Numerical Analysis of the Phase Change in High Power Latent Heat Storages with 3D Wire Structures

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Abstract

Latent heat storage devices use the melting enthalpy of a so-called phase change material (PCM) to store thermal energy with a high volumetric density at a nearly constant temperature. Because of the low heat conductivity of PCM, the storage power is limited. Open porous metals, such as 3D wire structures, are able to improve the effective heat conductivity and allow the design of systems with tailored storage capacity and power. For temperatures of 130 °C to 350 °C (process heat applications) nitrate salts like KNO3, NaNO3, LiNO3 and their eutectic mixtures are used as PCM (Figure 1).

Geometric and material properties of the wire structure as well as manufacturing steps like brazing the nodes inside the wire structure have impact on the kinetic of the PCM melting process. Especially, the brazing of the nodes of the wires may have a strong influence on the resulting thermal power.

By using the transversely isotropic geometry of typical 3D wire structures, a unit cell was identified and modeled. COMSOL Multiphysics® software was used to investigate the transient behavior of the PCM melting front. The simulations were conducted for non-brazed and brazed wire structures of different materials and leads.

All relevant thermal properties as density, heat conductivity and heat capacity were modeled as temperature dependent. Especially, the heat capacity was used to introduce the energy of fusion into the calculation by using a combination of different functions for solid and liquid state as well as the melting area.

Because of the high model complexity and the differences in length scales between the wire structure and the PCM, upscaling the simulations to the whole PCM storage unit is difficult. Therefore, a simplified geometry was created (Figure 2), which is intended to replace the full resolution model. To maintain the thermal behavior of the unity cell, the material properties of the wire and lead have to be combined and adjustments to the properties are made.

The accuracy of the heat capacity function was verified by comparing the simulation results to experiments.

The wire material has great impact on the time needed to melt the PCM inside the unity cell. By using a non-brazed copper structure, the PCM's melting time is reduced to about 20 % compared to a non-brazed iron steel structure. Brazing these structures reduces the melting time of the PCM by 50 % to 66 % compared to the respective non-brazed versions. Heat conductivity and heat capacity of the simplified geometry were adapted to maintain thermal behavior of the model. Comparative calculations revealed a material specific correction factor for the heat conductivity and the thermal behavior of the alternative geometry was proven.

With COMSOL, a model was developed to simulate the transient behavior of a PCM's melt front in a high power, high density latent heat storage with 3D wire structures. By comparing simulation with measurement results, the simulation model was validated. A simplified geometry with adapted thermal properties was created in order to scale the simulation model up to the whole storage unit.

Figures used in the abstract

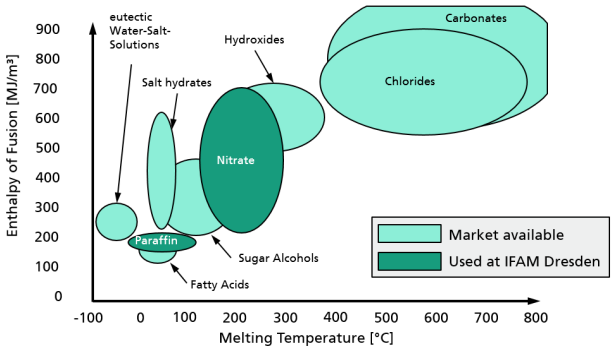

Figure 1: Properties of available Phase Change Materials (PCM).

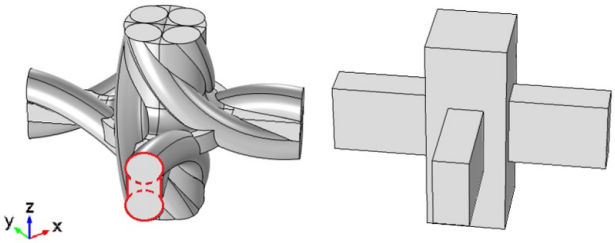

Figure 2: Complex (left) and simplified (right) model geometry.