Summary of the Effect of Different Fin Configurations on Phase Change Materials in LHTES Systems

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Case Report

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ABSTRACT

Phase Change Materials (PCMs) in Latent Heat Thermal Energy Storage systems (LHTES) are highly valued for their efficient storage of dense thermal energy. The configuration of fins plays a pivotal role in LHTES, influencing the melting process within PCMs. A comprehensive review of LHTES systems focusing on diverse fin configurations and their effects on PCM melting are provided. It categorizes existing research and explores how these configurations optimize PCM performance. Furthermore, the study assesses how variations in fin design can potentially shape the future of PCM technology, emphasizing enhancements in heat transfer rates and melting efficiency.

Keywords: PCM; LHTES; Fins; Thermal storage characteristics; Optimum angle

INTRODUCTION

Compared to traditional energy sources, the widespread adoption of solar energy and other renewables represents a crucial stride towards achieving "carbon peak" and "carbon neutrality." Effectively harnessing solar energy has thus emerged as a pivotal challenge for the advancement of human society [1]. The temporal disparity between supply and demand has prompted the development of various thermal storage technologies. These thermal storage systems enable the capture of excess heat during surplus periods for subsequent release during times of demand [2].

The impact of PCMs applied to different fin shapes—such as bifurcated, fan-shaped, stepped, snowflake-shaped, and annular—in LHTES are investigated. The study categorizes and consolidates the various fin shapes that yield notable optimization outcomes. Table 1 presents a summary of recent research on modified fin structures, serving as a valuable reference for future studies in this area.

Table 1. Studies related to the addition of fins.

Reference	Means	Fin type	Major results and conclusion
Triki et al. [3]	Simulation	H-fin	Effect of the H-fins number patterns, arrangement type, and stretched H-fins on the melting behavior was investigated
Khedher et al. [4]	Simulation	Curved fin	The optimum curvature angle, base length and angle between two fins of the curved fin are studied. Compared with the traditional longitudinal fin, the curved fins can double the heat storage rate
Boujelbene et al. [5]	Simulation	Arched fin	The arch fin is compared with+fin and X fin to improve the heat storage performance of the system
Li et al. [6]	Simulation	Twisted fin	Triple fin and double fin outperformed other cases in vertical and horizontal cases.
Ci et al. [7]	Simulation	V-fin	The working conditions of 19 different V-shaped fins were designed, and the effects of angle, length, number and arrangement of fins on the heat transfer performance of the heat storage unit were studied
Lee et al. [8]	Simulation Experiment	layering	The use of layered fin design in CTES system can greatly improve the performance of ice melting. The complete melting time of the improved and optimized design is 44.3% shorter than that of the original design
Fiti et al. [9]	Simulation	Longitudinal fin	Horizontal shell and tube PCM-regenerator with longitudinal unevenly distributed fins and eccentricity was investigated
Rozenfeld et al. [10]	Simulation Experiment	Spiral fin	The proposed model has many advantages, including improved melting, avoidance of pressure increases during melting and solidification, and ease of filling, unloading, and maintenance of the system

CASE PRESENTATION

Effect of different configurations of fins on PCM

The melting behavior of PCM within a vertically finned LHTES unit consisting of shell and tube is summarized. Increasing the heat transfer area is indeed a primary method for enhancing the melting rate of PCM within LHTES. By enlarging the surface area available for heat exchange, more heat can be transferred to or from the PCM, facilitating faster phase change.

ME, et al. [11] investigated the melting performance of a new stepped fin (Figure 1: Case A) for improving the thermal energy storage of PCM using this fin. The study demonstrated that stepped fins outperformed longitudinal straight fins in terms of melting performance within the LHTES. Specifically, downward stepped fins exhibited the highest effectiveness, achieving a 65.5% reduction in melting time when the step ratio (b/c) was optimized to 4. This improvement was determined through comparative analysis across different operational conditions.

Fan, et al. [12] explored the thermal performance of an optimized snowflake longitudinal fin (Figure 1: Case B) in vertical latent heat storage using numerical simulation. Their findings indicated that the melting time of the snowflake fin was 45.59% shorter compared to that of the conventional longitudinal rectangular fin. Furthermore, the study highlighted that factors such as the dimensions (length and width) of the fins, the specific shape of the snowflake, and the angle of its internal structure significantly impact the thermal performance of the energy storage system.

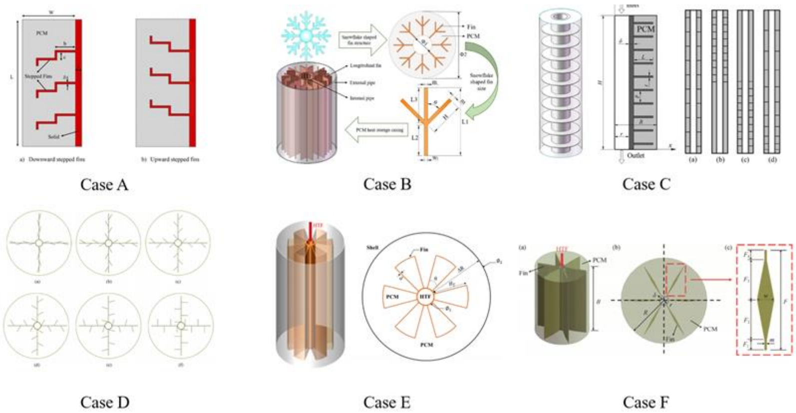
Liang, et al. [13] conducted numerical simulations to evaluate the thermal efficiency of various fin arrangements in a LHTES. These arrangements included bottom fins, top fins, and arithmetic fins (Figure 1: Case C). The arithmetic fins exhibited the most significant improvement, achieving a 49.9% reduction in melting time compared to no fins. Following this, middle fins showed a 46.9% optimization, bottom fins demonstrated a 38.9% improvement, and top fins exhibited a 13.9% reduction in melting time.

Mao, et al. [14] examined the impact of incorporating fins featuring dendrite-like bifurcated structures (Figure 1: Case D) within a thermal storage tank on the thermal storage properties of PCM using numerical simulations. Setting the bifurcation angle at 60° results in the maximizes the average heat storage rate. Specifically, the split fin configuration optimizes melting time by 65.1% and 33.3%, respectively, while boosting the average heat storage rate by 174.1% and 48.8% compared to non-finned and traditional longitudinal fin designs.

Mao, et al. [15] used a new fan fin configuration (Figure 1: Case E) and investigated the effect of fin height, fin angle, and number of fins on the parameters such as heat storage rate by numerical simulation. The results show that the fan-shaped fins can increase the heat transfer area and optimize the melting time by 66.4% compared with the finless configuration, and it is concluded that the fin angle is not the bigger the better.

Mao, et al. [16] conducted a study using a new pointer fin structure (Figure 1: Case F) to analyze its impact on the melting characteristics of PCM in LHTES through numerical simulations. Their findings revealed significant reductions in the melting time of the phase change material within the pointer fin heat storage tank: By 64.2% compared to no fins, and by 15.1% compared to traditional longitudinal fins. Additionally, the study concluded that placing the fin tip closer to the heat wall improves heat transfer effectiveness.

Figure 1. Different structure of fins. Case A: Stepped fins, Case B: Snowflake fins, Case C: Ring fins (d: arithmetic fins), Case D: Split fins, Case E: Fan fins, Case F: Pointer fins.



DISCUSSION

As an important configuration in the LHTES system, the fins play a key role in storing heat. Summarizing all the configurations, the following important findings can be learned:

- Studies examining the impact of fins on PCM within LHTES systems are uniformly focused on advancing sustainable energy development and optimizing energy efficiency.
- The modification of fin structures is guided by deliberate design principles. These changes aim to augment the heat exchange surface area between the fins and the PCM, thereby accelerating heat transfer rates and PCM liquefaction. Ultimately, this enhances the overall heat storage performance of LHTES systems.
- The heat storage characteristics, including heat storage capacity, average heat storage rate, and PCM melting time, were influenced by the optimization of fin structures. Among the various configurations studied, the snowflake fin was identified as optimal for enhancing heat transfer area, despite variations in heat storage tank sizes and inconsistent parameters across studies.
- Exploring the theoretical properties of arithmetic fins, characterized by an exponential increase in fin spacing, may provide valuable insights for comparing with other structural designs.

CONCLUSION

In vertical LHTES, the arrangement of fins plays a crucial role in enhancing heat storage efficiency and optimizing PCM melting processes. Researchers are actively exploring diverse fin configurations to boost overall heat storage capacity. Summarizing the effects of various fin designs lays the groundwork for refining configurations to maximize heat storage potential. Previous studies have yielded promising results, highlighting a bright future for the field and emphasizing the need for continued research to build on these achievements.

Future investigations should address potential limitations, such as the impact of fins on natural convection post-PCM liquefaction, to further optimize LHTES systems. Exploring intricate fin designs that enhance natural convection while minimizing structural changes is also recommended. Most studies to date have relied on numerical simulations, underscoring the importance of expanding research into experimental domains to validate findings and enhance practical applicability. Additionally, exploring advanced fin materials with high thermal conductivity could significantly enhance fin performance and durability in LHTES systems. Advancing research in LHTES systems holds promise for more effectively managing energy demand and promoting sustainable energy utilization.

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