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THERMAL DESIGN OF LATENT HEAT THERMAL ENERGY STORAGE FACILITY WITH SUPERCRITICAL CO2

Tomáš Melichar*
Research Centre Rez
Husinec-Rez, Czech Republic
Email: tomas.melichar@cvrez.cz

Karel Dočkal
Research Centre Rez
Husinec-Rez, Czech Republic

Otakar Frýbort
Research Centre Rez
Husinec-Rez, Czech Republic

Petr Hájek
Research Centre Rez
Husinec-Rez, Czech Republic

Radomír Filip
Research Centre Rez
Husinec-Rez, Czech Republic

ABSTRACT

Conversion of electric power to heat and from the stored heat back to power is the energy storage concept that allows high temperature and high-capacity accumulation (hundreds of MWh stored in the heat). Combination of the high temperature heat storage with use of the sCO2 energy conversion cycle may provide highly efficient and very flexible energy storage system. An aluminum alloy was identified as a suitable accumulation material for the latent heat storage due to its high latent heat, appropriate melting point (577°C) and acceptable price. The energy storage system with Al-Si12 alloy as the heat storage material and the sCO2 conversion cycle is being developed at CVR.

In this paper, design of a mock-up of the storage tank with the aluminum alloy, an electrical heating system and a sCO2 heat exchanger will be presented. The storage tank with capacity of 300 kWht will be fabricated, connected to the sCO2 experimental loop of CVR and operated at the relevant conditions to demonstrate capabilities of the energy storage concept. A thermal computational model that was developed to support design and optimization of the sCO2/metal heat exchanger will be also presented. Based on the computational model results, feasibility of this concept for the high capacity energy storage will be discussed.

INTRODUCTION

Energy storage systems based on power-to-heat-to-power (P2H2P) concept have potential to accumulate high amount of energy (up to hundreds of MWh stored heat) for relatively long time periods comparing to other energy storage technologies. The P2H2P concept considers transformation of surplus electric power to heat, storage of heat in the heat accumulation material and subsequent reversed heat to power conversion during increased electric energy demands using a thermal conversion cycle. Heat storage at high temperature level is essential to enhance thermal efficiency of the heat to power conversion cycle. Use of latent heat storage using phase change materials (PCM) as the heat accumulation material is an option to allow high-temperature and high-capacity energy storage. Comparing to sensible heat storage systems with lower specific heat capacity. the PCM-based storage tanks can have significantly lower dimensions. This is an important advantage, especially considering large systems with very high capacity, where costs of the heat storage vessel and the accumulation material itself forms significant part of total acquisition costs. A large number of available PCMs with various properties were identified [1]. Operational parameters and design of the heat storage system are influenced especially by melting point, latent heat and density of selected PCM but also other properties such as thermal (specific heat, thermal conductivity), physical (low vapor pressure at operational temperature, low volume variation during phase change), chemical (non-corrosiveness, chemical stability, compatibility with structural materials, non-poisonous) and economic (availability in abundant supply, cost per kWh of stored energy [2] has to be considered.

An energy storage system with PCM and supercritical CO2 (sCO2) cycle for heat to power conversion is being investigated at Research Centre Rez (CVR), Czech Republic. In the current stage, a scale-down mock-up of an accumulation system is being developed. The system will be composed of a storage vessel equipped with electric heaters for charging and heat exchanger for discharging. The heat to power conversion cycle will be

* corresponding author(s)

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simulated by existing large-scale experimental facility sCO2 loop, built and operated by CVR. The sCO2 loop facility provides wide range of operation parameters represented by sCO2 temperature up to 550 °C, pressure up to 25 MPa and mass-flow rate up to 0.35 kg/s [3]. The binary eutectic alloy of aluminum and silicon (AlSi12) was selected as the accumulation material. This alloy was selected due to melting point compatible with the sCO2 cycle (576 °C) [4], high heat of fusion (560 kJ/kg) [4] and acceptable price and availability. The compact storage tank with capacity of 300 kWht and both charge and discharge power of 50 kW was designed and will be fabricated and operated at CVR. The goal of the activity is to demonstrate the PCM-based energy storage system that coupled with the sCO2 cycle in a small-scale and to demonstrate thermal performance during cyclic loading.

In this paper, thermal and mechanical design of the storage vessel equipped with the electric heaters and sCO2 heat exchanger will be presented. Particular attention is paid on thermal analyses supporting design of the storage tank, that were carried out using a dedicated numerical model based on finite volume method (FVM) coupled with analytical approach. The model allows transient modeling of heat transfer and phase change of the accumulation materials and convective heat removal in the sCO2 heat exchanger. The computational model, numerical results and final design of the storage tank will be reported. Moreover, feasibility of the full-scale storage system will be discussed based on obtained results.

SYSTEM DESCRIPTION

In this section, the experimental facility will be described. Although the main focus is placed on the storage part of the system, the existing sCO2 loop that provides required operational parameters will be described as well. The sCO2 loop is designed as a simple Brayton cycle with regeneration, where a turbine is replaced with a regulation valve.

The scheme of the investigated system is shown in Figure 1. The storage part of the system is formed by the storage vessel (SV). The SV is filled with approx. 2 000 kg of AlSi12 eutectic alloy. Charging of the accumulator is performed using electric resistive heaters (EH) that are transforming electric power to heat. The EH in the form of conventional resistive heating cartridges composed of a resistive wire, ceramic insulation and metal coating are immersed directly in the accumulation material. During discharging, the accumulated heat is removed using a thermal cycle with sCO2. For this purpose, existing sCO2 loop will be coupled with the storage vessel. The interface between the AlSi12 and sCO2 is formed by heat exchanger (HX), which is also placed directly in the storage vessel. Design, layout and parameters of the storage vessel, heaters and heat exchanger will be presented in details in the following sections.

During the discharging operational regime, the sCO2 inlets to the SV from the high pressure side of the sCO2 loop. The sCO2 parameters at the inlet to the SV are pressure of 25 MPa, mass-flow rate of 0.3 kg/s and temperature of approx. 420 °C. The inlet temperature is controlled by the existing electric heater of the sCO2 loop (H1 in Figure 1). The sCO2 flows through the heat exchangers HX and is heated to 550 °C (that corresponds to 50 kW of removed heat considering mass-flow rate of 0.3 kg/s). This temperature is given by operational limits of the sCO2 loop, but at the same time, is relevant the temperature level that is expected in real sCO2 energy cycles. The hot sCO2 goes to cooler C2. This cooler will be used to control maximum temperature of sCO2 below 550 °C to protect the upstream components of the sCO2 loop. The regulation valve RV simulates expansion in a turbine. The pressure is regulated to approx. 12.5 MPa. The sCO2 then flows to existing oil cooler C3, where the fluid is cooled to 450°C (limit temperature of regenerative heat exchangers). After the cooler C3, high-temperature (HTR) and low-temperature (LTR) regenerative heat exchangers are located. After the LTR, the sCO2 is cooled in water cooler C1 to approx. 25 °C. The forced circulation in the loop is ensured by pump P that ensures pressure in the high pressure part. The sCO2 is preheated in the high-pressure side of both LTR and HTR.

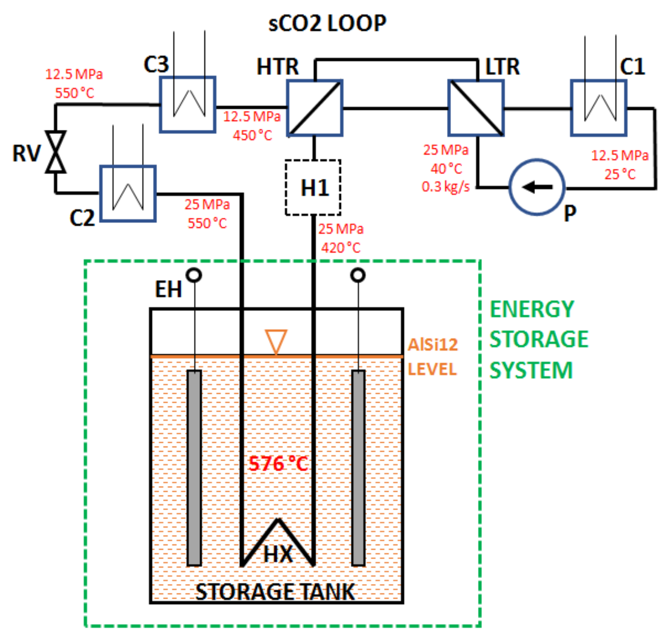

Figure 1: Scheme of the mock-up storage system

The main parameters of the mock-up storage system are summarized in Tab. 1.

Table 1: Main parameters of the mock-up storage system

Accumulation material	AlSi12
Volume of AlSi12	0.75 m^3
Operational temperature	550 – 600 °C
Nominal charging/discharging power	50 kW
Charging/discharging time	5 hours
Capacity of the storage vessel	300 kWh_t
sCO2 inlet temperature	420 °C
sCO2 nominal pressure	25 MPa
sCO nominal mass-flow rate	0.3 kg/s

As mentioned, the sCO2 loop is designed as a simple Brayton cycle operated at the relevant sCO2 thermal cycles parameters. It is also expected that the same technology will be used for charging of a real storage system (resistive electric heaters). Thus, the layout of the whole experimental system is practically identical to possible future real scale energy storage system. The experimental facility will therefore allow short term demonstration of the storage system in a small scale.

DESIGN OF THE STORAGE VESSEL

Dimensions of the storage vessel are based on volume of accumulation material that is needed to store required amount of heat. The SV volume V can be calculated using the following formula:

$$V = \frac{t \cdot P \cdot 3600}{h_f \cdot \rho}$$

Where t is time of charging / discharging (5 hours), P is charging / discharging power (50 000 W), h_f is heat of fusion of AlSi12 (560 000 W/kg) and ρ is density of AlSi12 (2700 kg/m^3). Resulting minimum volume of AlSi12 is 0.6 m^3. The volume is increased by 25% to 0.75 m^3 compensate possible drop of heat of fusion that might be caused by impurities in the accumulation material. It is also expected that not all the accumulation material will be solidified during discharging. The volume corresponds to 2025 kg of AlSi12. The dimensions of the SV are internal diameter of 1.09 m and height of 1 m. The AlSi12 level corresponds to height of 0.8 m, the volume above the level will be filled with an inert gas (argon). The cover gas will ensure inert atmosphere in the SV that will reduce oxidation. Moreover, the cover gas will compensate volume expansion of the accumulation material during the phase change. Pressure slightly higher than the atmospheric will be kept in the SV to avoid penetration of the air inside the SV.

The CAD model of the SV with the main components is shown in Fig. 2. The HX is composed of U-tubes, the sCO2 is distributed to the individual tubes in a manifold located above the AlSi12 level. The heaters are guided to the SV through an upper lid that is connected to the vessel by a flange. The lid is also equipped with holes for thermocouples and an inert gas pipeline. The SV is filled and drained from a dedicated filling vessel using a filling tube that ends slightly above the vessel bottom. Draining is performed by increasing of the inert gas pressure above the level and pushing AlSi12 to flow out through the filling tube. The external surface of the SV will be equipped with a thermal insulation.

One of the obstacles for long term operation of the systems is degradation of structural materials in the AlSi12 environment. The materials must be resistant to corrosion but at the same time, they must withstand mechanical loading. Several materials were identified as potentially applicable for the HX as well as for the other components that are facing the AlSi12. For example, Al based ceramics such as Al_2O_3, AlN or Si_3N_4 that could be used as coatings showed good resistance [5], [6]. Boron Nitride coatings tested on crucibles with AlSi12 showed good results for 720 cycles while signs of corrosion (formation of intermetallic layers) were found on uncoated stainless-steel (SS) samples according to [7]. A refractory material TCON® (SiC, Al2O3 and AlSi12 composition) with good corrosion and wear resistance was developed specifically for Al containers [8]. A plasma-sprayed ceramic coating was used for a latent heat storage system prototype with AlSi12 and a Stirling engine. The coating showed good corrosion resistance but some cracks in the coating were observed after the experiments [9]. Metal materials are expected to be less resistant, although titanium or niobium showed relatively good behavior [10]. Even though a long-term operation of the experimental facility is not expected, an extensive materials research is needed before implementation of energy storage systems. A dedicated research of corrosion resistance of preselected materials for the HX was initiated at CVR in 2020.

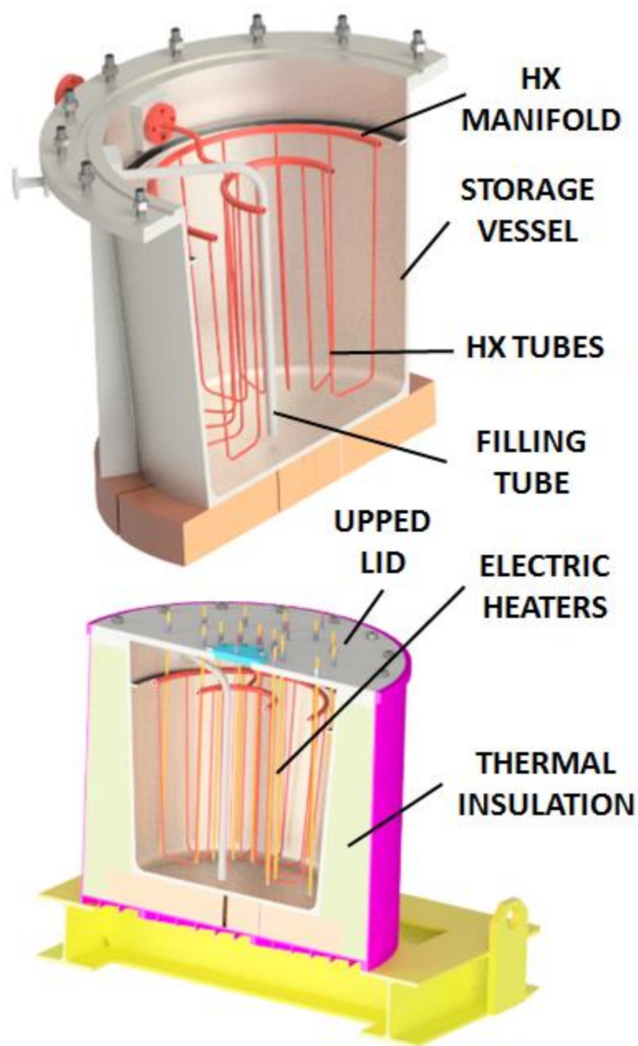

Figure 2: Model of the storage vessel

COMPUTATIONAL MODEL

In this section, the computational model that was prepared and utilized for detailed thermal analyses and optimization of the individual components will be described. The main motivation of the model development is to allow modelling of the whole vessel behavior at reasonable computational time and with acceptable accuracy. The model must consider transient heat transfer in the accumulation material including solidification and melting during both operational regimes (charging and discharging). Therefore, both the sCO2 heat exchanger and the electric heaters must be modelled. Based on 3D nature of the computational domain and complexity of the physical behavior, Computational Fluid Dynamic (CFD) method seems to be suitable for this purpose. However, due to relatively large geometric size of the domain and long time periods to be simulated, full CFD modelling of both the AlSi12 and sCO2 domains was identified as inappropriate due to very high computational time. It was therefore proposed to simplify modelling of the sCO2 heat transfer in the HX tubes. For this purpose, an approach represented by CFD modelling of the AlSi12 domain coupled with simplified modelling of the convective heat transfer in the HX tubes was adopted. The simplified modeling of the convective heat transfer in sCO2 based on analytical and empirical formulas is acceptable as number of correlations for heat transfer and pressure drop in tubes valid for relevant parameters is available. Moreover, there are significant benefits coming from use of the coupled model. A full CFD model would require relatively fine mesh (estimated up to dozens of millions mesh elements) and small time steps (below 1 s) to fulfill the CFL condition while relatively coarse mesh and time steps of up to dozens of seconds are sufficient for the coupled model. This will result in many times lower computational time and hardware requirements. The main characteristics of both methods are summarized in Tab. 2.

Table 2: Main characteristics of computational methods

	Full CFD	Coupled
Mesh size	High	Low
Time step	Low	High
Computational time	Very high	Low
Accuracy	High	Acceptable

The whole computational domain is shown in Fig. 3. Due to axisymmetric layout, just 12° sector of the vessel is considered with symmetry boundary condition (BC) applied on the lateral walls of the model. The heaters are simply modelled using heat flux boundary condition. As detailed modelling of temperature field in the heaters is not the fundamental issue of these analyses, thus the heaters structure is not included. The sCO2 HX is represented by the convection BC applied on the channel surface. The zero heat flux BC representing the heat insulation is applied on the external surfaces. The CFD model therefore consists of just one fluid volume representing AlSi12. The CFD model is prepared using CFD code ANSYS FLUENT 19.1.

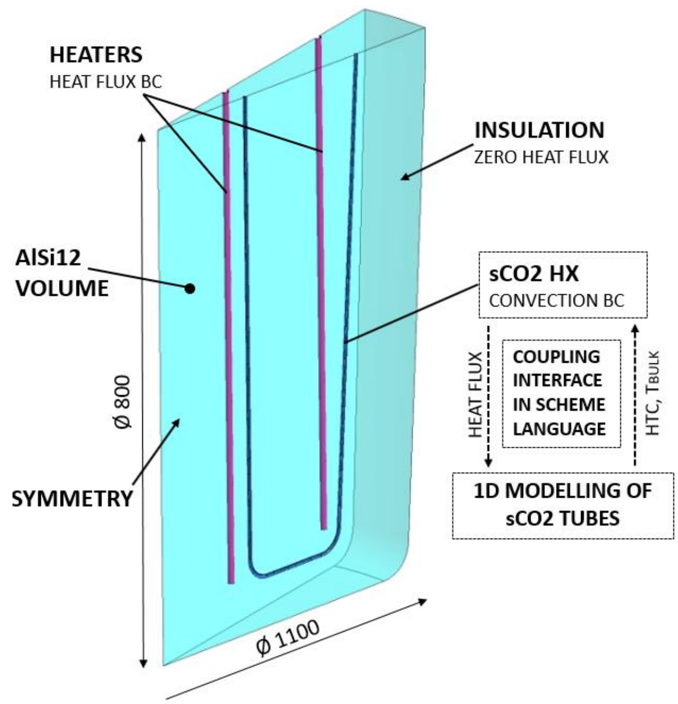

Figure 3: Computational domain

External 1D modeling of the sCO2 HX channel is based on calculation of sCO2 bulk temperature (T_{BULK}) and heat transfer coefficient (HTC) as an input for the convection BC in the CFD solver. The interface surface (the HX channel wall) is artificially split in smaller faces with respect to the flow direction. As thermal behavior of both fluids depends on one another, the parameters must be transferred in both ways. The coupling scheme is also indicated in Fig. 3. The 1D modeling as well as the communication between the CFD model and 1D model is ensured by Scheme programming language [11] that is fully compatible with the ANSYS Fluent environment. On the first face of the channel wall (corresponding to sCO2 inlet), T_{BULK1} and HTC are set manually. On the consequent faces, T_{BULKi} is calculated from heat flux on the previous face given by the CFD solver according to the following formula:

$$T_{BULK\ i+1} = \frac{q_i \cdot A_i}{\dot{m} \cdot c_p} + T_{BULK\ i}$$

Where q_i is heat flux (W/m2), A_i is face area (m2), $\dot{m}$ is mass flow rate in one HX channel (kg/s) and c_p is sCO2 heat capacity. After every time step i, the set of q_i values is transferred from CFD model to Scheme model, where corresponding $T_{BULK\ i}$ values are being calculated. After that, $T_{BULK\ i}$ values then are transferred back to CFD model where they are used as the parameters of the convection BC. After this procedure, simulation of the next time step $i + 1$ can start.

It was found that HTC values are not significantly affected by change of corresponding sCO2 bulk temperature and even less by pressure loss in the pipe. For this reason, constant value of

HTC was used for all HX channel surface. The HTC value was calculated from well-know Gnielinski correlation that is applicable for tubes geometries [3] and relevant ranges of Re and Pr numbers:

$$HTC = \frac{Nu \cdot \lambda}{D_h}$$

$$Nu = \frac{\left(\frac{f}{8}\right) \cdot (Re - 1000) \cdot Pr}{1 + 12.7 \cdot \left(\frac{f}{8}\right)^{0.5} \cdot \left(Pr^{\frac{2}{3}} - 1\right)}$$

$$f = (0.79 \cdot \ln Re - 1.64)^{-2}$$

$$for\ Pr > 0.7\ and\ Re > 2300$$

Where λ is sCO2 thermal conductivity and D_h is hydraulic diameter. Partial results and parameters can be seen in Tab. 3. The sCO2 properties were considered for constant sCO2 temperature of 500 °C and are summarized in Tab. 4.

Table 3: sCO2 parameters

Total mass flow rate	0.3 kg/s
Mass flow rate per channel	0.02 kg/s
Hydraulic diameter	0.006 m
Flow velocity	4.3 m/s
Reynolds number	111 200
Prandtl number	0.75
Nusselt number	202
Heat transfer coefficient	2160 W/m·K

As mentioned, ANSYS Fluent was chosen as the numerical solver. As flow of AlSi12 is not modeled, less complex code based on FEM or FVM method could be used. However, the benefit of ANSYS Fluent code is the existing solidification / melting module [13] that has been already validated on solidification experiments in similar geometry [14]. The final computational grid is composed of 430 000 polyhedral elements. As only the energy equation is being resolved in the AlSi12 domain, the mesh requirements are not very strict. The 1D model is discretized to 67 face elements with an average length of 25 mm. The following settings and simplifications were adopted.

- Solidification / melting module is turned on.
- Flow equations are disabled. Therefore, natural convection of AlSi12 is not considered.
- Spatial discretization of second order was used.
- Time step of 30 s was considered.
- Constant materials properties were considered (Tab. 4). This is acceptable as the SV is operated in relatively small temperature range (approx. 550-600 °C).
- The HX tube structure is considered using "shell conduction" option [13].
- Constant HTC is assumed in the sCO2 HX channels. However, relatively low effect of appropriate sCO2 operational parameters on HTC was observed (less than 10%).
- 3D model has 430 000 finite volumes, 1D model has 67 elements.

Used material properties are summarized in Tab. 4.

Table 4: Used materials properties

AlSi12 Heat of Fusion	560 000 kJ/kg [4]
Melting point	576 °C [4]
AlSi12 Density	2 700 kg/m^3 [4]
AlSi12 Thermal Conductivity	180 (solid) 70 (liquid) [4]
AlSi12 Heat Capacity	1 038 J/kg·K (solid) 1 741 J/kg·K (liquid) [4]
sCO2 Density	164.9 kg/m^3 [12]
sCO2 Thermal Conductivity	0.061 W/m·K [12]
sCO2 Heat Capacity	1 249 J/kg·K [12]
sCO2 Dynamic viscosity	0.0000368 Pa·s [12]

HEAT EXCHANGER DESIGN

Proper design of the HX is essential to ensure required operational parameters and function of the facility. The HX is placed in the accumulation material and is in operation during discharging operational regime, when the accumulated heat in AlSi12 is removed by sCO2. The fluid outgoing from the HX flows towards the thermal circuit for heat to power conversion.

At the beginning, a simple "0D" model of the HX was prepared for preliminary estimation of the basic dimensions of the HX. The number and diameter of tubes was designed in order to achieve reasonable flow velocities in the tubes (ensuring sufficiently high HTC and acceptably low pressure drop). Internal tube diameter of 6 mm and 15 tubes result in mass-flow rate of 0.02 kg/s and average velocity of 4.3 m/s in each tube. Regarding the tubes length, it was found that relatively short length of tubes is needed to remove required amount of heat power. This is given by relatively intense heat transfer at both sides of the HX. Moreover, the length of the tubes is also given by the nature of the SV behavior. As the accumulation material is operated at practically constant temperature during the phase change, higher heat flux occurs at the beginning of the tube, where temperature difference between the fluids is higher. At the outlet part of the HX tube, sCO2 is heated to temperature close to the AlSi12 and the heat transfer is not too efficient. For this reason, the tubes are designed as a simple U-shape with length of 1.7 m.

In the next phase, the HX tubes layout was optimized using the complex computational model described in the previous section. The point of these analyses was to propose exact dimensions and to verify the component behavior. Moreover, as the tubes are considered as U-shaped, two positions of sCO2 inlet and outlet are possible. If the sCO2 enters the HX through the inner leg, the solidification will start from the center of the vessel. Conversely, if the cold sCO2 enters the outer leg, the solidification will start from the SV wall. Analyses of both options were carried out to evaluate temperature field and freezing process. The results are shown in Fig. 4 (for inlet in the outer leg) and in Fig. 5 (for inlet in the inner leg). The solidified fraction and temperature field was depicted for two times (the transient analyses started from constant temperature of AlSi12 of 600 °C).

In each picture, left side shows solidified fraction in the SV (blue color corresponds to solidified part while red color to liquid fraction). The right side of each picture shows temperature field.

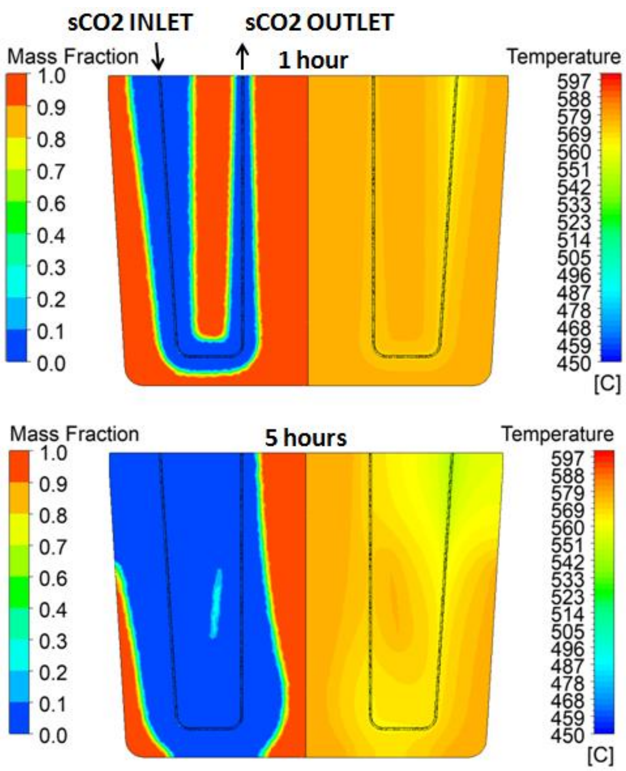

Figure 4: Solidification process and temperature field during discharging for sCO2 inlet located in the outer leg of the HX

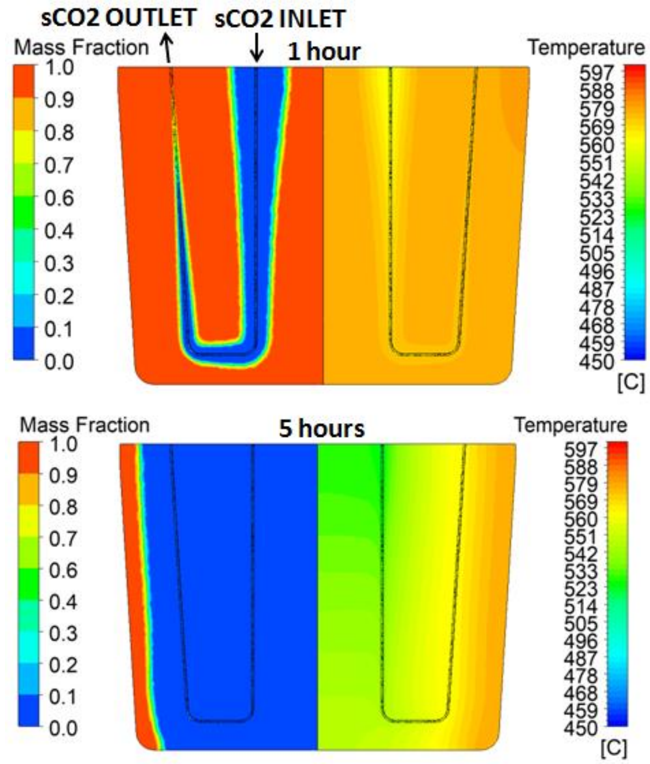

Figure 5: Solidification process and temperature field during discharging for sCO2 inlet located in the inner leg of the HX

For the final layout, the option with inlet located in the inner leg was selected due to benefits that can be seen in Fig. 5 below. It can be observed that liquid fraction remain in the outer part of the SV. If the AlSi12 stays liquid in this location during both operational regimes, it can reduce additional stresses on the SV structure caused by volumetric change during the phase change. The disadvantage of this layout is the temperature distribution, which is less uniform comparing to the option with inlet located in the outer leg.

The final layout of the HX is shown in Fig. 6. The main parameters of the HX are then summarized in Tab. 5. Based on the analyses, it was found that inlet sCO2 temperature of 420 °C will lead to discharging power of approx. 50 kWt.

Figure 6: Layout of the HX

Table 5: Layout of the HX

Number of U-tubes	15
Inlet sCO2 temperature	420 °C
Tubes dimension	10 × 2 mm
Tube length	1.7 m
Total tubes length	25.5 m
Total heat transfer area	0.64 m^2
Heat power	50 kW

HEATERS DESIGN

The second important activity related to the SV thermal design is connected with layout of the heaters that are used for charging of the SV. The heaters are based on an available technology (electric resistive heating rods). The rods will be placed directly in the accumulation material. Proper layout of EH is essential to assure uniform temperature field and to avoid overheating of AlSi12. The first proposal of the EH is based on allowable maximum heat flux on the heaters surface, which should not exceed 16 W/cm^2. Taking into consideration this parameter, heating rods of outer diameter of 12 mm and active length of 0.78 m were selected. Based on this, it is clear that relatively low number of heaters would be needed to unsure required power input. However, the temperature field has to be examined to decide final number and positions of the heaters. For this purpose, the computational model was employed.

In Fig. 7, development of temperatures in the SV is depicted. Two layouts were considered (with 15 heaters and with 30 heaters). Fig. 7 shows minimum, maximum and average temperature and liquid fraction development. The continuous lines represent layout with 30 heaters, dashed lines represent layout with 15 heaters. It is obvious that temperature field for layout with 30 heaters is more uniform, where the maximum temperature difference does not exceed 25 °C. Moreover, the maximum temperature grows rapidly for layout with 15 heaters at the end of the charging cycle even before the all AlSi12 is melted. For this reason, the layout with 30 heaters was selected.

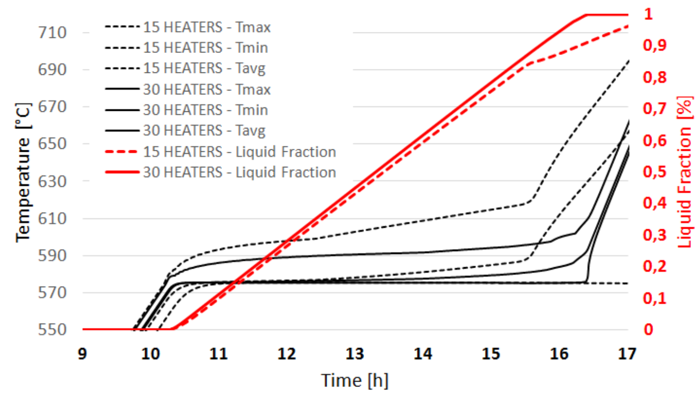

Figure 7: Layout of the HX

Using the computational model, exact positions of the heaters were optimized. The heating rods are split in two groups of 15 pieces that placed at two diameters. The inner heaters will be operated with lower power (1.09 kW per rod), while power of the outer heaters will be 2.26 kW. The main parameters of the EH are summarized in Tab. 6.

Table 6: Layout of the HX

Number of heating rods	30
Heating rods diameter	420 °C
Heating rods length	10 × 2 mm
Total power	50 kW
Heaters power	2.26 kW (outer) 1.09 kW (inner)
Power density	7.7 W/cm^2 (outer) 3.7 W/cm^2 (inner)

As mentioned, the sCO2 loop is designed as a simple Brayton cycle operated at the relevant sCO2 thermal cycles parameters. It is also expected that the same technology will be used for charging of a real storage system (resistive electric heaters). Thus, the layout of the whole experimental system is practically identical to possible future real scale energy storage system. The experimental facility will therefore allow short term demonstration of the storage system in a small scale.

CYCLE SIMULATION

Using the optimized geometry, the final model was used for simulation of complete cycle composed of charging and discharging of the SV. The simulation started from cold state (20 °C) at time 0 h (the simulation thus corresponds to the "first" charge as the other charges will start from preheated vessel). The SV was charged for 12.5 hours with constant heating power of 50 kW. After that, the heaters were turned off and the regime was switched to discharging. The SV was then discharged for 5 hour to time 17.5 h. Development of selected parameters is shown in Fig. 8. Liquid fraction development is depicted with red line. It can be seen than the maximum ration of liquid fraction was 95% at the end of charging. Black continuous line indicates average temperature of AlSi12 while black dashed line show outlet temperature of sCO2 (constant mass-flow rate was considered during the whole cycle). The blue lines represent heat power of the SV. It can be seen that discharging power is slightly higher than 50 kW. This can be compensated by decrease of sCO2 flow rate or by increase of sCO2 inlet temperature.

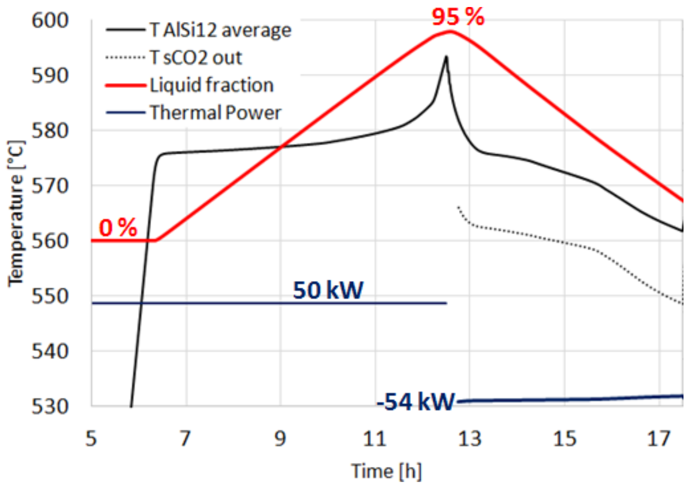

Figure 8: Time development of parameters in the storage vessel during the first cycle

Contours of liquid fraction and temperature field in the vessel during the cycle for four times of the cycle are shown in Fig. 9.

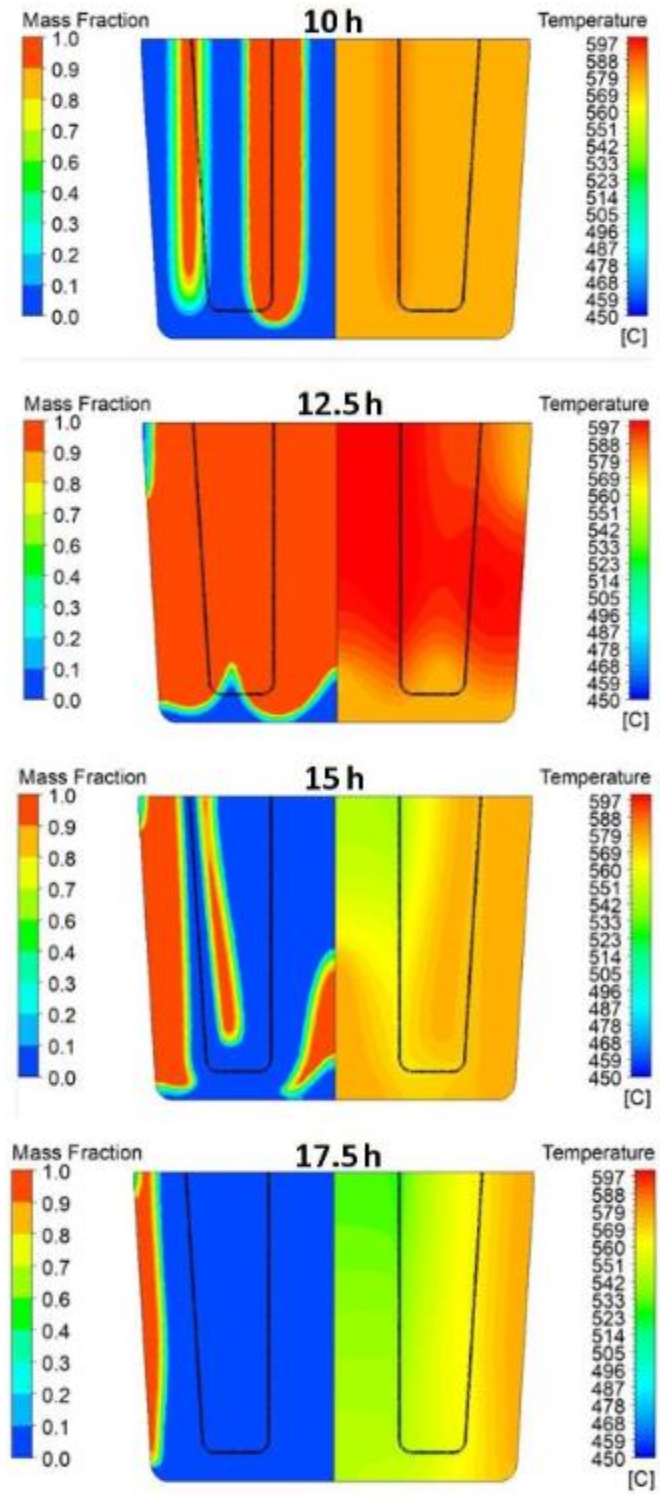

Figure 9: Solidification process and temperature field during the first cycle

CONCLUSIONS

The experimental facility allowing transformation of electric energy to heat, heat storage in latent heat of AlSi12 and subsequent heat removal using the sCO2 thermal cycle was designed. The facility will allow demonstration of the storage system in the small scale. The dedicated numerical thermal model of the storage vessel was developed and applied to support the facility design. The following findings and outcomes were achieved.

- The numerical model that combines 3D modeling of the AlSi12 volume including phase change and 1D modeling of the sCO2 heat exchanger was employed. The model allows simulation of behavior of the whole vessel for relatively long time periods at reasonable computational time.
- AlSi12 seems to be suitable accumulation material from the thermal point of view (high latent heat, high thermal conductivity, suitable melting point). However, structural materials or possible coatings degradation is significant obstacle for the long-term operation.
- The design supporting calculation showed significant benefits of the concepts regarding the components design. The heat exchanger requires small heat transfer area and thus low amount of material. This gives significant benefits comparing to other high capacity storage systems (such as rock-based or molted salt-based ones), where the heat exchangers forms significant cost of the facility.
- The computational model results showed suitable temperature and freezing front development during an operational cycle. Based on the results, operation of the facility seems to be feasible.
- Before implementation of larger systems, great focus should be placed on safety aspects. Even though the storage vessel will be operated at atmospheric pressure, high pressures are expected at the secondary fluid side (sCO2). Possible rupture of the HX tube may lead in abrupt pressure increase in the storage vessel and subsequent accident. The HX tubes are exposed not only to internal pressure and secondary thermo mechanical stresses but also to additional stresses caused by AlSi12 expansion during phase change. Therefore, special attention must be paid on this issue.

As the next steps, the storage vessel will be fabricated and connected to the existing sCO2 loop. Performance of the facility will be experimentally evaluated. Dedicated materials test will be carried out in the relevant AlSi12 environment to support materials selection. Moreover, the storage vessel components should be studied from the mechanical point of view.

NOMENCLATURE

CAD	Computer Aid Design
CFD	Computational Fluid Dynamic
CFL	Courant–Friedrichs–Lewy condition
CVR	Research Centre Rez
EH	Electric Heaters
FEM	Finite Elements Method
FVM	Finite Volumes Method
HX	Heat Exchanger
HTC	Heat Transfer Coefficient
HTR	High Temperature Recuperator
LTR	Low Temperature Recuperator
P2H2P	Power to Heat to Power
PCM	Phase Change Materials
sCO2	Supercritical Carbon Dioxide
SS	Stainless Steel
SV	Storage Vessel

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