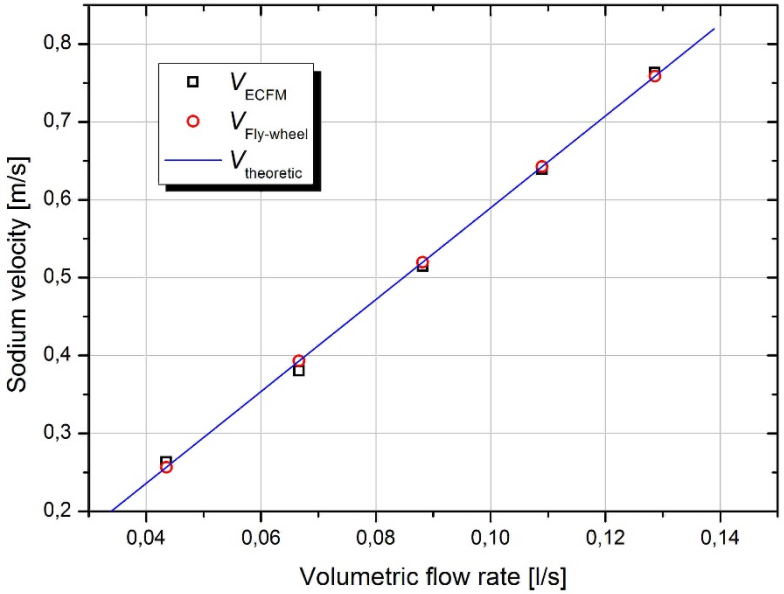
Velocity values





Calibration equation for the ECFM sensor:

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

Percent error: < 3%

Theoretic sodium velocity:

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

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Conclusions

- 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 instantaneously the flow changes. It can be recommended for tracking fast transient flows.
- ECFM: 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.
- 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.
- 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.

Thank you for your attention!

Alexandru Onea	alexandru.onea@kit.edu	+49 (0)721 608 22949
Nico Krauter	n.krauter@hzdr.de	+49 351 260 3457