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ABSTRACT:

Thermal Performance of a New Latent Thermal Energy Storage Based on Macro-Encapsulated Phase Change Material Modules during the Discharging Process

G.A. D'Errico1, M. Dongellini1, C. Naldi1, C. Biserni1, G.L. Morini1
1Department of Industrial Engineering, Alma Mater Studiorum – University of Bologna, Bologna, Italy.

The transition from fossil fuels to renewable energy sources has gained increasing global attention in response to the challenges posed by climate change and resource depletion. Thermal Energy Storage (TES) systems are a key technology in enabling the large-scale integration of renewable sources by decoupling energy production from consumption, thus enhancing both flexibility and overall efficiency. Within this framework, Latent Thermal Energy Storage (LTES) systems represent a suitable and promising technology. LTESs employ Phase Change Materials (PCMs) as heat-storing medium. Thanks to the solid-liquid transition (and vice-versa) undertaken by these materials, LTES can store both sensible and latent heat, enabling a higher volumetric storing density compared to traditional sensible TESs [1-2].

The aim of this work is to analyze, through experimental tests, the thermal performance of a LTES prototype consisting of a storage tank containing macro-encapsulated PCM modules immersed in water. Specifically, the prototype comprises a tank divided into four independent modules, allowing flexible adjustment of the volumetric capacity up to 130 liters. The selected PCMs are hydrated salts with different melting temperature ranges embedded within an innovative polypropylene macroencapsulation system, manufactured by the German company kraftBoxx GmbH [3].

Different experimental tests were carried out on the prototype by varying the Heat Transfer Fluid (HTF) operating conditions (i.e., mass flow rate and inlet temperature to the TES). The LTES prototype was tested during the discharging phase to investigate its thermal performance, and the results were compared with those of an equivalent sensible TES, based on water only and tested under the same operating conditions.

The TES thermal performance during the discharging process was evaluated using two indicators: thermal energy released during the process and average heat transfer rate between the heat-storing material and the HTF. The experimental results point out that, in all the tested cases, the ability of the PCM to store both sensible and latent heat strongly influences the system thermal performance: the total energy released during the discharging phase increases by up to 90% from the sensible to the latent configuration. However, the duration of the discharging process increases by up to 100% as a

result of the lower thermal conductivity of the PCM, which consequently leads to a decrease of up to 30% in the average heat transfer rate. Despite the reduction in the average heat transfer rate, the possibility of doubling the heat-storing capacity underscores the potential of a new generation of LTES systems able to enhance the efficiency of thermal energy storage, thereby facilitating their integration with renewable energy sources.

[1] T. Xu, E. N. Humire, S. Trevisani, M. Ignatowicz, S. Sawalha, J. N. Chiu, Experimental and numerical investigation of a latent heat thermal energy storage unit with ellipsoidal macro-encapsulation, Energy, 238, 121828 (2022).

[2] A. Heinz, C. Moser, Numerical modelling and experimental testing of a thermal storage system with non-spherical macro-encapsulated phase change material modules, J. Energy Storage, 58, 106427 (2023).

[3] https://heatstixx.de/en/products-heatstixx/