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A Review on Effect of Geometric Parameter of Shell and Tube on PCM In Latent Thermal Energy Storage

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Abstract

Thermal energy storage is crucial for balancing energy demand and supply, maintaining system stability, and enhancing the utilization of intermittent renewable energy sources. Phase Change Material (PCM)-based thermal energy storage has significant potential to meet large-scale energy demands while providing economic and environmental benefits. This paper reviews research focused on improving heat transfer between PCM and hot fluid in shell and tube Latent Heat Thermal Energy Storage (LHTES) units. It concludes that in LTES systems with multiple Heat Transfer Fluid (HTF) tubes, heat transfer can be enhanced by orienting the tubes in an upward and downward V shape. Additionally, incorporating various fin shapes increases the PCM melting rate. Splitting a single inner tube into multiple tubes also improves heat transfer efficiency.

Keywords; Latent thermal energy storage, Phase change material, Heat transfer fluid, Fins, shell and tube.

INTRODUCTION

The production of energy serves as the primary catalyst for worldwide advancements in many sectors of society, such as the economy and scientific endeavors. Nevertheless, the combination of an economic crisis, volatile oil and gas prices, geopolitical challenges, and an increasing environmental awareness has led to a significant adoption and advancement of renewable energy sources[1]. These sources are clean, globally accessible, and limitless. Furthermore, energy efficiency has emerged as a crucial objective due to its role in achieving energy savings and implementing high-efficiency systems, which are essential for advancing towards a more sustainable and environmentally friendly society. Global energy policy are influenced by this circumstance, both in Western and Eastern nations [2]–[4].

When it comes to the use of energy, the building industry ranks high in industrialised nations. Take the European Union as an example: the construction industry is responsible for about 40% of the region's CO2 emissions and nearly 40% of its final energy consumption. Most of it may be traced back to rising heating and cooling needs as a result of higher average incomes[5]. It is becoming more and more necessary for non-sustainable buildings to rely on active systems to maintain acceptable levels of internal temperature. In addition, this causes a rise in both energy consumption and the emissions of greenhouse gases. Thus, the cost of running a structure has increased[6]. Energy efficiency and building sustainability may be greatly advanced by measures such as decreasing cooling load and enhancing energy conservation. More importantly for cutting down on buildings' energy use, however, is the mandated usage of renewable energy sources.[7]

Thermal energy storage

An effective TES is necessary since the production of electricity results in a significant quantity of waste heat that may be used for subsequent cooling, heating, and other purposes. Similar to how heat is recovered in CHP plants, this waste heat may be used to generate more electricity. The term "cogeneration" may also be used to describe this method. Exhaust gases from turbines or engines that use fuel to generate heat are routed via heat recovery devices to be reused as useful energy. With this heat, structures may be heated or cooled as needed [8].

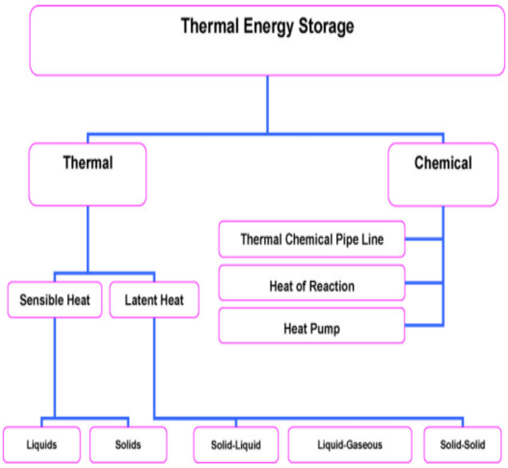

Figure 1 Thermal energy storage techniques [9]

There are two varieties of Thermal Energy Storage (TES) sinks: direct contact and indirect contact.[10]

Direct Contact

The direct contact container in thermal energy storage is composed of TES, a material that is directly amalgamated with HTF (Heat Transfer Fluid; PCM).is an indirect contact. So, during this methodology the chosen PCM is not ready to soluble in HTF and for separating from one another it's necessary to possess an oversized density distinction among PCM together with the HTF. During this methodology HTF is pumped up inside the vessel which heats the PCM as well as cause tendering, the result's a good performance of heat transfer as a result of an instantaneous contact. Once this dynamic charging method, because of the density distinction HTF upsurges and will be existent from the container.

Indirect Contact

Another quite Thermal Energy storage container that using the indirect contact technique, during this method HTF passes by means of heat exchanger that occurred in the container, the performance of “heat transfer” is be determined by the “thermal conductivity” of PCM together with the contact surface area among the PCM as well as HTF.

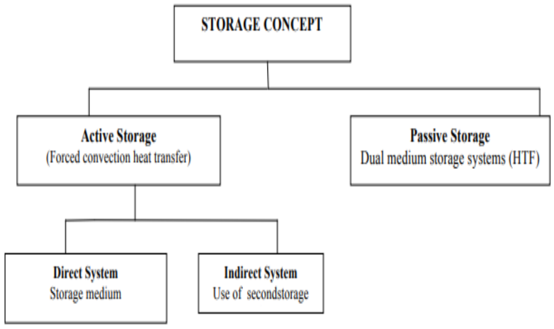

Figure 2 Different storage systems [11]

PCM Material

There are several uses for PCMs, including thermal energy transfer and storage. The phase transition in PCM materials occurs at room temperature, allowing them to store vast amounts of heat energy. It does this by undergoing a phase change when exposed to temperatures above or below its melting point [8]. Therefore, the PCM material may undergo a phase transition and either absorb or release heat when its temperature approaches a constant. Phase transition materials with a “thermal conductivity” below 0.5 W/(mK) may influence the enhanced transfer of heat in a "heat exchanger system". At low temperatures, controlling the "thermal conductivity" of phase transition materials necessitates new methods. [12].

PCMs are used in situations where the temperature changes rapidly (-20ºC to +200^{0}C). The PCMs are often used in four distinct temperature bands. Phase transition materials work well in home and refrigeration environments with temperatures between -20 ° C and +5 ° C. It is common practice to use these PCMs for heating and cooling commercial buildings within the temperature range of 5 to 40 degrees Celsius. “Temperatures between (+40° C) and (+80° C) are optimal for solar-based heating and electronic application and cooling, while temperatures between (+80° C) and (+200° C) or more are optimal for absorption cooling power production and waste heat recovery”[7].

Transfer of heat during phase transition

The variations in temperature that may exist within the PCM capsules are not accounted for by the packed bed models. As a result of their low thermal diffusivities (high Prandtl numbers), the majority of PCMs used in commercial "latent heat thermal energy storage systems" may as well not have calculated heat exchange rates between the PCM and "heat transfer fluid". As a result, predicting how these systems would behave thermally is rather difficult. To overcome this restriction, the issue of heat transport inside the PCM capsule must be resolved. During a solid-liquid phase transition (melting or solidification), the medium undergoes a phase transformation and the active zone either absorbs or releases thermal energy. The heat exchanger's surface comes into touch with the liquid during dissolution, enabling convection. The liquid condenses on the "heat transfer" surfaces when energy is released from storage, forming a continuous layer of stationary solid material that releases heat via fusion. Heat transfer is impeded as this solid layer develops, resulting in an increase in energy release times, as it typically has limited thermal conductivity. Energy is more easily supplied for melting than extracted for solidification because convection transfers heat more efficiently than conduction. Since the surface heat flow might change depending on the relative importance of the two types of resistance, the surface heat flux can be either variable or constant. Surface heat flow will eventually decrease when conductive resistance predominates, but when the convective resistance is dominant, the LHTS system may attain a virtually uniform surface heat flux over time. Various materials, including "rings", "high conductivity particles", "metal fibers", "metal honeycombs", "metal matrices (wire mesh)", "fins", and "graphite", may be employed to improve the internal heat transmission in PCM storages. Additionally, the system design is further complicated by the volume change that occurs during phase change.

LITERATURE REVIEW

(Liu et al., 2023)[13] examined the impact of different structures of fins. The findings show that applying the four fins that are straight with gradient form may significantly cut the melting time by 16.9%. Rebuilding the gradient fin location also results in an additional 41.1% reduction in melting time. The melting rate will decrease and the melting duration will increase by more than 4.66 times when the deformation occurs in the opposite direction.

(Shafiq et al., 2021) [14] In order to replicate the basic case, six horizontal fins are inserted, three across each of the preheated walls. Configuration-A, which includes three different fin angle combinations, significantly lengthens the PCM melting time by sixteen percent and decreases the average energy storage rate by fourteen percent. On the other hand, the thermal performance of TESU is significantly enhanced by the addition of straight and angled type hybrid fins in configuration-S, as evidenced by an 18% increase in the melting rate and a 19.8% increase in the average energy storage rate. The most effective configuration is the L configuration, which consists of linear fins of varying lengths and thicknesses. The TESU's melting ability is enhanced by 39.5% and its mean energy storage rate by 65.07% in the ideal configuration-L.

(Mahdavi et al., 2021) [15] consider shell that contains PCM contains four "heat transfer fluid (HTF)" channels. The findings showed that depending on where the hot and cold tubes are positioned, the steady-state liquid percentage may vary from 37% to 60%. Placing the heated tubes in the lowest section of the chamber allows for the highest percentage of liquid to be reached. Under SCD, fins provide a different result than in melting circumstances, when fins were more practical according to the liquid fraction criteria. To shorten the reaction time, Cu nanoparticles have been added to the PCM; nevertheless, given SCD circumstances, their impact is minimal. When the PCM is in the SCD state, it is thus not recommended to use nanoparticles.

(Wołoszyn et al., 2021) [16] introduces a novel design for "double-tube latent heat thermal energy storage units". This research demonstrates that the latent heat thermal energy storage unit (M06) greatly reduces the phase change material (PCM) melting time when compared to helical-coiled (53%), horizontal (66%), and vertical (76%) systems. At the end of the melting process, the M05 helical-coiled unit with spiral fins reaches a maximum exergy efficiency of 0.77. The energy efficiency of the M05, M06, and M08 units is highest at time points t=1200 s and t=3307 s.

(Qaiser et al., 2021) [17] examined the heat exchange rates in the triple tube V-configuration and vertical double tube V-configuration are 23.7% and 33.6% higher, respectively, than in the Base Case. Moreover, the matching total melting durations are decreased by 21.7% and 27.7%. In addition, we suggest making elliptic adjustments for double tube configurations and triangular modifications for triple tube setups. Both designs reduce the phase change material's (PCM) total melting time by 50% by increasing the average heat transfer rate by 85% when compared to the Y-fins single tube architecture in the Base Case. For all scenarios, increasing the HTF temperature by 5.6% leads to an increase in the average Nusselt number of more than 37% as compared to the Base Case. Furthermore, the correlations between the average Nusselt number and the melting Fourier number are also determined.

(Khan et al., 2021) [18] study the architecture of Y-finned tube is modified at five distinct eccentric locations, namely e = 0.14, 0.28, 0.42, 0.56, and 0.63. Comparing an optimized eccentric unit with an eccentricity value of 0.42 to a concentric LHTESU with an eccentricity value of 0, there is a 34.14% reduction in melting time and a 30.7% increase in "thermal energy storage" rate. Al2O3 and CuO nanoparticles are added to the pure PCM at different percentages ranging from 0.5% to 10% by volume in order to increase the "thermal efficiency" of the improved eccentric unit even more. The addition of 1% Al2O3 to the nano-enhanced PCM enhances the rates at which the optimal LHTESU melts and stores energy by 10%.

(Kousha et al., 2019) [19] At HTF inlet temperatures of 70 °C, 75 °C, and 80 °C, cases with 1, 2, 3, or 4 internal tubes are inspected. When the HTF inlet temperature is 80 °C, the time needed for full melting is 43% less than when using a single HTF tube, and the time needed for solidification is 50% less when employing a 4-tube heat exchanger. The findings indicate that as the number of tubes increases, the surface-averaged Nusselt number falls. This phenomenon might be explained by the restriction of the top pipes, which prevents the flow of the PCM melt.

(Rathod & Banerjee, 2015) [20] consider a shell-and-tube liquid heat storage unit (LHSU) with three longitudinal fins installed on its "heat transfer fluid (HTF)" tube is subjected to experimental testing in order to determine the increase in heat transfer efficiency. The time required for solidification and melting is used to determine the augmentation of heat transfer, considering different fluid inlet temperatures and HTF flow rates. Experiments show that increasing the "heat transfer fluid" inlet temperature is more effective than increasing the HTF mass flow rate for better heat transfer. The installation of three fins has been shown to decrease solidification time by up to 43.6%.

CONCLUSION

This study synthesizes insights from various literature works on enhancing heat transfer between Phase Change Materials (PCM) and heat transfer fluids in shell and tube latent heat storage units. Key findings indicate that repositioning the inner tube within the shell can significantly improve thermal performance. Altering the shape of the inner tube from circular to elliptical has also been shown to enhance heat transfer efficiency. Additionally, the inclusion of fins with various shapes further optimizes the heat exchange process. The strategic arrangement of multiple inner tubes, whether positioned in the lower and upper parts of the latent thermal energy storage unit, configured in a V-shape, or aligned horizontally, vertically, or at different angles, has proven to be effective in boosting thermal energy storage and retrieval. These adjustments collectively contribute to a more efficient heat transfer mechanism, offering valuable insights for designing advanced latent heat storage systems. The findings emphasize the importance of geometric and positional modifications in the inner tube design for maximizing the effectiveness of thermal energy storage units.

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