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Enhancing The Thermal Performance Of Latent Heat Thermal Energy Storage (LHTES) System Based Solar Heat Exchanger Using Computational Fluid Dynamics (CFD) Approach

Amit S. Kolekar[1], Sanjay V. Kadam[2]
[1]PG- student Mechanical- Heat Power Engineering, RIT
Email: amitkolekar143@gmail.com
[2]Professor Mechanical- Heat Power Engineering, RIT
Email: sanjay.kadam@ritindia.edu

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Abstract:

Abstract – Thermal energy storage systems had been gaining importance as these systems helps in conserving energy from the renewable energy sources such as solar energy source. The latent heat thermal energy storage system (LHTESS) include the phase change process in its working cycle. Phase change materials such as Paraffin wax will act as energy storage. In LHTESS, the charging process (PCM melting) absorbs the energy while the discharging process (PCM solidification) would release the energy. The thermal performance of the LHTESS is defined as the effective energy (heat) transfer mechanism between the PCM and the heat transfer fluid (HTF) such as water or air. There are multiple parameters that influence the thermal performance of the LHTESS such as number of fins, fin orientation, HTF flow and thermal conditions, system orientation etc. In order to predict the thermal performance of LHTESS, both experimental and numerical (CFD) approach had been used. In this journal, the recent research on the thermal performance enhancements on LHTESS had been summarised.

Keywords – LHTESS, PCM, Paraffin wax, CFD Simulations.

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I. INTRODUCTION

The latent heat thermal energy storage systems (LHTESS) involve a phase change material (PCM), such as paraffin wax, in a closed container while a heat transfer fluid (HTF) moves from inlet to outlet through pipes that are surrounded . During the HTF motion, heat transfer occurs between the HTF and the PCM. There are two energy cycles on the LHTESS, namely charging cycle and discharging cycle. In this review journal, the recent research on the thermal performance enhancements on LHTESS had been summarised.

II. LITERATURE REVIEW:

Solidification mechanism of phase change materials inside a triplex-tube heat exchanger was investigated **Ammar M Abdulateef**[1] with the help of experimental as well as numerical simulations.

The authors had selected RT82 Paraffin as the phase change material in their studies. In their study, various fin configurations – internal longitudinal fins, external longitudinal fins, internal-external longitudinal fins, internal triangular fins, external triangular fins and internal-external triangular fins – were analysed. These analyses were conducted for three flow rates of Heat Transfer Fluids (HTF). The authors had observed an increase in solidification rate with the increase in HTF' mass flow rate.

Saied Seddegh[2] had studied the influence the geometry orientation over the thermal performance – in terms of melting (charging process) and solidification (discharging process) – of the PCM with the help of Computational Fluid Dynamics simulations. The authors had chosen *ANSYS FLUENT* for these transient CFD simulations as the Enthalpy-Porosity approach was available. They had applied Coupled algorithm for the necessary pressure-velocity coupling. For solving the Momentum and Energy equations, the authors had chosen Second-order Upwind scheme for better accuracy.

The phase change materials that are used for thermal energy storage systems suffer from low thermal conductivity. Various researches had been conducted to design fin configurations to improve the thermal performance of these systems. **GnanaduraiRavikumar Solomon** [3] had investigated the impact of fin heights over the solidification rate. This experimental study was conducted on vertically oriented cylindrical latent heat energy storage unit with fins. The authors had also studied the fin' impact on the sensible cooling and sub-cooling mechanisms on PCM.

Abduljalil A Al-Abidi[4] had concluded that the heat transfer fluid (HTF) inlet temperature had a higher impact on the melting of phase change material than the HTF' mass flow rate. The authors had conducted experimental studies on a triplex tube heat exchanger with the internal-external type fin arrangement. In this study, RT82 Paraffin was selected as the PCM while hot water (90° C) acted as HTF.

Kunal Bhagat[5] had developed a numerical model to analyse the multi-tube thermal energy storage system with fins. Their system had a central tube for the heat transfer fluid also a tube at an angle of 60° apart. These seven tubes were enclosed with the phase change material. The authors had applied periodic approach for performing the CFD simulations for their study. This helped in reducing the simulation time in their studies. The PCM temperature predictions between CFD simulations and the experimental from their investigations were in good agreement. The authors had concluded that the thin fins helped in enhancing heat transfer rate while increasing the fin thickness would result in reduction of PCM volume, hence the overall thermal capacity of the system.

Martin Longeon[6] had studied the impact of the heat transfer fluid's injection direction for the charging and discharging cycle in a compact latent thermal energy storage system. Their research work had included both experimental and CFD simulations. While validating the data between these methods in terms of Paraffin wax temperature predictions, the authors had suggested that the PCM's specific heat value plays critical role in discharging cycle results. Based on the results obtained, the authors had concluded the direction of heat transfer fluid' injection had less impact on discharging cycle as compared to the charging cycle. They had recommended top injection for the heat transfer fluid for the charging cycle while a bottom injection for the discharging cycle. The authors had conducted CFD simulations using *ANSYS FLUENT*. And, the results were found to be in good agreement with the experimental data in terms of PCM temperature.

In order to have efficient heat transfer between the phase change material (PCM) and the heat transfer fluid (HTF) in the latent thermal energy storage system (LHTES), the fins are usually placed on the pipe carrying the HTF. Multiple research had been undertaken to identify effective fin design. **A Sciacovelli**[7] had studied two innovative fin design – single bifurcation and double bifurcation fins. These fins were of Y-shaped as compared to the typical fin designs such as longitudinal fins. These bifurcation shaped fins ensures the reach of fins extend to the maximum distance in to the phase change material hence resulting in better heat transfer rate. The authors had conducted the study with the CFD simulations and the Response Surface Method. Based on their results, they have observed 24% increase in discharge cycle efficiency with the help of double bifurcation fin design.

Shengxiang Deng [8] had conducted a similar study on identifying the influence of fins over the performance of the latent heat thermal energy storage system. The authors had undertaken a 2-dimensional CFD simulations with Lauric acid as phase change material in this research. The angle between the twin fins in their study was varied by 30°, 60°, 90°, 120°, 150° and 180° to compare the results against base model configuration. They had also extended the study by varying the fin length as well. From their results, they had observed an increase melting time of 66.7% for the optimum fin angle of 30°.

A finite-volume method based, fully implicit, numerical model for the melting process inside the enclosure of Octadecane, a phase change material, was developed by **NourouddinSharifi**[9] for non-uniform grids. The enclosure consisted of cavity for the PCM and horizontally oriented fins for the heat transfer enhancement. The authors had investigated the impact of fins such as number of fins, fin thickness and the fin length over the PCM melting mechanisms. For these transient process, they had concluded that the time-step of 0.01 seconds to be sufficient for the simulations.

Multiple shell-and-tube heat exchanger configurations for the Latent Heat Thermal Energy Storage (LHTES) system was studied using *ANSYS FLUENT* by **SoheilaRiahi**[10]. The configurations in their study were Fin Plate Vertical (FPV), Parallel Flow Horizontal (PFH), Counter Flow Horizontal (CFH), Parallel Flow Vertical (PFV) and Parallel Flow Horizontal (PFH). The phase change material (PCM) in their study was Sodium Nitrate while air was circulated as heat transfer fluid (HTF). In their simulations, air-flow was modelled as laminar conditions while the density variations on both fluid and solids due to the heat transfer were considered to be negligible. Also, symmetry model approach was applied by the authors to model the LHTES system.

Zakir Khan[11] had investigated experimentally the latent heat storage system in a longitudinal finned shell and tube heat exchanger model with paraffin as the phase change material. The authors had focussed on the LHTES system's transient thermal performance and the effective heat transfer mode under these devices. They had identified the conduction mode of heat transfer as dominant among other modes in LHTESS. Also, low heat transfer at the bottom part of the LHTESS was observed as compared to the central and the top portion.

The influence of HTF inlet temperature and the flow rate over the melting process of a finned-LHTESS was experimentally studied by **Moe Kabbara**[12]. In their study, the authors had chosen Dodecanoic Acid as the phase change material due to its melting temperature (43 ± 0.5°C) and has low hysteresis along with lower cost. Based on their research work, the authors had observed that HTF inlet temperature to have significant impact on the PCM melting time as compared to the HTF flow rate. When the HTF inlet temperature was increased from 60°C to 70°C, the PCM melting time reduced by 3.5 hours. However, for an HTF flow rate increase of 0.7 liters/min to 1.5 liters/min, the authors hadn't observed any noticeable improvement in thermal performance of LHTESS although they were able to reduce the melting time by 1 hour by increasing the HTF flow rate from 1.5 litres/min to 2.5 litres/min.

Francis Agyenim[13]have studied the sub-cooling process in the PCM melting on a Tube-In-Tube LHTESS. In their study, Erythritol with a melting temperature of 117.7 °C was chosen as PCM while air at 140 °C was chosen as HTF. The authors had studied three geometrical configurations – Control PCM system (no fins), Circular Finned PCM system and Longitudinal Finned PCM system. Based on the Cycle Time vs. PCM Temperature curve from their experimental studies, it was observed that the longitudinal finned LHTESS had high temperature gradient during the charging process followed by the Control system and then Circular finned system. At the Cycle Time of 100 minutes, the temperature on the longitudinal finned system was nearly 105°C while the circular finned system was at 78°C. This indicates the low thermal performance during sensible heat addition on the charging cycle of the LHTESS with circular fins.

A numerical simulation based investigation on thermal performance improvement on a triplex tube heat exchanger with PCM charging cycle was studied by **Abduljalil A Al-Abidi**[14]. The authors had studied two fin geometrical assembly – internal and external – along with fin parameters such as number of fins, fin thickness and fin length. The primary mechanism of heat conduction, melting and the natural convection in the PCM was modelled in *ANSYS FLUENT* with Boussinesq approximation. The PCM melting was found to be reduced with the increase in fin length however, for the increase in fin thickness resulted in negligible reduction in the melting time.

Conventional LHTESS are oriented either in vertical or in horizontal direction. **N Kousha**[15] had studied the impact of LHTESS unit' inclination angle over the PCM melting on a Tube-In-Tube heat exchanger LHTESS. The authors had studied four angle of inclinations - 0° [horizontal orientation], 30°, 60° and 90° [vertical orientation]. The authors had observed an initial high heat transfer on the horizontal orientation as compared to the vertical orientation. This was attributed the gravitational effects of natural convection of melting. However, after this initial stage, melting rate on the vertical orientation had increased relatively. They had concluded that inclination angle had a significant impact on the solidification process rather than on the melting process.

Thermal storage capacity of the LHTESS suffers due to the low thermal conductivity of the phase change materials (PCMs) such as Paraffin. Hence, various researchers had focussed on enhancing the heat transfer characteristics of the LHTESS. The most common approach has been the inclusion of fins on the HTF pipe. **Manish Rathod**[16] had investigated the influence of longitudinal fins on the thermal performance – in terms of PCM's solidification time – with the help of experiment studies. In their test model, three longitudinal fins that were made of brass were attached at an angle of 120°. The overall solidification time were reduced by 43.6% with the addition of these fins.

Conventional design of LHTESS are of cylindrical in shape. **SaeidSeddegh**[17] had compared the thermal performance of conical and cylindrical shaped LHTESS with the help of experimental studies. The advantage of conical shape – with the larger radius at the bottom – ensured the improvement in the natural convection mechanism during the charging process of LHTESS. However, the authors had observed minimal influence on the discharging process in their study on conical shaped LHTESS.

Most research on LHTESS are focussed on the thermal performance such as melting/solidification time. The cost associated in building a LHTESS often overlooked. **Ralf Raud**[18] had developed mathematical optimization method for the LHTESS to estimate the thermo-economic cost. In their optimization study, the authors had investigated the connection between LHTESS geometry that includes fins and their thermo-physical properties and cost for two different PCMs with the melting time as the constraint. Based on their research work, the authors had identified that the selection of fins with high thermal conductivity leads to significant reduction of LHTESS cost.

Saied Seddegh[19] had conducted experiments on shell and tube latent heat storage systems in which the PCM was stored on the shell-side. The authors had investigated the performance of this shell-and-tube-latent-heat-storage system for four cylinder diameter based on the shell-to-tube radius ratio and four operating conditions based on the heat transfer fluid inlet temperature. Based on the results obtained from this experimental study, they had concluded that the HTF inlet temperature had stronger influence on the LHTESS performance while the HTF flow rate had insignificant impact on the performance. Also, they had observed a reduction in charging time nearly 38% when the shell-to-tube-radius ratio was reduced from 8.1 to 2.7.

M. J. Hosseini[20] had conducted a study the thermal performance of double pipe, longitudinal orientation, heat exchanger for various fin heights as well as Stephan Number for the charging process. RT50 was chosen by the authors as the PCM in their study due to its melting temperature (45 -

51°C) was found to be suitable for solar energy storage systems. In this study, both experimental and numerical (CFD) approach had been applied. For the numerical simulation, the enthalpy-porosity method that are available in common CFD softwares such as *ANSYS FLUENT* had been utilized for modelling the PCM melting. Based on their study, the authors had concluded that the increase in fin height resulted better thermal penetration in the PCM, leading to reduced melting time.

The concept of LHTESS was applied for improving the cooling coefficient of performance (COP) of the air-conditioner system by **Dongliang Zhao** [21] with numerical simulations. In their LHTES system, water (for charging process) and air (for discharging process) were used as heat transfer fluid. The authors had defined PCM heat storage system effectiveness as a ratio of actual-to-theoretical heat transfer in the system and is generally higher than 0.5. As the fin height was known to have significant impact on the thermal performance of LHTESS, the authors had recommended the numerical (CFD) approach to identify the optimal fin height.

With the help of 3-dimensional CFD simulations, **Mushtaq I Hasan** [22] had applied LHTESS for improving the heat transfer characteristics of micro-channels. In this study, air was flowing over the micro-channels while the PCMs were placed at the base of the micro-channel heat sink. The authors had compared four different PCMs (Paraffin wax, RT41, n-eicosane, P116) in this study. The application of PCM for the micro-channel heat sink enabled to maintain overall reduced surface temperature.

Sohif Mat [23] had conducted numerical and experimental studies for a triplex-tube LHTESS with a various fin configurations. Their 2-dimensional numerical simulations (CFD) were performed in *ANSYS FLUENT* with enthalpy-porosity approach with transient solver. The authors had applied 0.5 seconds as time step for their simulations. For these CFD solver settings, the PCM average temperature predicted from the simulations were in good agreement with the experimental approach. The authors had investigated the thermal performance of the LHTESS under three heat load conditions – heating from inside the tube, heating from outside the tube and heating from both sides. Of these there heating method, the authors had predicted that the internal heating resulted in maximum melting time while both-side heating method resulted in minimal melting time.

The PCM solidification inside the co-axial cylinder was studied by **ImenJmal**[24] using numerical simulations (CFD). In this study, Paraffin wax was chosen as the PCM while air was supplied as heat transfer fluid in two-passages. The authors had compared the solidification process with and without the natural convection on the PCM. Based on their results, they had concluded that the contribution from the natural convection was significant and must be included in numerical simulations.

A transient, laminar, 3-dimensional numerical simulation based approach was conducted by **M. Esapour**[25] to investigate the LHTESS geometrical parameters as well as operational conditions – HTF inlet temperature and flow rate - over the PCM melting time. For the geometrical parameters, the authors had varied the number of HTF tubes as well as the positioning of the HTF tubes, resulting in 12 geometrical configurations. With the increased number of HTF tubes, the overall heat transfer surface area also increases. This resulted in faster melting time (10%) in their study. The HTF inlet

III. OBSERVATIONS:

The major observations from this literature review has been listed below.

- 2-dimensional CFD simulations with time-steps of 0.5 seconds in the enthalpy-porosity approach on commercial CFD softwares had predicted the thermal performance of LHTESS comparable to experimental approach.
- HTF inlet temperature has significant influence on the LHTESS performance

while the impact of HTF flow rate was minimal[19].

- The phase change process of the PCM in the LHTESS were modelled using the Enthalpy-porosity approach in the CFD software rather than the multi-phase approach.

IV. CONCLUSION

A MODEL WITH PCM MELTING METHOD IS CREATED AND THERE WILL BE A PHASE CHANGE OCCURS WITH RESPECT TO TIME THE HEAT TRANSFER WILL BE TAKE PLACE.HELICAL PIPE WILL BE DESIGNED WITH BEST HELIX ANGLE AND IT WILL BE TRANSFER HIGH AMOUNT OF ENERGY AND MELTING WILL BE TAKES PLACE AT SHORTEST TIME. THEMODIFICATIONOF THE NEW LHTES DESIGN REDUCES THE PCM MELTING TIME BY APPROXIMATELY 20% AS COMPARED TO OTHER.

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