EXPERIMENTAL AND NUMERICAL STUDY OF A SHELL-AND-MULTITUBE LATENT THERMAL ENERGY STORAGE WITH A PERFORATED PLATE FOR SOLAR THERMAL APPLICATIONS

Summary

In this study, a perforated-plate-assisted shell-and-multitube latent heat thermal energy storage (LTES) prototype was designed and experimentally tested in a domestic hot water (DHW) system. The main objective was to mitigate the shell-side flow maldistribution and short-circuiting reported in previous studies, thereby reducing non-uniform heating among PCM tubes. A 3D CFD model was developed and validated against the experimental data to clarify the internal heat transfer and flow distribution mechanisms. Results show that the perforated plate improves water distribution across the tube bundle, and enhances melting and solidification uniformity among PCM tubes. Furthermore, the LTES prototype has competitive heat exchange performance in domestic hot water applications compared with previously reported designs. The main performance limitations were also identified.

Keywords: Latent heat storage, perforated plate, experiment, numerical simulation, thermal performance

Field of application for the findings: Solar thermal applications

Addressed audience: Researchers, thermal system designers, LTES developers, solar heating engineers

1. Introduction

With increasing global challenges in energy, environment, and climate, expanding the use of clean alternative energy sources has become essential. Solar thermal systems can provide clean heat and support decarbonization. However, the intermittent of solar energy makes reliable hot water delivery difficult. Latent thermal energy storage (LTES) can store surplus solar heat in phase change materials (PCM) during sunny periods and release it during off-sun hours. Recent studies have shown that solar-LTES coupling can improve heating efficiency and better satisfy domestic hot water (DHW) demand (Chopra et al., 2022).

Due to its advantages in solar thermal applications, latent heat thermal energy storage (LTES) has attracted increasing attention at the component level, as insufficient charging and discharging rates can reduce heat supply stability. Previous studies have examined the heat transfer performance of PCM in different heat exchanger designs. For example, Wang et al. (2021) developed a multi-tube LTES with shell-side HTF and PCM-filled tubes, and experimentally achieved higher heat transfer capacity rates during both charging and discharging than earlier reported LTES prototype. However, using a validated CFD model, Wang et al. (2022) found that significant fluid short circuit occurred on the shell side during charging in this construction, leading to uneven melting among PCM tubes and likely lowering the effective storage capacity and heat storage/delivery efficiency in DHW system.

To overcome this limitation, a new shell-side-HTF, multi-tube PCM LTES prototype was developed with an inserted perforated plate to improve flow distribution and tube utilization. The LTES prototype was experimentally evaluated under operating conditions representative of a coupled solar domestic hot water system. Then, a validated 3D CFD model was employed to clarify its internal thermodynamic behavior and the impact of the perforated plate.

2. Experimental setup

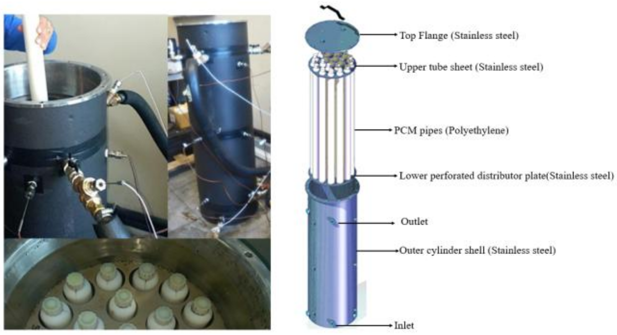


Fig. 1: LTES prototype in the experiment

Fig.1 illustrates the LTES prototype employed in the experiments. The storage tank is a vertical cylinder with a height of 1.16 m and an outer diameter of 0.345 m. Twenty PCM tubes are vertically installed inside the tank, each measuring 0.94 m in length and 0.045 m in inner diameter.

3. CFD model

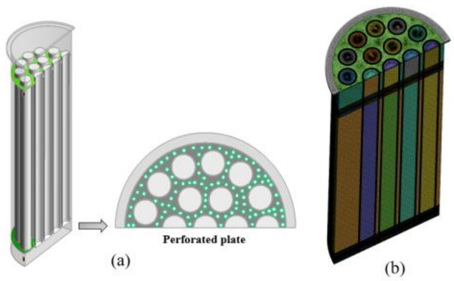
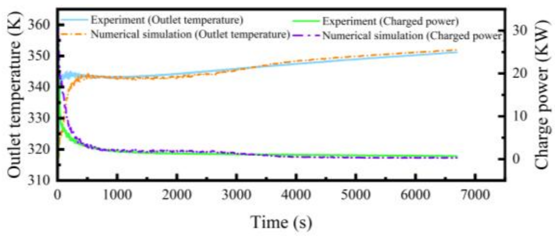


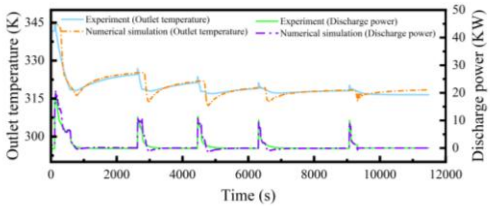
Fig. 2: LTES prototype (a) Physical model (b) Mesh model

Exploiting the symmetry of the LTES Tank, a half model was constructed (Fig. 2 (a)). All dimensions match the experimental setup. The geometry was then discretized into hexahedral cells, as shown in Fig. 2 (b). The fully structured hexahedral mesh has a total of 3,528,883 cells with a maximum skewness of 0.69.

4. Results and discussion



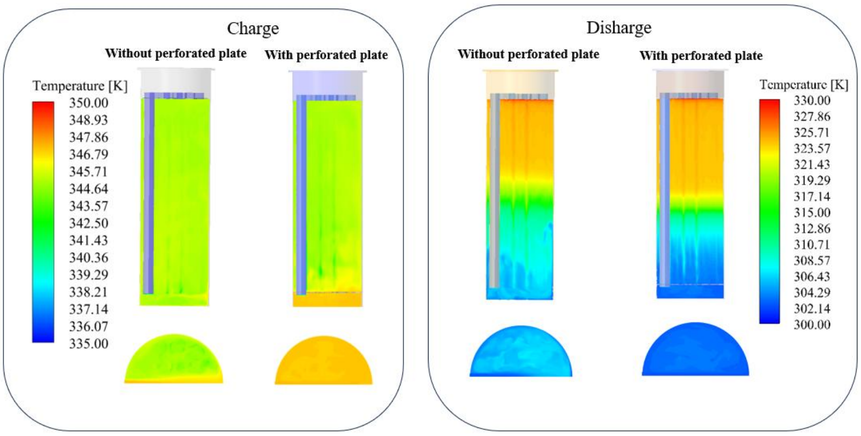
(a)



(b)

Fig. 3: Comparison results between experiment and numerical simulation (a) charge (b) discharge

Fig.3 (a) and (b) compare the outlet temperature and charge/discharge power during charging and discharging, respectively. The results reflect the dynamic charge and discharge behavior of the LTES prototype that can be accurately characterized by the CFD model.



(a) (b)

Fig. 4: The impact of perforate plate on water temperature distribution

(a) Charge process (b) Discharge process

As shown in Fig. 4, perforated plate markedly improved shell-side flow distribution and promoted a more even distribution of the inlet hot and cold water.

5. References

Chopra, K., Tyagi, V.V., Pandey, A. K., Popli, S., Singh, G., Sharma, R. K., Sari, A. 2022. Effect of simultaneous & consecutive melting/solidification of phase change material on domestic solar water heating system. *Renewable Energy*, *188*, 329-348.

Wang, G., Dannemand, M., Xu, C., Englmair, G., Furbo, S., Fan, J. 2021. Thermal characteristics of a long-term heat storage unit with sodium acetate trihydrate. *Applied Thermal Engineering*, *187*, 116563.

Wang, G., Xu, C., Englmair, G., Kong, W., Fan, J., Furbo, S., Wei, G. 2022. Experimental and numerical study of a latent heat storage using sodium acetate trihydrate for short and long term applications. *Journal of Energy Storage*, *47*, 103588.