ABSTRACT

Modular heat storage cells containing a supercooling salt hydrate phase-change heat storage material were developed for implementation into a portable electric thermal storage (ETS) indoor heating system. ETS systems can generate indoor heating cost-savings for customers using low-cost off-peak electricity for charging from time-of-day electricity rate pricing. The supercooling ability of the phase-change material (PCM) was used in this research to retain heat storage for extended periods of time at room temperature without heat loss (≥40% of heat stored at 110°C), and released on-demand using nucleation triggers built into each heat storage cell. An ETS system was developed to facilitate heat exchange with the heat storage cells for either charge or discharge using a circulated heat transfer fluid (HTF), exchanging heat also with a liquid-to-air heat exchanger to generate useful room heating.

An equimolar mixture of sodium acetate trihydrate and water (SAT PCM) was used in the heat storage cells to store thermal energy with combined sensible and latent heats resulting in charge capacities up to 475 kJ/kg between 20°C and 110°C. Heat discharge capacities up to 449 kJ/kg can be achieved with minor or no supercooling of the SAT PCM and continuous useful heat release from the SAT PCM ≥28°C. Triggering heat release only after idle supercooling between 20°C and 28°C would result in a discharge heat capacity of 425 kJ/kg.

Heat storage cells underwent three design iterations, incrementally improving on leak-tightness, heat transfer performance, supercooling reliability, and nucleation-triggering strategies. This culminated in the Mark III modular, rectangular heat storage cell design developed in this research, containing 2.4 kg (0.3 kWh capacity at 110°C) and equipped with pairs of plate heat exchangers. Stable supercooling was observed for 167 days before autonucleation, while repeated cycling (including supercooling and solidification) for a total of 131 cycles without noticeable degradation was observed. Although the $U$ values obtained exceeded PCM literature benchmark (0.03 kW m² K⁻¹), the heat exchange capacity rate, $UA$, is four times lower than required to deliver an average heat transfer rate of 600 W to a liquid-to-air heat exchanger.