Assessing the impact of copper wools on a phase change material-based TES tank prototype

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Assessing the impact of copper wools on a phase change material-based TES tank prototype

Assessing the impact of copper wools on a phase change material-based TES tank prototype

A Ribezzo[1], M Morciano[1], G Zsembinszki[2], S Risco Amigo[2], S Mani Kala[2], E Borri[2], L Bergamasco[1], M Fasano[1], E Chiavazzo[1] and L F Cabeza[2]

[1] Department of Energy, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[2] GREiA Research Group, University of Lleida, Pere de Cabrera s/n, 25001 Lleida, Spain

eliodoro.chiavazzo@polito.it; luisaf.cabeza@udl.cat

Abstract. Phase Change Materials (PCMs) stand out as a promising solution within the current array of Thermal Energy Storage (TES) technologies, thanks to their superior energy storage capacities (compared to sensible solutions) and technological readiness. Nonetheless, the limited thermal conductivity of these materials may lead to incomplete phase transitions during use, resulting in a decrease in their effective energy storage capabilities. The major solutions to mitigate this issue that are present in literature either require a significant modification in the heat exchanger design (e.g. by fins) or are costly and still lack robustness and reliability (e.g. by additivities). In this study, the use of copper wools is proposed as fillers within a PCM-based heat exchanger prototype, and the assessment of its impact on the heat transfer behaviour of the material is evaluated by performing charging and discharging processes. This type of inclusion was chosen as it is relatively cheap, it can be implemented within an already existing heat exchanger, and it does not suffer from segregation. Two different wools were tested in two configurations, thus resulting in five test cases (four containing the wools and one containing solely PCM). The promising results, especially the remarkable decrease in the time needed for the complete solidification of the PCM within the tank (up to 67%), open the opportunity to additional numerical analyses regarding different configurations and/or materials, thus possibly targeting further optimizations in terms of the specific energy density and the specific power density.

1. Introduction

Phase change materials (PCMs) have gained significant attention in various fields due to their ability to store and release large amounts of latent heat during phase transitions, finding applications in thermal energy storage, building thermal management, and electronic cooling [1–3].

However, their inherent low thermal conductivity poses a major challenge, affecting significantly important figures of merits in plants. In recent years, researchers have focused on finding solutions to enhance the thermal conductivity of PCMs, such as adding highly conductive nanofillers (carbon nanotubes, graphene nanoplatelets, etc.) within the PCM matrix, thus generating the so-called PCM nanocomposites [4]. Yet, challenges like segregation and interface resistances hinder the desired conductivity improvement and stability over time [5].

To address the limitations of PCM-based nanocomposites, the use of metallic wool as a low-cost, sustainable, and effective material to enhance heat transfer in PCMs is gaining attention [6,7]. Metallic wool, which is made of continuous metal fibers (with dimensions in the order of 10-100 μm), offers several advantages over traditional additives. From one side, the use of metallic wool represents an innovative approach for enhancing the thermal conductivity of PCMs, as the continuous fibers can provide a three-dimensional thermal conductivity pathway, facilitating efficient heat transfer throughout the PCM matrix. This continuous network has the potential to significantly enhance the effective thermal conductivity of the material composite, surpassing the limitations faced by previous nanocomposite approaches. Moreover, metallic wools are cheaper than carbon-based nanocomposites, and are also easier to implement compared to fins as they can be placed in already-built solutions. Nonetheless, in literature, only a few preliminary works have deepened such solutions in a lab-scale (or real-scale) application [6,7].

The proposed work aims to investigate the impact of copper wool on the thermal behavior of PCM in a lab-scale shell and tube tank prototype. The experimental setup involves two copper wool dimensions in two configurations within the tank, allowing for comparative analysis against the baseline, i.e. the solely PCM case. Therefore, the research aims to identify the optimal copper wool configuration among the tested ones for maximizing heat transfer efficiency.

2. Material and methods

The PCM chosen for the experiment is n-octadecane, (purchased from Alfa Aesar, Germany), which is widely used due to its desirable phase change properties. Copper metal wool (thicknesses: fine - 60 μm and thick - 120 μm; single fibre thermal conductivity: 383 W/(m K); single fibre density: 8.9 g/cm^3) purchased from STAX, Germany, was used as fillers. The material composite within the TES tank is designed in two different configurations of two copper wool-PCM composites (fine and thick), allowing for comparative analysis against the baseline, which consists solely of PCM. The two configurations are shown in Figure 1.

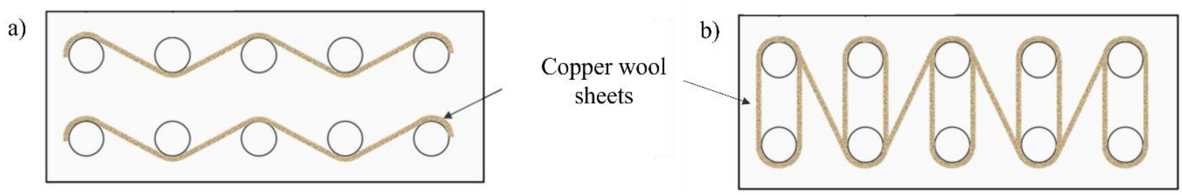

Figure 1. The two configurations of the copper wool. Configuration A with lower amount of wool a) and configuration B with higher amount of wool b).

The experimental setup available at the GREiA laboratories, which is shown in Figure 2, includes two fluid pumps, for circulating the heat transfer fluid (HTF), a chiller, that is employed to cool down the HTF, an inertia tank with inbuilt two resistances, for heating the HTF during charging, the shell and tube tank under study containing the PCM and the metallic wool, temperature sensors (PT100) strategically placed within the PCM and at the inlet and outlet sections of the HTF, and the data acquisition system. The charging and discharging cycles were performed three times for each configuration, thus carrying out an uncertainty analysis of the temperature measurements.

3. Results

Figure 3 shows a representative overview (in the baseline case, i.e. solely PCM) of the experimental measurements performed as: in subfigure a) a schematic of the shell and tube tank and the positions of the sensors within the PCM are displayed, in b) and c) the experimental temperature measurements both within the PCM and at the inlet and outlet sections of the tank during the charging and discharging processes are shown.

The figure of merit adopted for the comparison between the five cases tested is the time needed for the PCM temperature to reach 20°C during the discharging process and 40°C during the charging one. The results obtained by the comparison are reported in Figure 4. Here, it can be seen that, while during the charging process, a slight increase in the time needed to reach the target temperature was necessary when adding the wool (from 34 up to 48 minutes), a remarkable enhancement in the discharging times was evident, reaching a maximum time decrease of 67% in the configuration B with fine fibres.

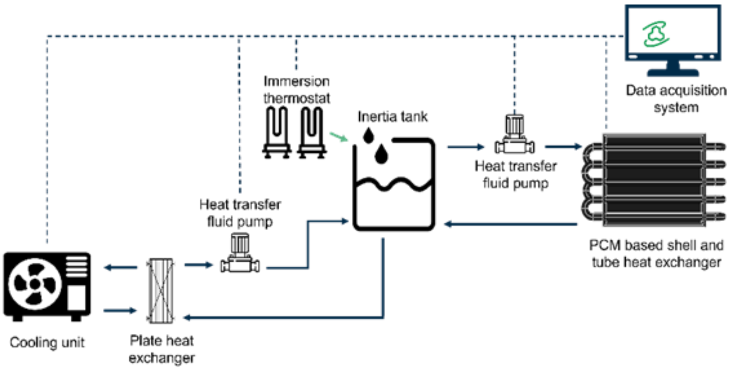

Figure 2. Schematics of the experimental layout for the charging and discharging processes of the heat exchanger containing the PCM composite.

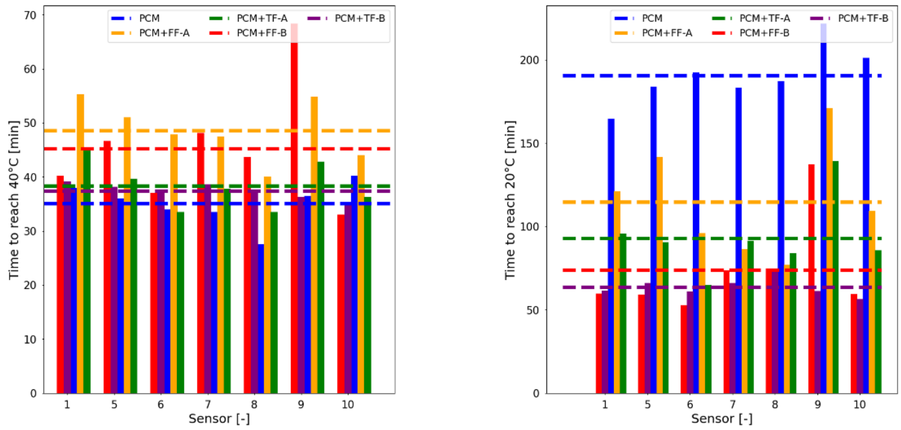

Figure 3. Comparison between charging (left) and discharging (right) times needed to reach the target temperatures in the five cases tested (4 cases with the wool and the baseline case containing solely PCM).

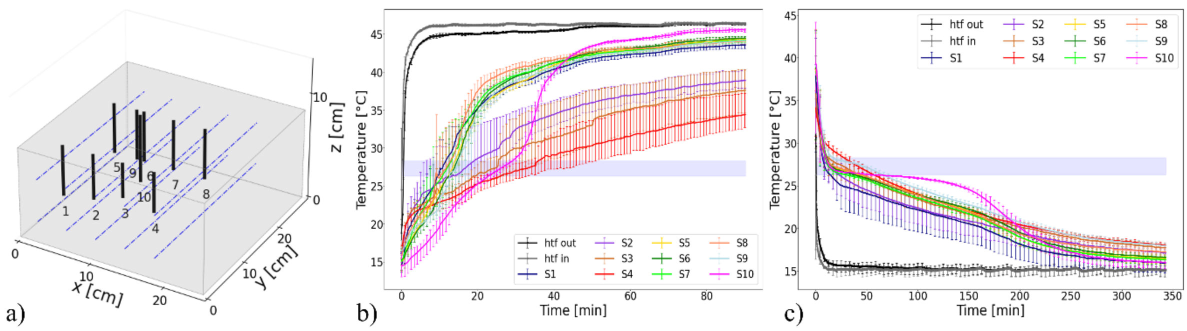

Figure 4. Overview of the experiments carried out for the baseline case. In a) the schematics of the temperature sensors, the position of the tubes and the inlet and outlet sections are reported (continuous vertical lines, dashed horizontal lines and arrows, respectively). The temperatures measured by each sensor (both within the PCM and the HTF) are displayed for b) charging and c) discharging processes.

4. Conclusions

In this study, copper wools with two different diameters (fine and thick) were added in two different configurations to a PCM-based shell and tube tank to assess the impact of those wools as heat transfer enhancers. Thanks to the experimental setup available at the GREiA laboratories, both the charging and discharging processes were tested in the five cases. The experiments have indicated a slightly poorer heat transfer during the charging process, which can be attributed to the decrease in the natural convection due to the copper wool presence. Nonetheless, a remarkable enhancement in heat conduction is evident during the discharging process in which the presence of the wool leads to a decrease in the discharging time by up to 67%. These promising results paves the way to future numerical analyses on different configurations and/or materials, in order to obtain an optimized compromise between the decrease in the specific energy density, and the increase in the specific power density.

Acknowledgments

This work was partially funded by the Ministerio de Ciencia e Innovación - Agencia Estatal de Investigación (AEI) (PID2021-123511OB-C31 - MCIN/AEI/10.13039/501100011033/FEDER, UE and RED2022-134219-T). This work is partially supported by ICREA under the ICREA Academia programme. The authors would like to thank the Departament de Recercai Universitats of the Catalan Government for the quality accreditation given to their research group (2021 SGR 01615). GREiA is certified agent TECNIO in the category of technology developers from the Government of Catalonia. Partial support of the Italian National Project PRIN Heat transfer and Thermal Energy Storage Enhancement by Foams and Nanoparticles (2017F7KZWS) is also acknowledged.

References

[1] Zalba B, Marín J M, Cabeza L F and Mehling H 2003 Review on thermal energy storage with phase change: Materials, heat transfer analysis and applications *Appl Therm Eng* **23**
[2] Oró E, de Gracia A, Castell A, Farid M M and Cabeza L F 2012 Review on phase change materials (PCMs) for cold thermal energy storage applications *Appl Energy* **99**
[3] Cabeza L F, Castell A, Barreneche C, De Gracia A and Fernández A I 2011 Materials used as PCM in thermal energy storage in buildings: A review *Renewable and Sustainable Energy Reviews* **15**
[4] Ribezzo A, Falciani G, Bergamasco L, Fasano M and Chiavazzo E 2022 An overview on the use of additives and preparation procedure in phase change materials for thermal energy storage with a focus on long term applications *J Energy Storage* **53**
[5] Ribezzo A, Bergamasco L, Morciano M, Fasano M, Mongibello L and Chiavazzo E 2023 Experimental analysis of carbon-based Phase Change Materials composites for a fast numerical design of cold energy storage systems *Appl Therm Eng* **231**
[6] Gasia J, Maldonado J M, Galati F, De Simone M and Cabeza L F 2019 Experimental evaluation of the use of fins and metal wool as heat transfer enhancement techniques in a latent heat thermal energy storage system *Energy Convers Manag* **184** 530–8
[7] Prieto C, Rubio C and Cabeza L F 2021 New phase change material storage concept including metal wool as heat transfer enhancement method for solar heat use in industry *J Energy Storage* **33**