LIFE CYCLE ANALYSIS OF PCM-ENHANCED DOMESTIC HOT WATER STORAGE

Matthias BERGER[1], Roger-Pius ZIMMERMANN[1,2], Tom FELDER[1], Simon MARANDA[1,2], Ludger Josef FISCHER[1]

Abstract

Encapsulated phase change material (PCM) can be used to increase the capacity of domestic hot water (DHW) storages by a factor of 2.5 to 3. This extra capacity allows for an increase of own-consumption and self-sufficiency of locally produced renewable energy from solar thermal or photovoltaic systems and thus reduces the energy demand taken from the grid or other fuel sources. While the energetic sustainability can already be seen directly from simulations, the environmental benefit in terms of avoided CO_2 emissions depends heavily on the life cycle analysis (LCA) of the added PCM capsules compared to the energy saved. This LCA was carried out for a demonstrator PCM-enhanced domestic hot water station and shows a very early break-even point for CO_2 emissions. In addition, a comparison was made with a battery system (as an electrical storage system in front of the heat pump, with equivalent heat capacity), which shows that the latent heat storage system with encapsulated PCM leads to 100 times fewer emissions per kWh of thermal energy delivered.

Methodology

The evaluation is using the ecoinvent database [1]. The proposed PCMs have been modeled as a full system, where the storage unit including the containment has been compared against conventional batteries, following a cradle-to-gate approach by the inventory, including transport and processing of all materials. The encapsulated PCM is based as either metal or high density polyethylene (HDPE) filled with salt hydrates and additives. The capsules increase the storage capacity of a domestic hot water tank (DHW) [2], thus potentially increasing the own-consumption of locally produced photovoltaic electricity [3,4]. As such the systems saves CO_2-emission related to the electricity mix of the local grid, and the big questions are: a) how long does it take to recover the LCA-costs of the capsules, and b) is the capsule-based solution better than an equivalent battery storage?

Results

The DHW application of PCMs include specific power requirements, which influence the capsule design (see Figure 1) [2]. The material composition of the resulting PCM, additives and shell (HDPE or steel) and their embodied CO_2-equivalent have been balanced against the storage capacity increase and savings in grid electricity. This has been carried out for the DACH region, assuming a refurbishment cycle of 50 years with 10’000 cycles. Depending on the national grid’s CO2 intensity, HDPE capsules break even after only 10% of the lifetime (after 1014 cycles) in the case of Switzerland. Compared to battery systems, PCM-enhanced DHW storage have a factor between 6 and 8 lower global warming potential and are therefore an alternative and environmentally friendly solution with respect to decarbonization. The following parameters have been calculated:

- Global warming potential (GWP) of PCM-enhanced DHW storages for HDPE and metal capsules as best- and worst-case scenario (not shown here) (*ecoinvent* vers. 3.7, method EF 2.0 midpoint)
- GWP relative to storage capacity (Fig 2 left) and relative to lifetime thermal energy delivered (Fig. 2 right) for the three systems metal capsules, HDPE capsules and batteries. Data for batteries from [5,6]
- CO_2 payback time in number of cycles according to Swiss, German and Austrian electricity grid’s carbon intensity (not shown here).

[1] Hochschule Luzern, CC Thermische Energiespeicher, Technikumstrasse 21, CH- 6048 Horw
+41 41 349 33 94, matthias.berger@hslu.ch, www.hslu.ch/tes
[2] Cowa Thermal Solutions AG, Technopark Luzern, Platz 4, CH-6039 Root D4, info@cowa-ts.com, www.cowa-ts.com

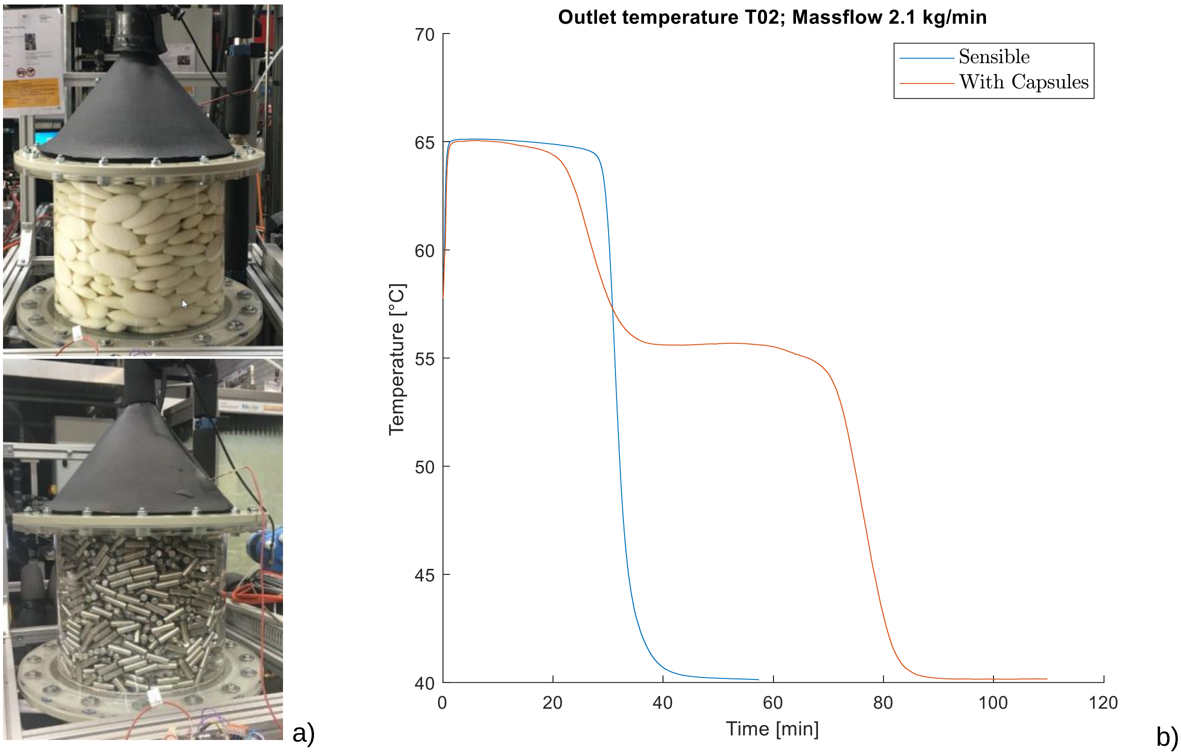

Figure 1: DHW testbed in a) with HDPE capsules (top) and metal capsules (bottom); temperature profile in b) during discharge with metal capsules.

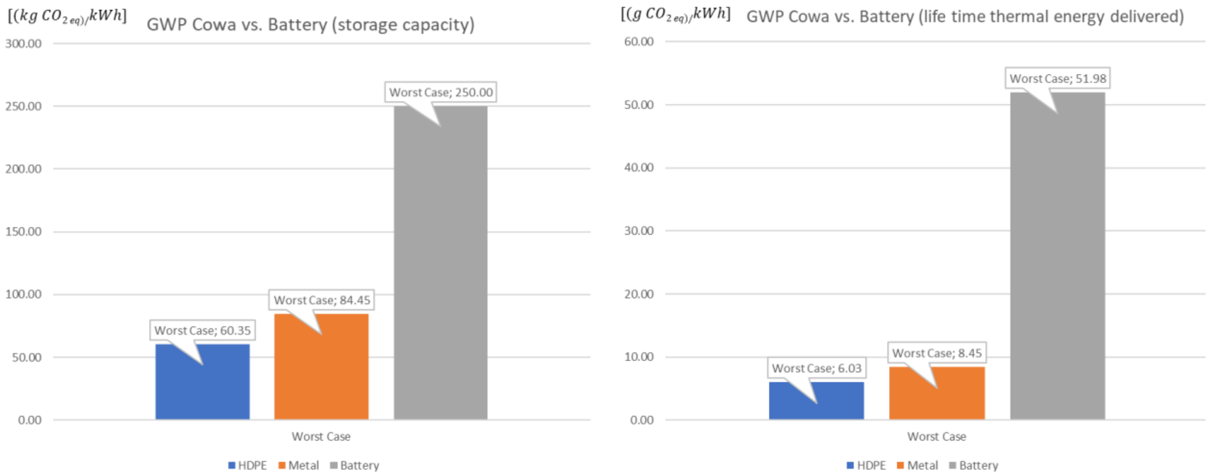

Figure 2: LCA comparison of HDPE and metal capsules with batteries. GWP relative to storage capacity (left) and relative to lifetime thermal energy delivered (right)

Referenzen

[1] Frischknecht, Rolf, et al. "The ecoinvent database: overview and methodological framework (7 pp)." *The international journal of life cycle assessment* 10(1), 2005, 3-9.

[2] W. Delgado-Diaz, A. Stamatiou, S. Maranda, R. Waser, and J. Worlitschek, “Comparison of Heat Transfer Enhancement Techniques in Latent Heat Storage”. *Applied Sciences* (*10)*, 2020, 5519.

[3] M. Zheng, R. Fang, and Z. Yu, “Life cycle assessment of residential heating systems: a comparison of distributed and centralized systems”, *Energy Procedia* (104), 2016, p. 287-292.

[4] Najafian, F. Haghighat, and A. Moreau, “Integration of PCM in domestic hot water tanks: Optimization for shifting peak demand”, *Energy and Buildings* (106), 2015, p. 59-64.

[5] T. Le Varlet, O. Schmidt, A. Gambhir, S. Few, and I. Staffell, “Comparative life cycle assessment of lithium-ion battery chemistries for residential storage”, *Journal of Energy storage* (28), 2020, 101230.

[6] C. Aichberger and G. Jungmeier, “Environmental life cycle impacts of automotive batteries based on a literature review”, *Energies* (13), 2020, 6345.