Experimental Insights into Charging and Discharging Behavior of a Triplex Tube Heat Exchanger-Based Latent Thermal Energy Storage System

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Abstract: This research paper presents an experimental investigation into the charging and discharging processes of a Latent Thermal Energy Storage System (LTES) equipped with a meticulously designed Triplex Tube Heat Exchanger (TTHX). While previous literature primarily focused on analytical approaches, this dissertation pioneers experimental studies to comprehend the temperature dynamics within the LTES when coupled with TTHX. Additionally, this research seeks to predict the charging and discharging behavior of Phase Change Material (PCM) within the LTES. For heat transfer within the system, water serves as the heat transfer fluid, while paraffin wax (melting temperature range of 58-60°C) functions as the PCM. The results presented herein demonstrate the efficacy of the TTHX design in facilitating efficient heat transfer within the LTES. This experimental investigation encompasses three distinct modes of operation to provide a comprehensive understanding of heat transfer mechanisms in the system.

Keywords: Thermal energy storage; Triplex tube heat exchanger; Phase change material.

1. Introduction

Solar energy, unlike energy from fossil, nuclear, and some other fuels, is not available at all times [1]. One main factor that limits the application of solar energy is that it is a cyclic, time-dependent energy resource. Therefore, solar energy systems require energy storage to provide energy during the night and overcast periods. Effective utilization of time-dependent energy resources and increasing societal energy demands can be matched with the help of energy storage systems that operate synergistically [2].

Thermal energy storage (TES) is an advanced energy technology that is attracting increasing interest for thermal applications such as space and water heating, cooling, and air conditioning. TES systems have enormous potential to facilitate more effective use of thermal equipment and large scale energy substitutions that are economic [3]. TES appears to be the most appropriate method for correcting the mismatch that sometimes occurs between the supply and demand of energy [4]. It is therefore a very attractive technology for meeting society's needs and desires for more efficient and environmentally benign energy use. Thermal energy may be stored by elevating or lowering the temperature of a substance (i.e., altering its sensible heat), by changing the phase of a substance (i.e., altering its latent heat) or through a combination of the two. Both TES forms are expected to see extended applications as new energy technologies are developed [5].

Usage of Phase change materials (PCMs) for the TES system provides a great benefit but their low thermal conductivity becomes a major drawback in the development of LHTES systems [6]. Due to their low thermal conductivities, most PCMs require the use of heat transfer enhancement techniques to improve the rates of charging and discharging of energy. Heat transfer enhancement can be obtained through several parameters like design parameters and operation parameters.

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2. Methods and Materials

Experimental setup consists of a LHTES designed equipped with a TTHX containing PCM (Paraffin wax 58-60°C) in this. Additionally, a centrifugal pump, a heater and a radiator equipped with exhaust fan are also managed for charging and discharging demonstration of LHTES. Flow meter and thermocouples are added for flow and temperature measurements at appropriate locations to analyze the experimental outcome. A data logger is also used to integrate different results into one single file that further helped to process the data. Figure 1 shows the schematic diagram of the setup.

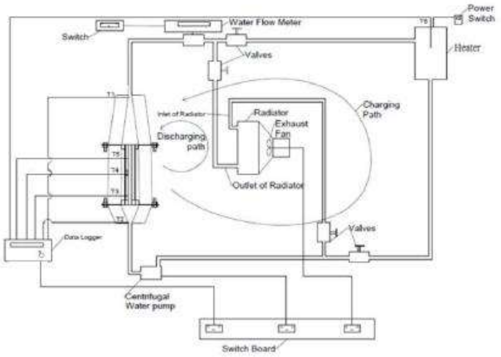


Figure 1: Experimental Setup for TTHX latent heat thermal energy storage

For our experimental study, a triplex tube heat exchanger (TTHX) method of heat transfer is selected and performance enhancement techniques in LHTES as shown in Figure 2. The heat exchanger comprised three horizontal stainless steel 304 tubes arranged concentrically of equal length 508mm. The diameter of the inner, middle and outer tubes was 25.4mm, 76.2mm, and 127mm respectively.

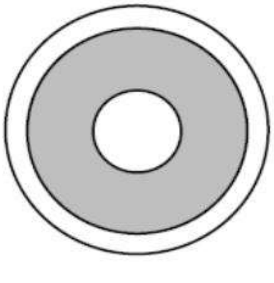


Figure2 Triplex tube heat exchanger

There are so many options to apply the fins in TTHX such as apply the fins on the inner tube which is known as TTHX with internal fins, apply the fins on the middle tube which is known as TTHX with external fins and apply the fins to create the cell in the inner and middle tube of TTHX as shown in Fig.1.3. For better performance, we create the 8 cells in the inner and middle tube of TTHX as shown in case F.

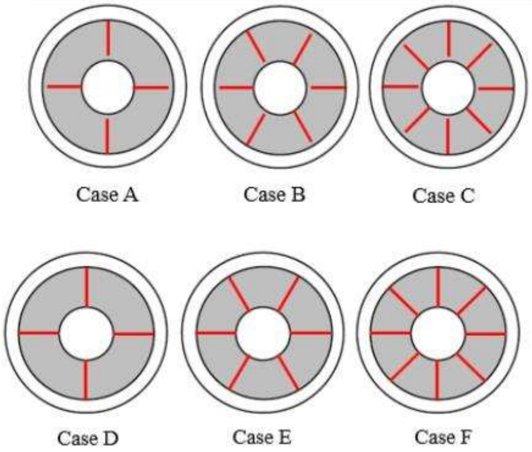


Figure 3: Configurations of Triplex tube heat exchanger

Thermal energy storage tank made up of stainless steel. Stainless steel is an alloy of steel with chromium and sometimes another element (such as nickel or molybdenum) that is practically immune to rusting and ordinary corrosion. 304 stainless steel is the most common stainless steel. The steel contains both chromium (between 18% and 20%) and nickel (between 8% and 10.5%) metals as the main non-iron constituents. It is austenitic stainless steel. It is less electrically and high thermally conductive than carbon steel and is essentially non-magnetic. It has a higher corrosion resistance than regular steel and is widely used because of the ease in fabrication which is formed into various shapes. Paraffin wax has been used a phase change material inside. Table 1 shows the thermo-physical properties of the paraffin wax.

Table 1: Thermo-physical properties of PCM

Property	**Paraffin wax**
Melting temperature, Tm (K)	**58-60°C**
Latent heat of fusion, L (kJ/kg)	**214.4**
Thermal conductivity, k (W/m K)	**0.2**
Density of PCM, Solid, ρs (kg/m^3)	**850**
Density of PCM, Liquid, ρl (kg/m^3)	**775**
C_{pl}, C_{ps} of PCM, (kJ/kg K)	**0.9**

3. Results and Discussion

This research is carried out to evaluate the charging and discharging of Latent Heat Thermal Energy Storage (LHTES) equipped with a Triplex Tube Heat Exchanger (TTHX) having Paraffin Wax with melting temperature of 58-60°C. Refer Figure 4, it has been observed that heater temperature is increase constantly for first 15 minutes and then after reaching close to 80°C, heater has been cut-off keeping heater temperature range within 75 to 80°C. This is done while keeping the design of heater as a restriction, as above this heater may get damaged.

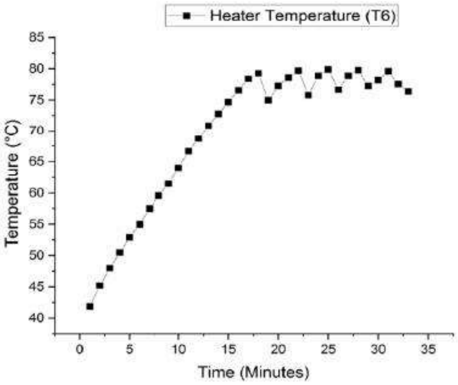


Figure 4: Variation of heater temperature with time

Figure 5 presents variation of temperature at the inlet and outlet section of the LHTES. These variations reflect that temperature difference across inlet and outlet is mainly because of the PCM filled inside the TTHX. It further elaborates the energy is being absorbed by the PCM inside continuously. Time taken for this experiment was around 35 minutes, which can be regarded as the charging time in the specified conditions.

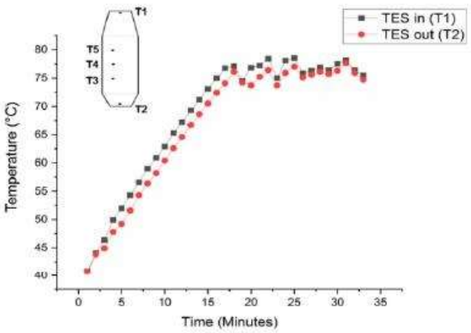
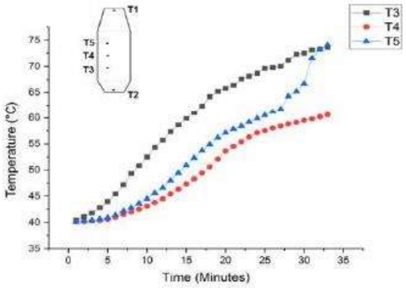


Figure 5: Variation of temperature at inlet and outlet of TTHX thermal energy storage while charging



THX thermal energy storage while charging

Figure 6 reports variation of temperatures inside the TTHX where PCM is filled. Thermocouples are placed at equal distances within the PCM filled inside TTHX in longitudinal direction. It is considered that temperature gradient in axial direction will be negligible due to less thickness and both side heating with the help of water (HTF). It can be seen from here that T4, which is placed in middle is having smallest temperature change when compared with the other two. This may be because of lower heat transfer within PCM due to its low specific heat. On the other hand temperatures T3, T5 are varying perfectly in conjunction with the heater temperature and TES inlet temperature T1. Variations in T3 are quite closer to the heater temperature because of high contact time of PCM at this location with HTF.

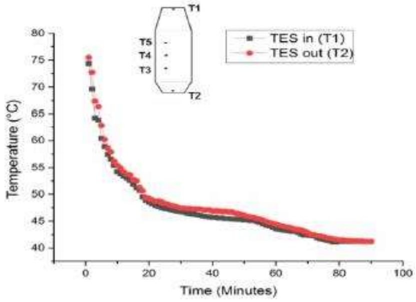


Figure 7: Variation of temperature at inlet and outlet of TTHX thermal energy storage while discharging

Figure 7 presents variation of inlet and outlet temperatures T1 and T2. Discharging is achieved by placing a radiator within this loop equipped with exhaust fan for proper heat transfer to the environment. It can be observed that initially the temperature drop is high because of the high temperature difference of HTF compared to the environment temperature. Further, as temperatures reach below 45°C, temperatures variations are declining vary slowly.

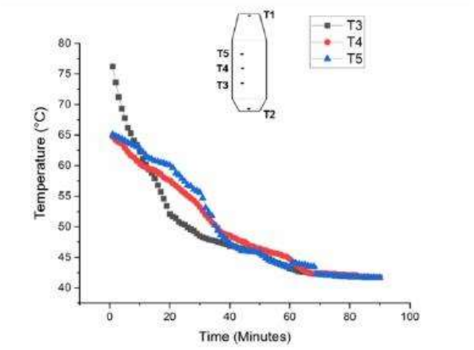


Figure 8 Temperature variations inside TTHX thermal energy storage while discharging

Figure 8 reports variation inside the LHTES where PCM is filled. The curve presents continuous drop in these temperatures indicating the energy retrieval from the LHTES and it can further be seen that TTHX is proved helpful for the effective retrieval of heat. Similar to the previous one, rate of energy retrieval became slow when its temperature difference compared to environment drops. It can be analyzed that solidification process of PCM is same throughout the storage while reaching temperature below 55°C.

4. Conclusion and Future Directions

Present work demonstrates the charging and discharging of a LHTES equipped with a well designed Triplex Tube Heat Exchanger (TTHX). TTHX is proved to be an efficient and effective heat exchanger which provides both sides heating to LHTES. However, there was mostly analytical work reported in the literature. Thus an experimental investigation is planned in this dissertation to carry out temperature variations within LHTES while using TTHX and further to predict charging and discharging behavior of PCM inside. Water is used as a heat transfer fluid to perform heat transfer within the charging and discharging loop of the LHTES containing paraffin wax (melting temperature 58-60°C) as PCM.

References

[1] Armaroli, N., & Balzani, V. (2016). Solar electricity and solar fuels: status and perspectives in the context of the energy transition. Chemistry–A European Journal, 22(1), 32-57.

[2] Al-Ghussain, L., Samu, R., Taylan, O., & Fahrioglu, M. (2020). Sizing renewable energy systems with energy storage systems in microgrids for maximum cost-efficient utilization of renewable energy resources. Sustainable Cities and Society, 55, 102059.

[3] Achkari, O., & El Fadar, A. (2020). Latest developments on TES and CSP technologies–Energy and environmental issues, applications and research trends. Applied Thermal Engineering, 167, 114806.

[4] Arteconi, A., Hewitt, N. J., & Polonara, F. (2012). State of the art of thermal storage for demand-side management. Applied Energy, 93, 371-389.

[5] Dincer, I. (2002). Thermal energy storage systems as a key technology in energy conservation. International journal of energy research, 26(7), 567-588.

[6] Zhang, N., Yuan, Y., Cao, X., Du, Y., Zhang, Z., & Gui, Y. (2018). Latent heat thermal energy storage systems with solid–liquid phase change materials: a review. Advanced Engineering Materials, 20(6), 1700753.