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Thermal design of latent heat thermal energy storage facility with supercritical CO2

Tomáš Melichar, Karel Dočkal, Otakar Frýbort, Petr Hájek, Radomír Filip

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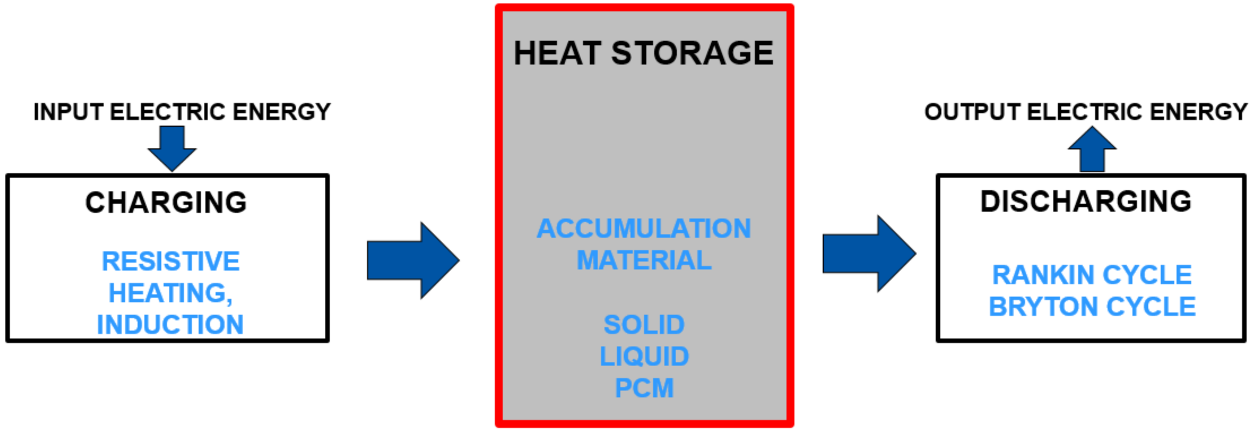
Content

- Thermal Energy Storage (TES)
- Concept of TES being developed by CVR
- Thermal Model
- Design and optimization
- Technology overview
- Conclusion and time plan

Thermal Energy Storage

PRINCIPLE

- Transformation of surplus electric energy to heat
- Heat storage
- Transformation of heat to power during increased consumption



CHARACTERISTCS

- High-capacity storage (up to thousands of MWh and hundreds of MWe output)
- Simple system configuration, cheap accumulation material → low investments
- Geologically independent
- Compatible with various power sources (renewables, fossil, nuclear)
- Low round-trip efficiency but intensification is possible

TES Concept of CVR

- An innovative concept of latent heat TES is being developed at CVR
- Proposed system contains
  - Resistive heaters for charging
  - Storage vessel with AlSi12 alloy
  - Heat to Power transformation using an sCO2 conversion cycle
- AlSi12 selected for its thermophysical properties and compatibility with sCO2 cycles
- Expected round-trip efficiency 43 %

	T_{melt}	Q_{latent}
Fe	1482 °C	247 kJ/kg
Ni	1453 °C	293 kJ/kg
Sn	232 °C	59 kJ/kg
Pb	333 °C	23 kJ/kg
Zn	419 °C	112 kJ/kg
Al	**660 °C**	**396 kJ/kg**
Si	1414 °C	1787 kJ/kg

→ **AlSi12** **577 °C** **520 kJ/kg**

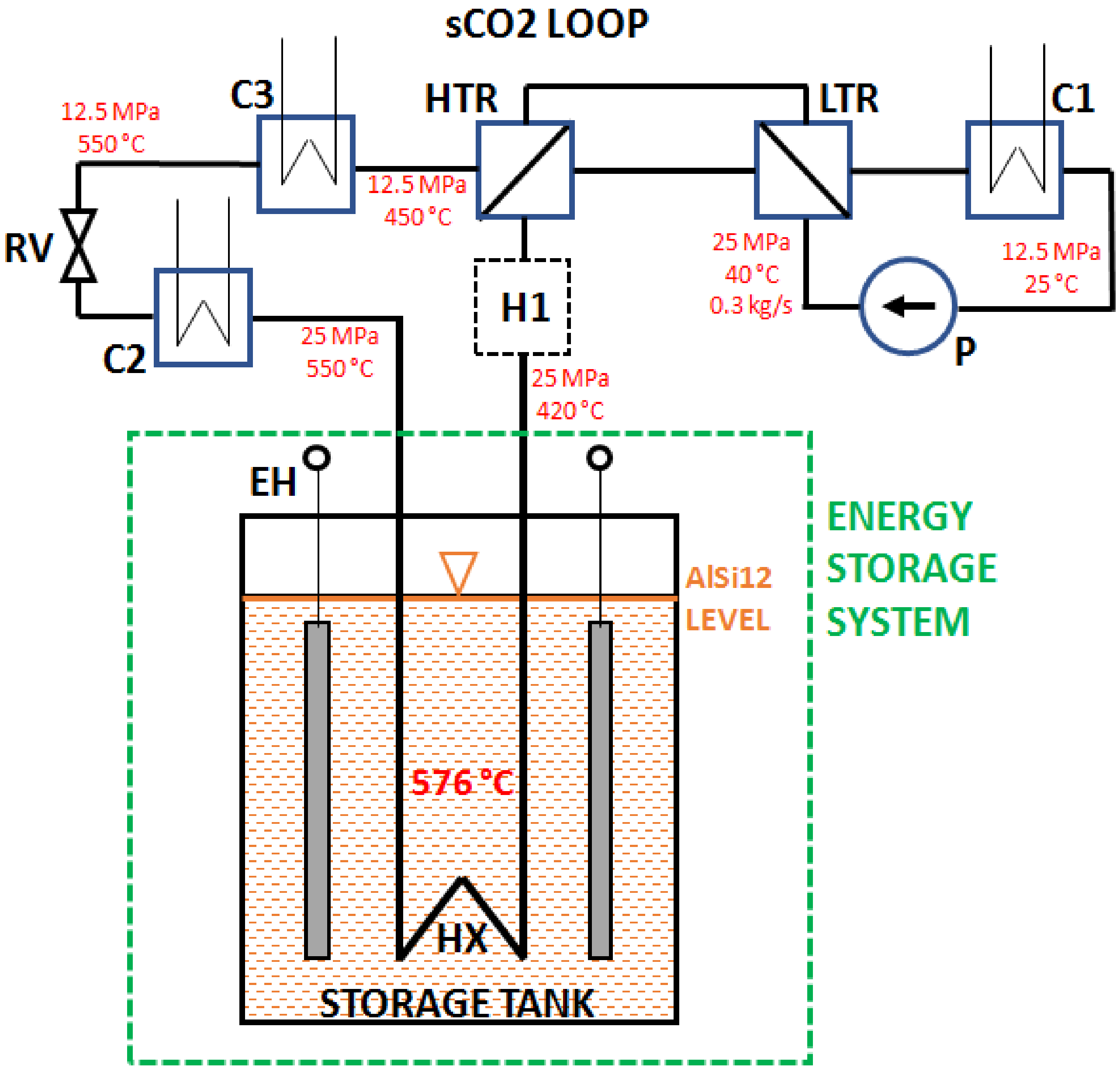
Small-scale demonstration unit

- A small-scale demonstration unit is being developed at CVR within TAČR – EFEKT project
- The system will be composed of a storage vessel with AlSi12
- Electric heaters and the heat exchanger will be immersed in the accumulation material
- Existing sCO2 loop will be coupled with the storage tank
- The facility will allow experimental verification of the whole system as well as of the storage vessel design

Main parameters of the small-scale demonstrator	
Operational temperature	577 °C
Capacity	250 kW_h
Power	50 kW_t
Charging / Discharging time	5 h
Storage tank volume	1 m^3

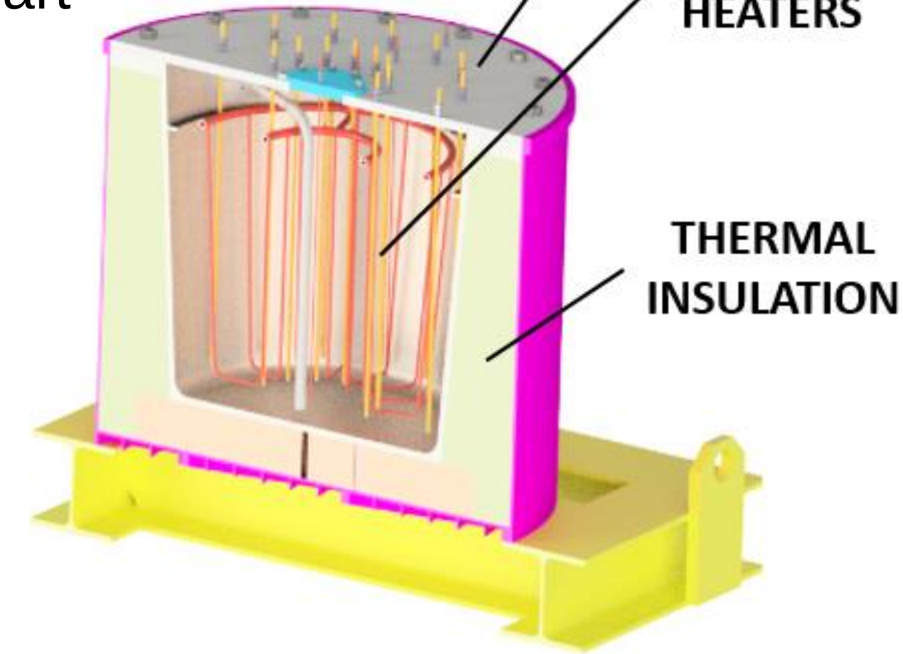
Small-scale demonstration unit

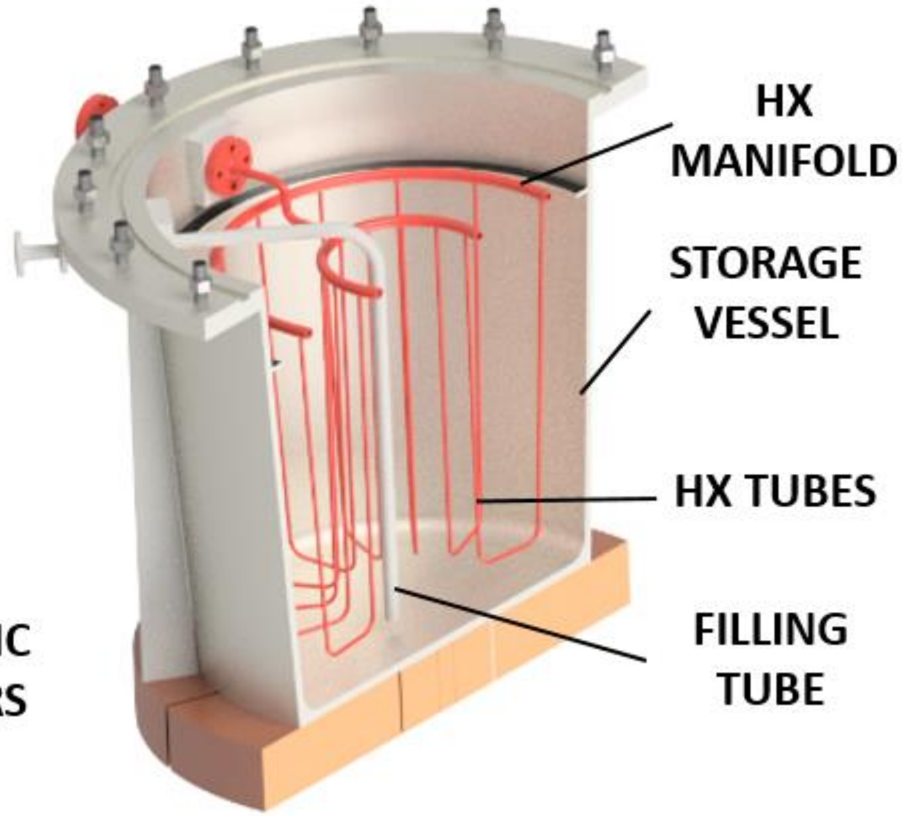
- Heaters and HX are immersed in the AlSi
- sCO2 loop in the simple Brayton cycle configuration
- sCO2 parameters
  - 25 MPa, 550 °C at HT part
  - 12.5 MPa at LT part



Storage Tank Design

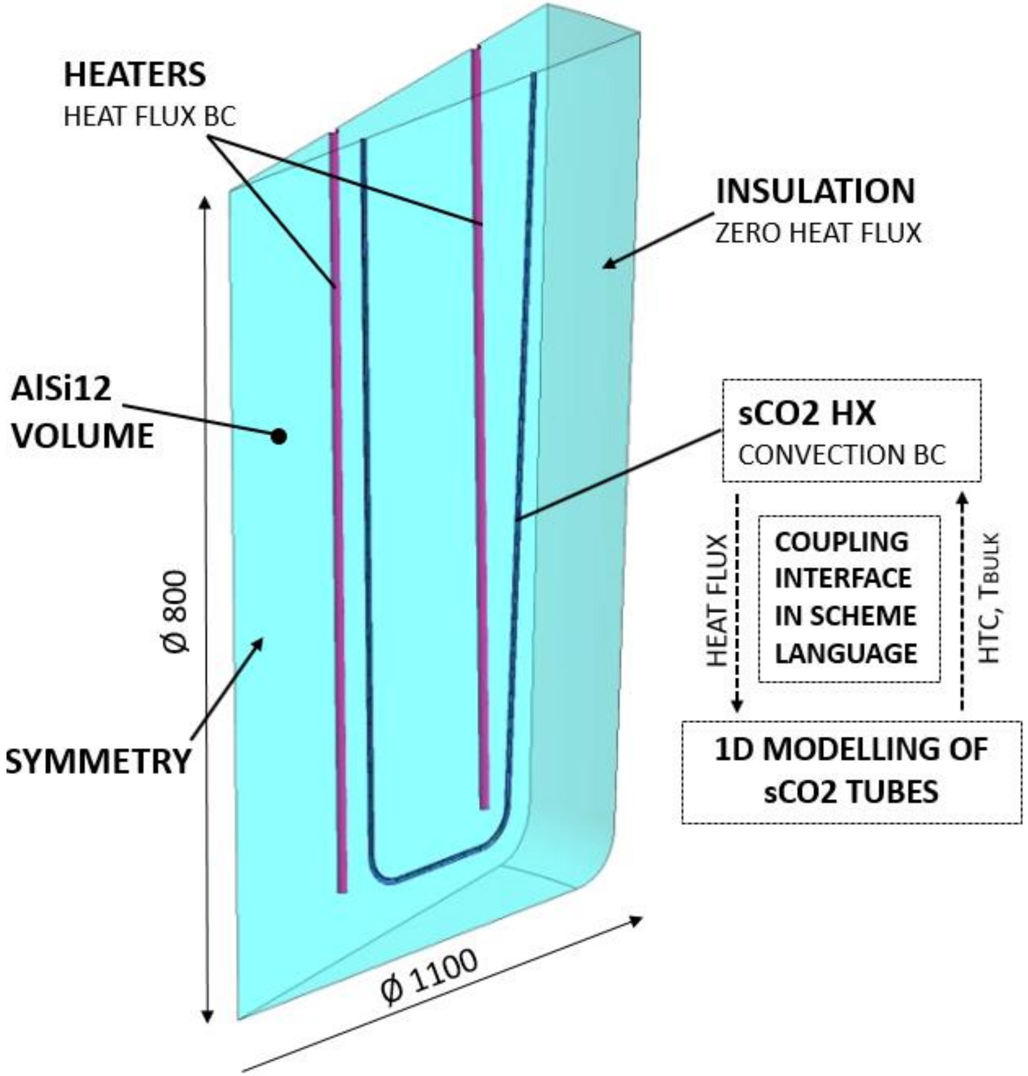
- Heaters and HX immersed in AlSi
- sCO2 loop in the simple Brayton cycle configuration
- HX in the form of U-tubes
- sCO2 parameters
  - 25 MPa, 550 °C at HT part
  - 12.5 MPa at LT part





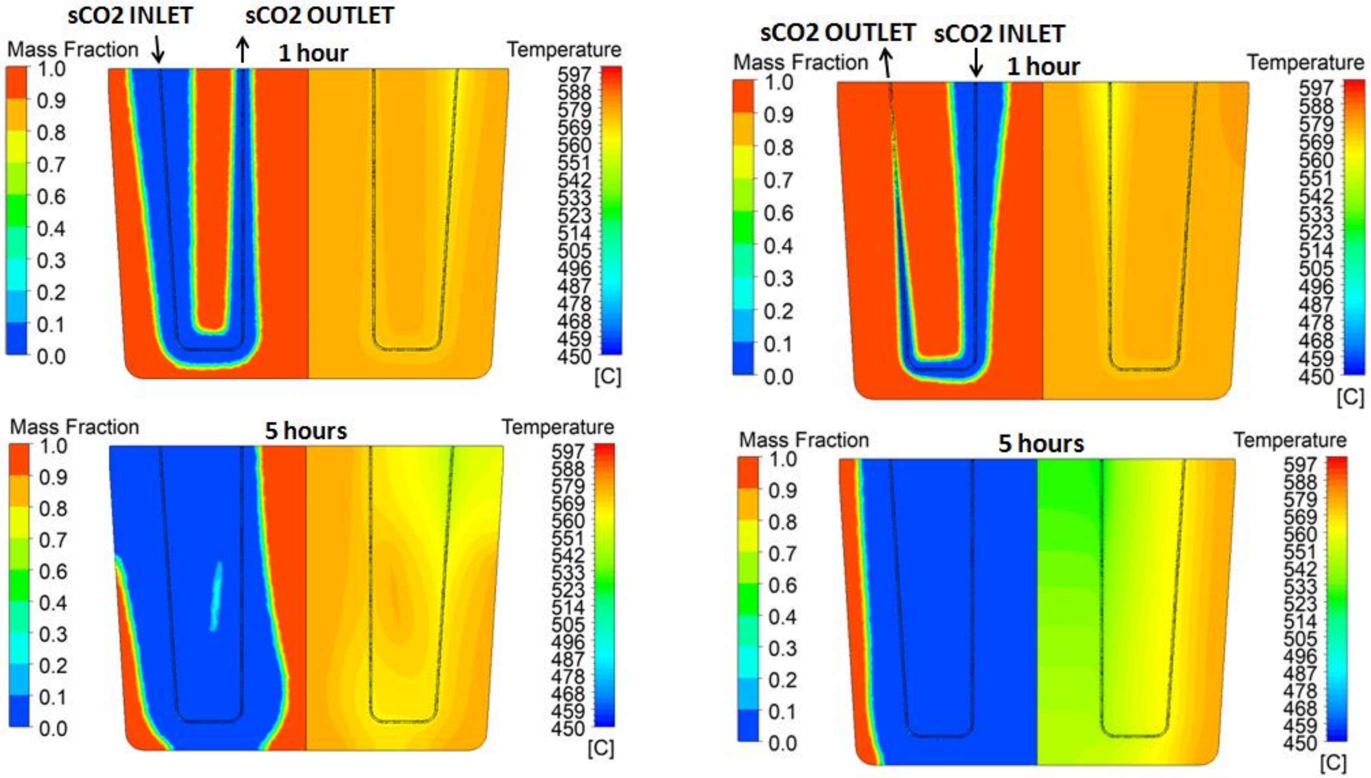
Thermal Model

- A dedicated thermal model was developed to support design of the storage tank
- The computational tool contains 3D model of AlSi volume considering heat conduction and phase change and 1D model of convective heat trasnfer in the HX tubes
- Coupling between ANSYS Fluent and 1D model using Scheme language
- The model contains one section with a U-tube and heaters
- The HX tube is split in 60 nodes, heat flux and sCO2 bulk temperature is exchanged between the model
- Dynamic simulation of temperature field and heat balance during cycles at reasonable computational costs



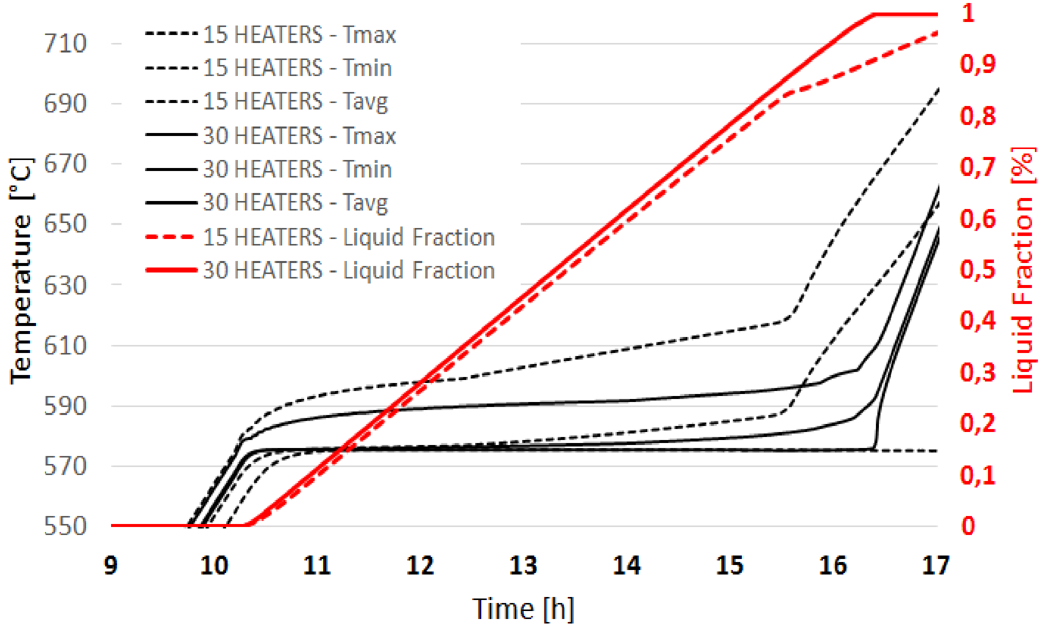
Thermal Model – HX Design

- The model was utilized for optimization of the tubes number, lengths and diameters
- Assessment of the „flow direction“ effects
- Low heat transfer area needed (1 m^2 / 50 kWt)

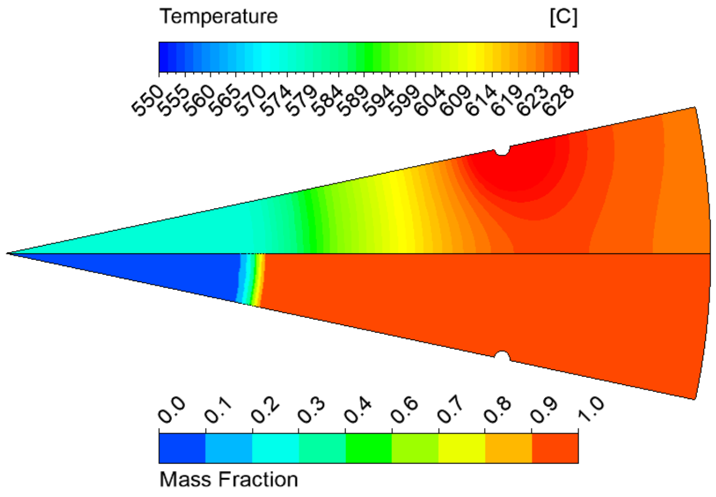


Thermal Model – Heaters Design

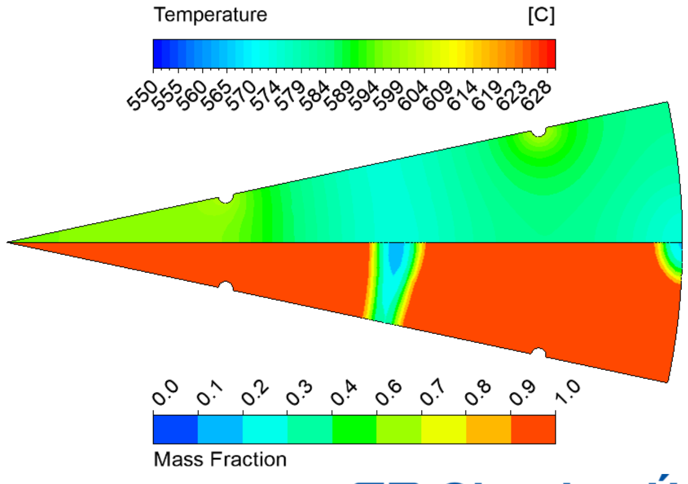
- Optimization of the heaters layout and iner vs outer heaters power
- The goal is to uniform temperature field during the charging cycle and to avoid overheating



ONE HEATER LAYOUT



TWO HEATERS LAYOUT



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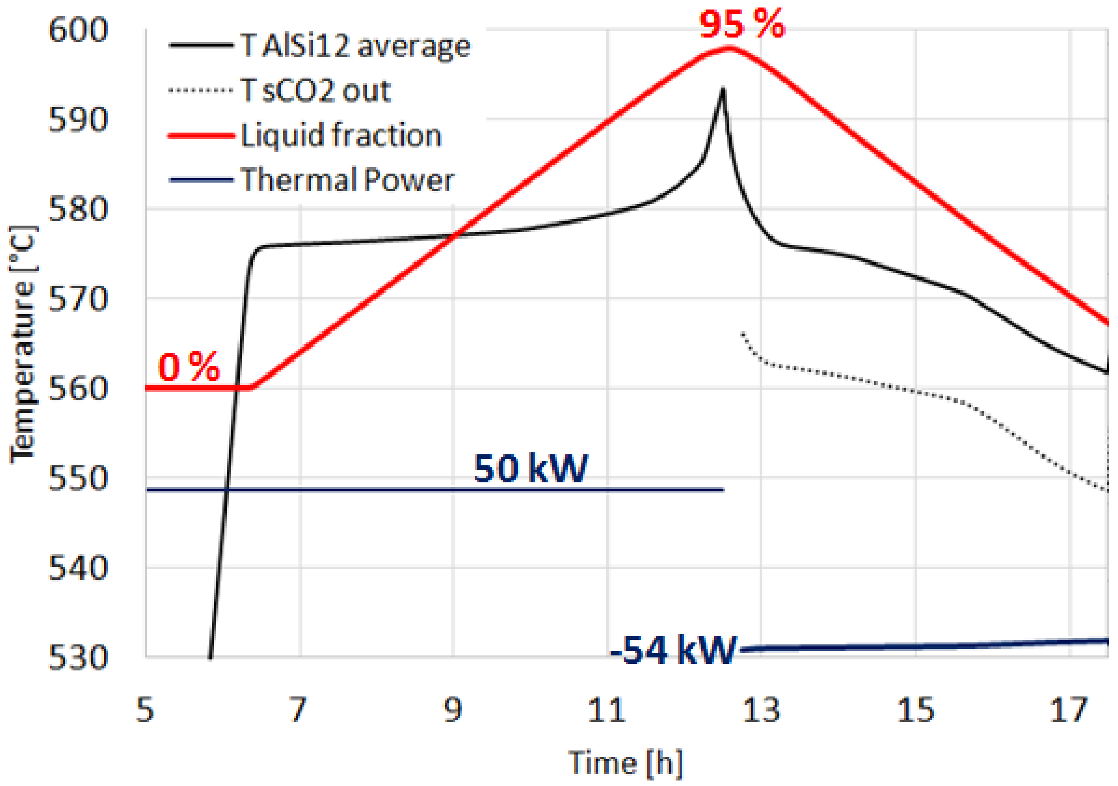
Thermal Model – Cycle Simulation

- Simulation of the first cycle
- Charging from the cold state, discharging
- The AlSi12 maximum temperature is kept below 600°C during whole cycle
- The system provides 50 kW output thermal power for 5 hours



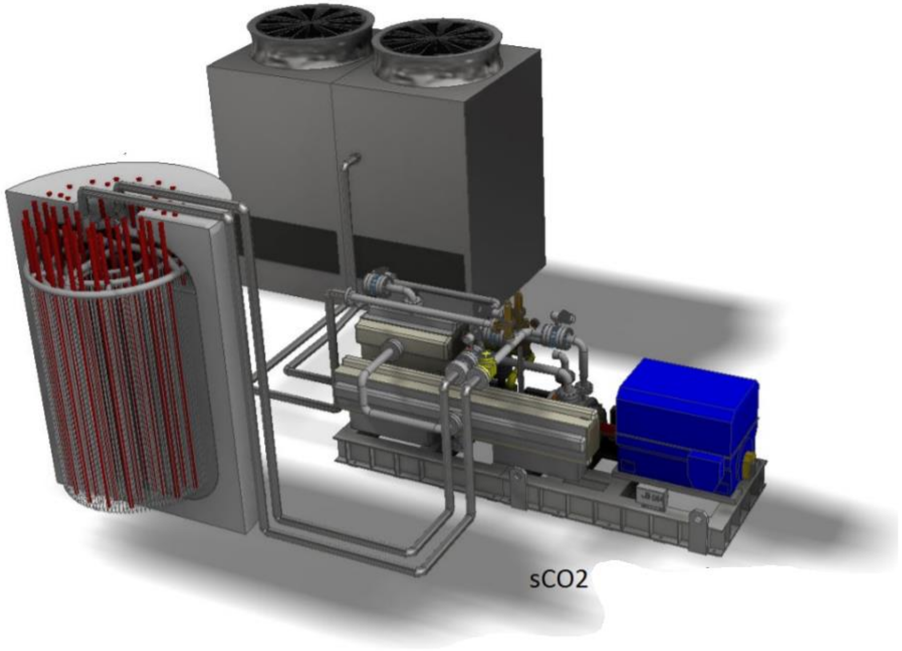
Technology Overview

- TES concept allows high-capacity storage
- Compact solution due to storage vessel design and sCO_2 cycle
- High storage density due to latent heat (approx. 4-times higher than molten salt storage)
- Simple configuration, no need of active components in the storage part
- Small heat exchanger
- Higher efficiency of H2P due to sCO_2 cycle
- CAPEX estimate: costs similar to the molten salt concept but higher efficiency (up to 45%)

- No long-term and large-scale operational experience
- Materials degradation – extensive materials research needed
- Structural issues due thermal-mechanical loads and phase change
- Relatively high round-trip efficiency comparing to other TES concepts but lower comparing to some other storage options → intensification possible by change of the accumulation material

Conclusions and Time Plan

- Design of the innovative latent-heat storage small-scale demonstrator unit was made and verified by the computational model
- The storage tank will be fabricated, filled and coupled with the sCO2 loop
- Experimental verification of the system scheduled for 2022
- In parallel, dedicated materials research will be ongoing to assess and enhance the life-time
- Larger-scale demonstration unit with subsequent implementation is planned to be realized in the mid-term



Thank you for your attention!

Tomas Melichar
Research Centre Rez
tomas.melichar@cvrez.cz

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