

Experimental Study on the Temperature Gradient in Latent Heat Thermal Energy Storage

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Extended Abstract

The increasing demand for energy, coupled with growing risk of climate change, highlights the urgent need for a transition toward sustainable energy. Approximately 80% of total primary energy consumption is still derived from fossil fuels [1], emphasizing the importance of integrating renewable energy. Nevertheless, the intermittence of renewable energy sources presents challenges in maintaining the stability and reliability of energy supply. To address these challenges, the deployment of thermal energy storage (TES) systems is essential for buffering supply fluctuations and ensuring consistent energy availability. Among the various TES technologies, phase change material (PCM) TES is receiving attention owing to its ability to store and release large amounts of thermal energy within a relatively narrow temperature range. However, low thermal conductivity of PCM limits the heat transfer rate and increases charging and discharging time.

To enhance the thermal conductivity of PCM, many methods, such as advanced heat exchanger [2], nanoparticles [3], and metal foam [4], have been investigated. Moreover, various studies have been conducted on the full-scale PCM TES to experimentally verify the temperature profile of PCM. Palkalka et al. [5] experimentally confirmed dead volume regions in PCM TES owing to the unpredictable temperature gradient. Dogkas et al. [6] experimentally investigated PCM TES and reported that small areas of PCM remained unmelted during the discharging process. Mahdi et al. [7] performed charging and discharging experiments for latent heat helical coil thermal energy storage. Despite these findings, experimental studies quantitatively analyzing the internal thermal behavior of PCM TES are still limited.

In this study, charging and discharging experiments were conducted for the PCM TES to quantify the temperature gradient. A 30 L scale fin-tube heat exchanger-based PCM TES system was constructed, and the experiments were conducted under varying inlet temperatures and flow rates. Several thermocouples were used in PCM TES along vertical and horizontal directions to capture detailed temperature profiles across the storage. Experimental results showed that maximum temperature differences in PCM TES were 12.6 and 15.8 °C for the charging and discharging processes, respectively. These temperature gradients resulted in spatially non-uniform phase change of PCM, such as partial melting or solidification in certain regions. During the discharging process, a sudden temperature drop followed by a slight temperature increase was observed because of subcooling of PCM, and this behavior varied depending on location. Although the magnitude of the temperature gradient increased with an increase in flow rate, a specific transient trend was maintained. The local minimum values of the temperature difference changed to 5.5, 4.1, and 3.7 °C, as the flow rate varied from 10 to 8 and 6 L min⁻¹, respectively.

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References

- [1] T. Ahmad and D. Zhang, "A critical review of comparative global historical energy consumption and future demand: The story told so far," *Energy Reports*, vol. 6, pp. 1973-1991, 2020.
- [2] B. K. Choure, T. Alam, R. Kumar, "Optimization of heat transfer in PCM based triple tube heat exchanger using multitudinous fins and eccentric tube," *J. Energy Storage*, vol. 102, 113981, 2024.
- [3] P. Rolka, T. Przybylinski, R. Kwidzinski, M. Lackowski, "Investigation of low-temperature phase change material (PCM) with nano-additives improving thermal conductivity for better thermal response of thermal energy storage," *Sus. Energ. Tech. Assess.*, vol. 66, 103821, 2024.
- [4] X. Xu, L. Chen, M. Song, H. Li, W. Liu, H. Yao, Y. Huang, "Simulation on heat transfer and thermal storage processes of gradient foamed metal-PCM microstructure composite," *J. Energy Storage*, vol. 116, 115939, 2025.
- [5] S. Pakalka, J. Doneliene, M. Rudzikas, K. Valancius, G. Streckiene, "Development and experimental investigation of full-scale phase change material thermal energy storage prototype for domestic hot water applications," *J. Energy Storage*, vol. 80, 110283, 2024.
- [6] G. Dogkas, J. Konstantaras, M. K. Koukou, M. G. Vrachopoulos, C. Pagkalos, V. N. Stathopoulos, P. K. Pandis, K. Lymperis, L. Coelho, A. Rebola, "Development and experimental testing of a compact thermal energy storage tank using paraffin targeting domestic hot water production needs," *Ther. Sci. Eng. Prog.*, vol. 19, 100573, 2020.
- [7] M.S. Mahdi, H. B. Mahood, A. A. Khadom, A. N. Campbell, M. Hasan, A. O. Sharif, "Experimental investigation of the thermal performance of a helical coil latent heat thermal energy storage for solar energy applications," *Ther. Sci. Eng. Prog.*, vol. 10, pp. 287-298, 2019.