Molten Salt Electric Heaters: Lessons Learned from DLR's TESIS Facility and Intensive Prototype Testing

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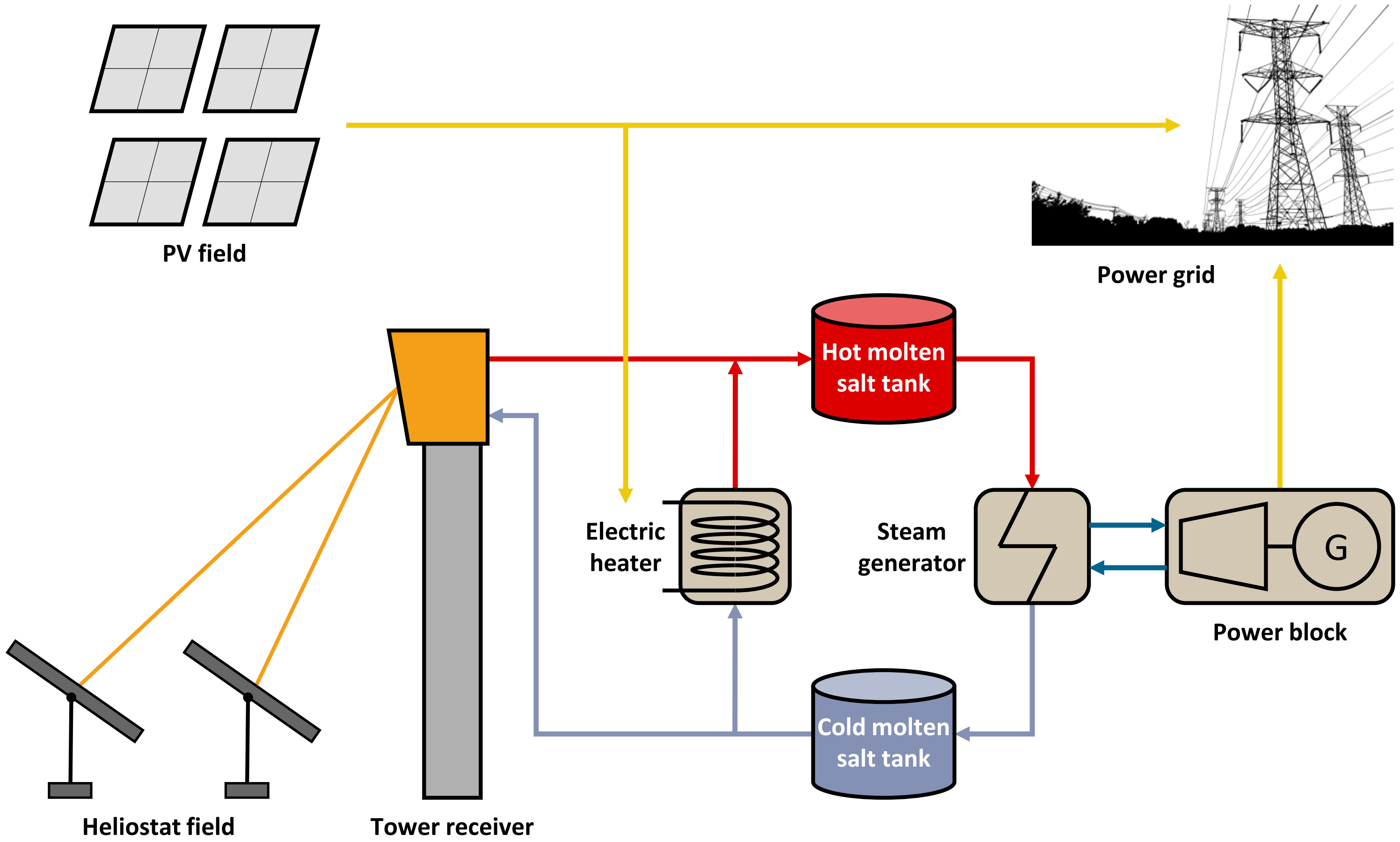
Motivation: Electric heater required for hybrid CSP/PV



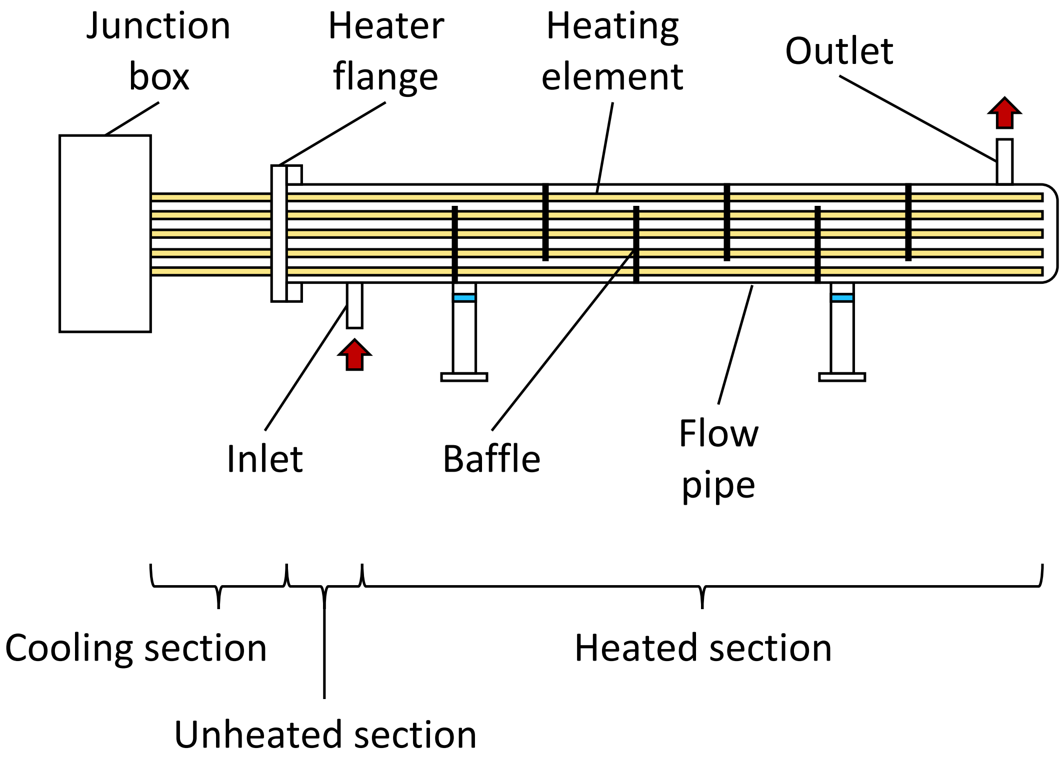
Application in hybrid CSP/PV plants:

- Excess PV electricity can be converted to thermal energy
- Proven 2-tank molten salt storage system is applied for both CSP and PV

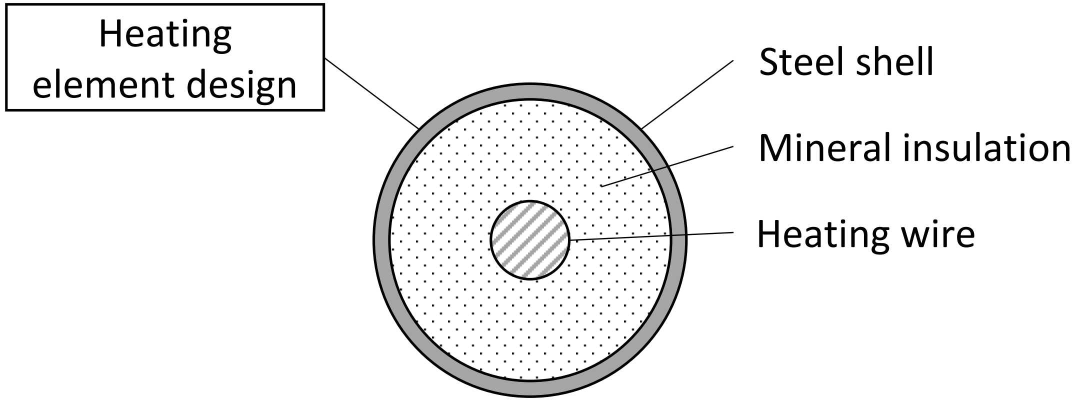
Required research objectives:

- Development towards higher temperatures and module sizes
- Improve reliability and serviceability
- Promote competition and lower prices

Methods: Resistive flow heaters



Source: Schniewindt GmbH & Co. KG (https://schniewindt.de/index.html)



Methods: DLR’s electric heater experience

DLR

TESIS:com test facility

- Qualification of molten salt components
- In operation since 2019
- 420 kW electric heater as integral part of TESIS:com

E-Heat project

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Vulcanic

Kraftanlagen Gruppe
A member of Bouygues Construction

SCHNIEWINDT
THE POWER OF ELECTRIFYING IDEAS

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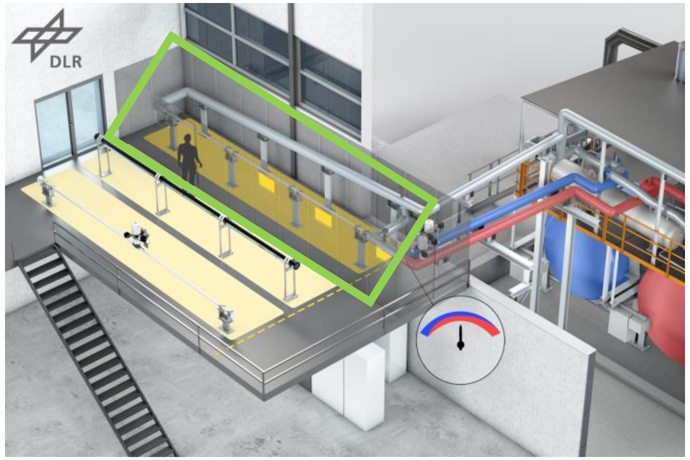
- Heat transfer with molten salt in cross-flow configuration
- Experiments with two 360 kW electric heater prototypes
- Critical design criteria and development needs

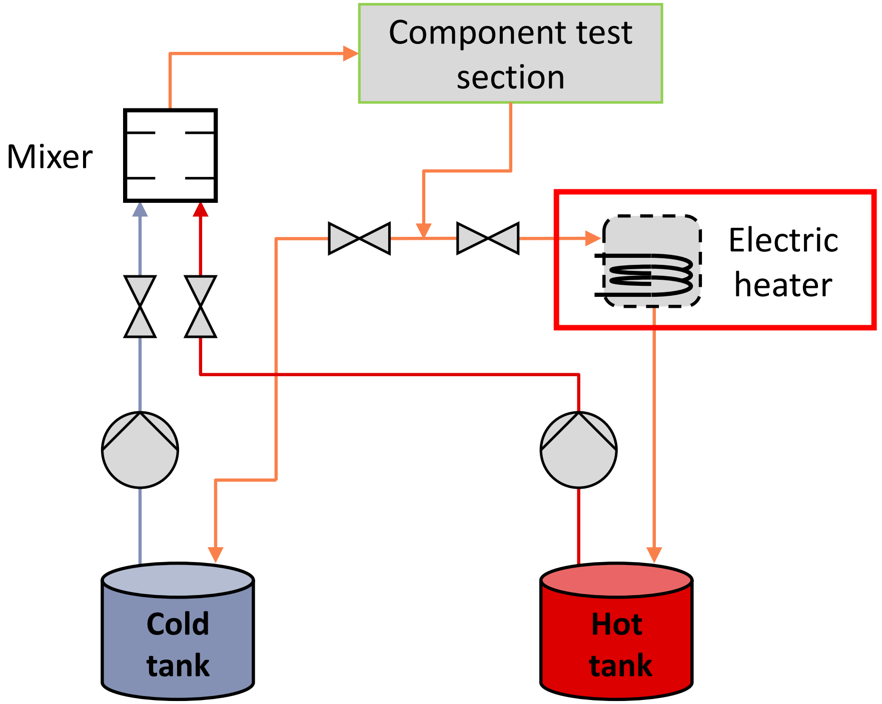
Methods: TESIS:com test facility

TESIS:com test facility specifications

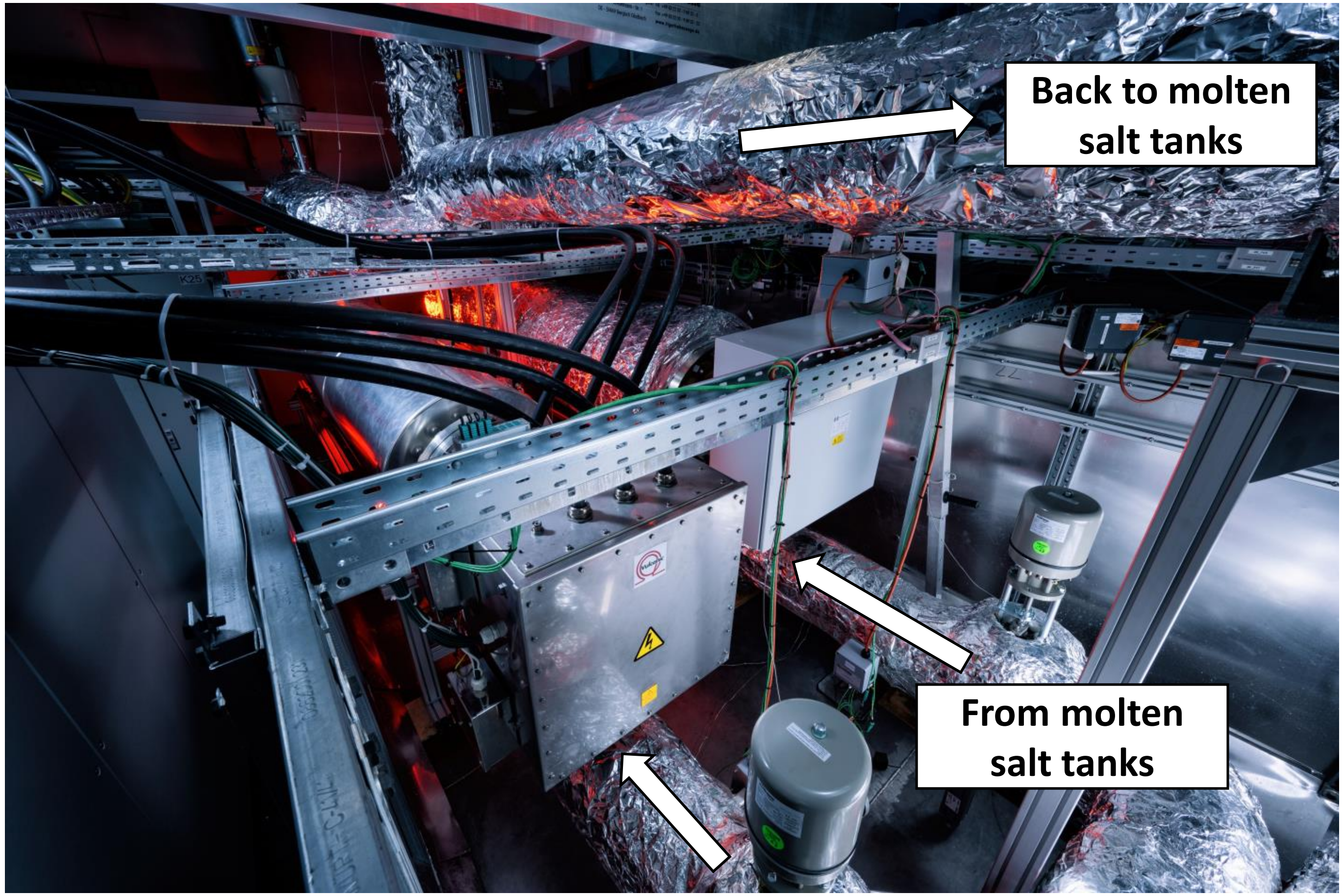
- Solar salt (60% $NaNO_3$ and 40% KNO_3)
- 290 °C - 560 °C inlet temperature
- 0.5 kg/s - 8.0 kg/s mass flow rate
- 420 kW electric heater to maintain hot tank temperature

- 360 kW prototypes installed in test section (project E-Heat)





Methods: Experimental setup of E-Heat project



Heater specifications

- Electric power: 360 kW_{el}
- Length: 4.0 – 4.5 m
- Diameter: 0.3 – 0.4 m
- Insulation thickness: 0.15 m
- Inclination: 2° (for drainage)
- Max. salt temperature: 560 °C

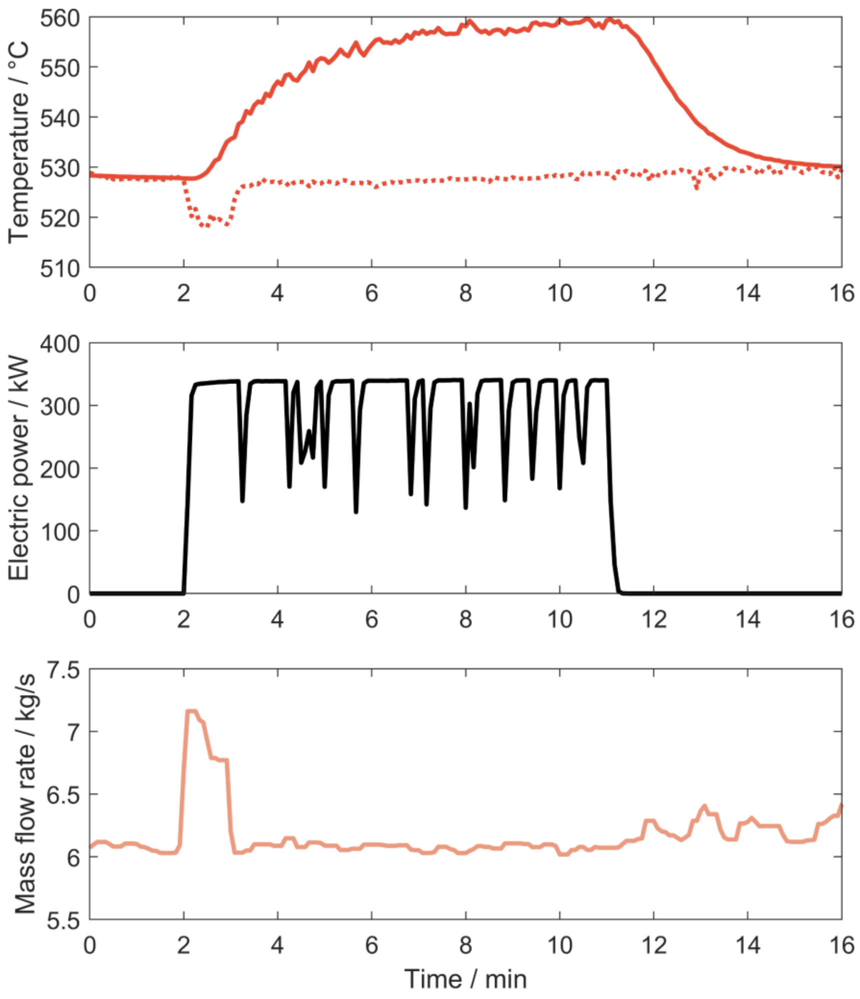
Results: Cycle tests

Exemplary thermal cycle:

- Temperature increase 525/530 °C → 560 °C
- Max. heating power 340-350 kW
- Mass flow rate 6,1-6,2 kg/s

Final results:

- 3 months testing per heater
- Constantly exposed to molten salt at > 500 °C
- Each heater completed > 5,000 cycles at different inlet temperatures and flow rates
    - ➢ Corresponds to 14 years of operation*



* Assuming a daily start-up of the heater in a hybrid PV and CSP system

Results: Steady State test

Steady State test conditions (average values):

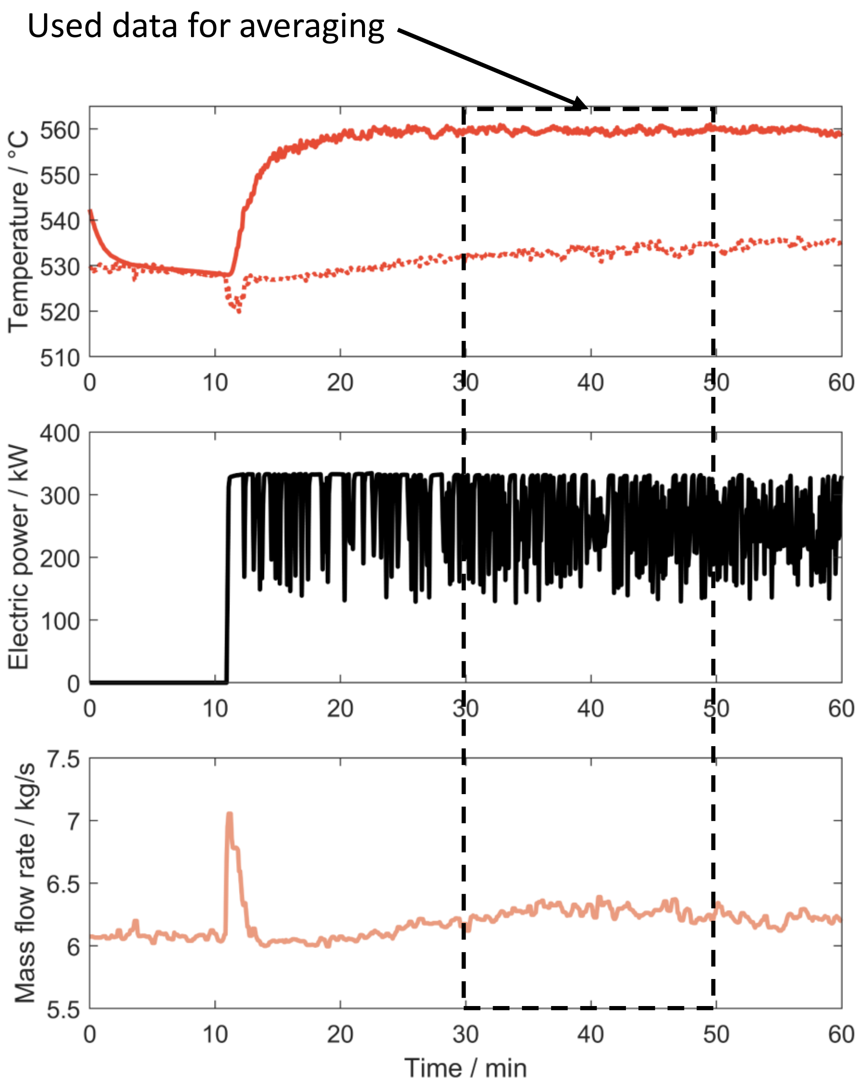
- Temperature increase 533 °C → 560 °C
- Heating power 265 kW
- Mass flow rate 6,3 kg/s

Conclusion:

- Test condition not perfectly ideal
    - Varying mass flow rate and inlet temperature
    - Fluctuating heating power
- Data fluctuations are compensated by averaging

$$\eta = \frac{\dot{m}(u_{\text{out}}(T_{\text{out}}) - u_{\text{in}}(T_{\text{out}}))}{P_{\text{el,heater}}}$$

- **<u>Calculated efficiency: 98%</u>**



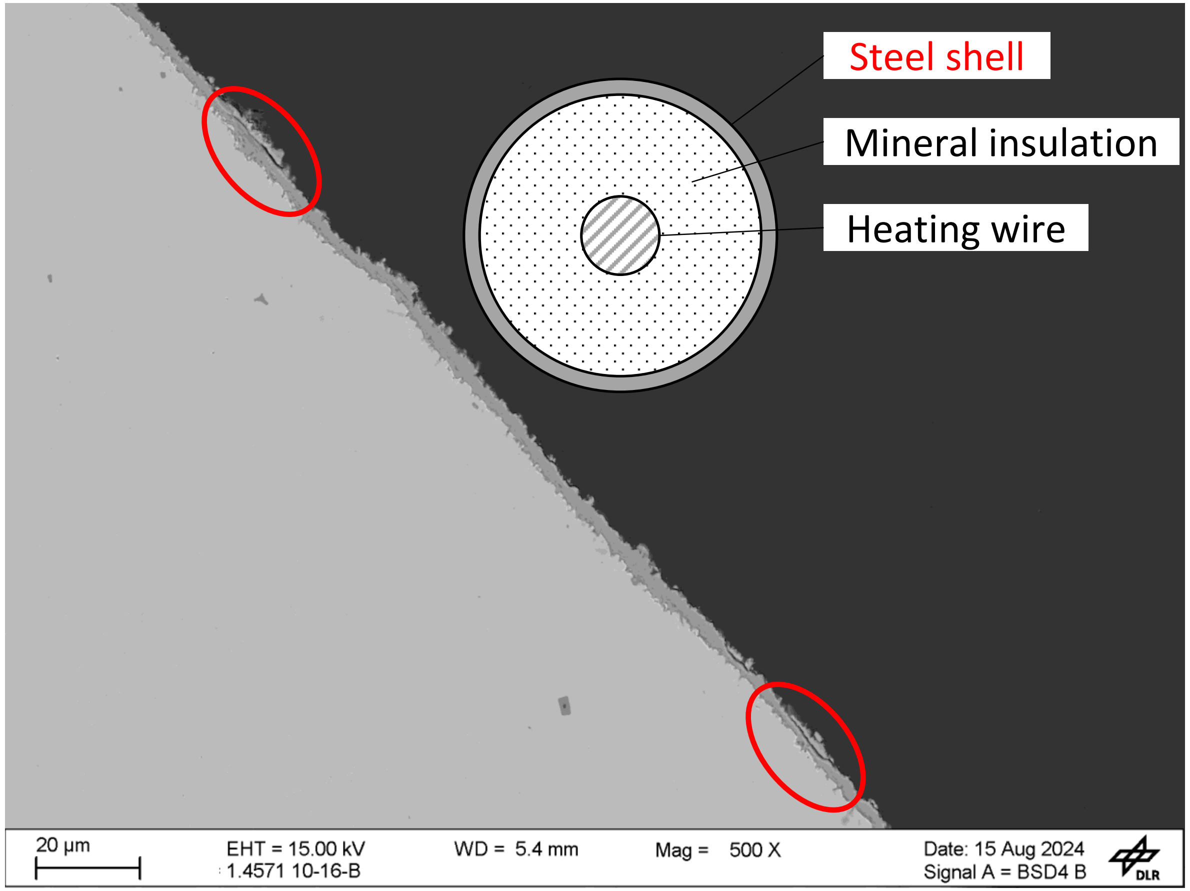
Results: Scanning electron microscopy

General information on the SEM analysis:

- Heating elements are machine-made and not perfect test samples, e.g. surface roughness
- Condition before and between tests is unknown → only snapshot after E-Heat experiments

Sample 1.4571 (316Ti) observations:

- SEM image shows the steel shell of a heating element
- Uneven steel shell and oxide layer
- Oxide layer thickness roughly 5-10 µm
- Frequent cracks in the oxide layer



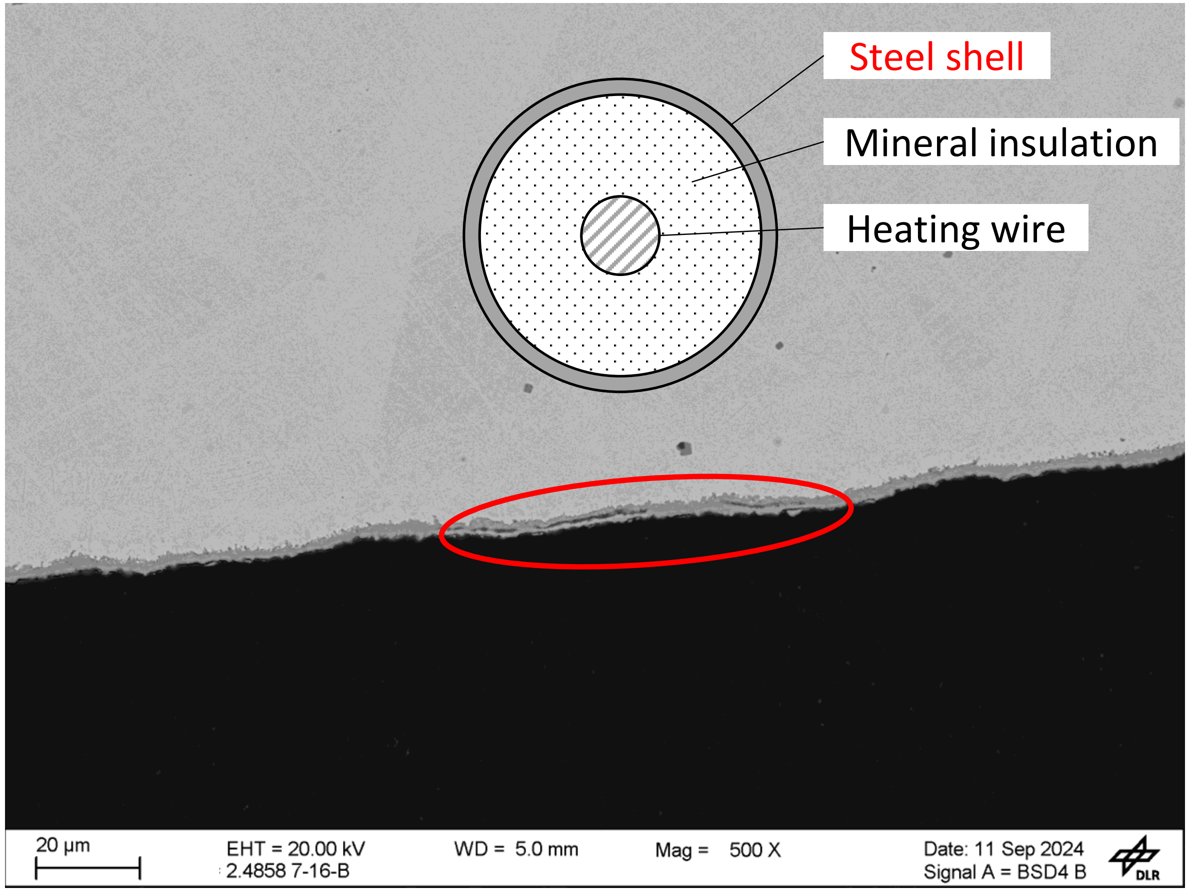
Results: Scanning electron microscopy

Sample 2.4858 (Alloy 825) observations:

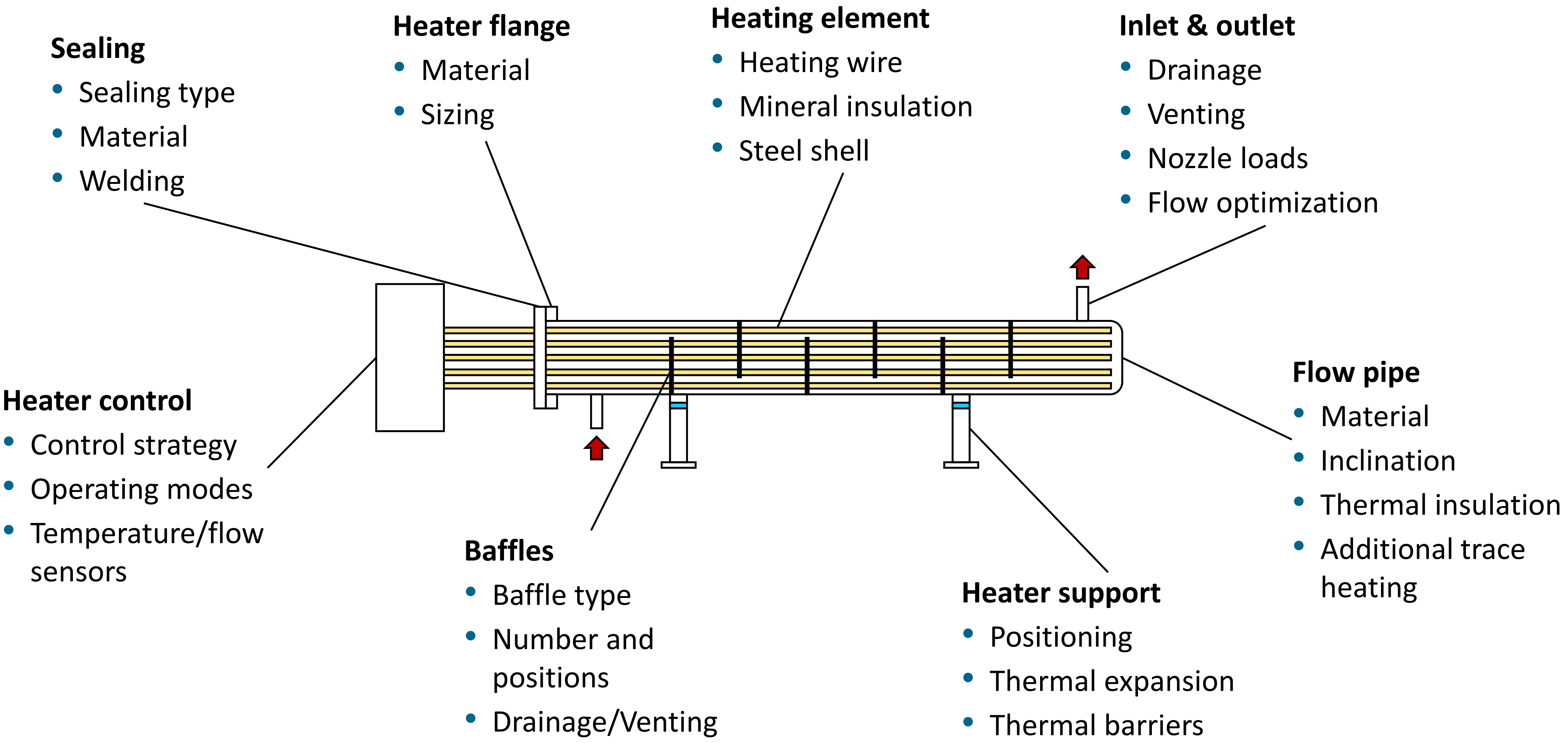
- Uneven steel shell and oxide layer similar to 1.4571 sample
- Oxide layer thickness < 5 µm
  Thinner oxide layers typical for Nickel alloys
- In total fewer cracks compared to 1.4571

Main conclusions:

- Oxide layers displays many cracks regardless of steel shell material
- Continuous temperature changes (>5,000 cycles) are likely to be the cause for cracks
- No reasonable predictions possible about lifetime of heating elements



Results: Design and operating criteria



Summary

- Molten salt electric heaters are crucial components in hybrid CSP/PV plants

  → Important aspects are: Temperature, module size, reliability, serviceability and price

- Main results of the E-Heat project
  - Electric heater tests successfully completed
  - > 5.000 thermal cycles with each heater at temperatures > 500 °C
  - SEM analysis shows an intact oxide layer with visible cracks
  - Cracks probably caused by continuous thermal cycles during tests

- Design and operating criteria of electric heaters are manifold and should be thoroughly considered to achieve high performance and long service life

Thank you for your attention!

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