Experimental Investigation of Triplex Tube Heat Exchanger Charging and Discharging for Latent Thermal Energy Storage System

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Abstract- This study investigates the experimental dynamics of charging and discharging within a Latent Thermal Energy Storage, amplified by a carefully engineered Triplex Tube Heat Exchanger. As evident, the previous literature predominantly centered on analytical approaches, this research pioneers experimental studies aimed at grasping the temperature dynamics within the LTES when coupled with the TTHX. Furthermore, the research endeavors to anticipate the charging and discharging behavior of the phase change material employed in the LTES. The heat transfer process within the system employs water as the heat transfer medium, while paraffin wax (with a transition temperature range of 58-60°C) acts as the phase change material. The results presented herein underscore the effectiveness of the TTHX design in facilitating proficient heat transfer within the LTES. This experimental investigation incorporates three distinct modes of operation, offering a comprehensive insight into the heat transfer mechanisms within the system.

Keywords– Solar energy, phase change material, thermal energy storage, triplex tube heat exchanger.

1. INTRODUCTION

Solar energy, in contrast to fossil, nuclear, and certain other fuels, is not consistently accessible [1]. The diurnal nature of solar energy poses a significant limitation to its vast applications. Consequently, solar energy systems necessitate energy storage solutions to ensure a continuous energy supply during periods of darkness and overcast weather. Addressing the challenge of effectively harnessing time-dependent energy resources and meeting growing societal energy needs requires the coordinated operation of thermal energy storage (TES) systems [2].

The TES emerges as a cutting-edge technology increasingly capturing attention, especially for its applications in space and water heating, cooling, and air conditioning. TES systems hold substantial promise in elevating the efficiency of thermal equipment and facilitating widespread, economical energy alternatives. [3]. Addressing the occasional misalignment between energy supply and demand, TES emerges as a particularly fitting solution [4]. TES techniques encompass two primary methods: one involves adjusting the temperature of a substance to alter its sensible heat, while the other entails changing the phase of a substance to modify its latent heat. These methods can also be combined to store thermal energy effectively. The continuous development of new energy technologies is anticipated to broaden the applications of both forms of TES [5].

Using PCMs in a TES offers many advantages, yet their drawback lies in low thermal conductivity, posing a challenge for the development of Latent Thermal Energy Storage (LTES) [6]. The inherent low thermal conductivities of many PCMs necessitate the application of heat transfer enhancement techniques to optimize the efficiency of energy charging and discharging processes. Achieving enhanced heat transfer involves manipulating various parameters, including both design and operation parameters.

The aim of this investigation is to predict the charging and discharging behaviors of the PCM utilized in the LTES system. Water functions as the heat transfer medium in the system, while paraffin wax, characterized by a melting temperature range of 58-60°C, acts as the PCM. The results outlined in this inquiry underscore the efficacy of the Triplex Tube Heat Exchanger (TTHX) configuration in enabling efficient heat transfer within the LTES. This experimental inquiry encompasses three essential phases, aiming to elucidate the intricate dynamics of thermal energy storage and release. This experimental investigation incorporates three distinctive modes of operation, contributing to a comprehensive comprehension of the heat transfer mechanisms within the system.

2. DESIGN OF LTES

The experimental setup features a LTES system, intricately designed with a TTHX that integrates PCM in the form of Paraffin wax, possessing a melting temperature range of 58-60°C. Complementing this setup are essential components including a centrifugal pump, a heater, and a radiator equipped with an exhaust fan, all meticulously orchestrated to illustrate the charging and discharging mechanisms of the LTES. To facilitate analysis of the experimental outcomes, flow meters and thermocouples are strategically placed for measuring flow rates and temperatures at relevant locations. A data logger is employed to consolidate various results into a single file, aiding in data processing. Figure 1 shows the schematic diagram of the setup.

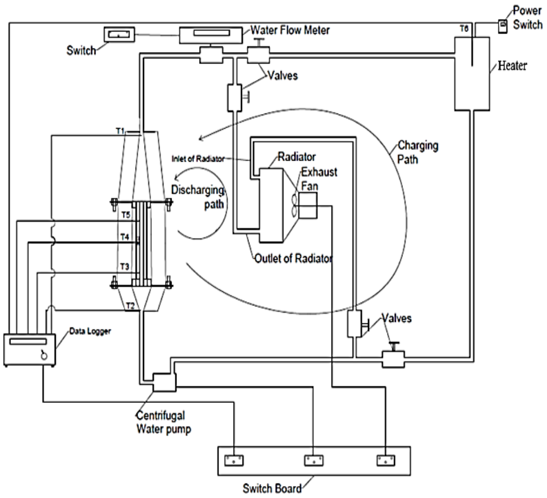

Figure 1: Experimental Setup for LTES

In this experimental inquiry, the focus lies on heat transfer, integrating performance enhancement strategies within Latent Thermal Energy Storage (LTES), as depicted in Figure 2. The heat exchanger comprises three concentric horizontally aligned stainless steel 304 tubes, each measuring 508mm in length. The inner, middle, and outer tube diameters are 25.4mm, 76.2mm, and 127mm, respectively.

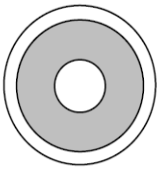

Figure 2: Triplex tube heat exchanger

Various options exist for applying fins in Triplex TTHX. These include placing fins on the inner tube, referred to as TTHX with internal fins, attaching fins to the middle tube, known as TTHX with external fins, and implementing fins to create cells in both the inner and middle tubes of TTHX, as depicted in Figure 3.

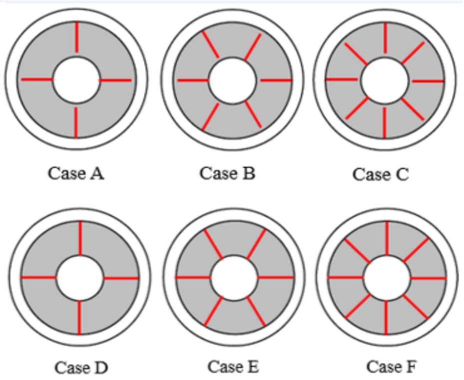

Figure 3: Various Configurations of TTHX

The TES tank is constructed from stainless steel, an alloy known for its resistance to rusting and ordinary corrosion. Stainless steel is formed by combining steel with chromium and, at times, another element such as nickel or molybdenum. Among the various types of stainless steel, 304 stainless steel is the most common, characterized by Chromium (18-20%) and nickel (8-10.5%). It belongs to the austenitic stainless steel category, exhibiting lower electrical and higher thermal conductivity than carbon steel, and it is essentially non-magnetic. Possessing superior corrosion resistance compared to regular steel, it is widely used due to its ease of fabrication into various shapes. Table 1 shows the desired thermos-physical properties of the PCM used. Phase change materials (PCMs) have some limitations including limited range of operating temperatures, leakage, high cost, and compatibility issues with some applications.

Table 1: Thermo-physical properties of Paraffin wax

Property	Value
Transition temperature (°C)	58-60
Latent heat (kJ/kg)	214.4
Thermal conductivity, (W/m K)	0.2
Density (Solid), (kg/m3)	850
C_{pl}, $C_{ps,}$ (kJ/kg K)	0.9

3. RESULTS AND DISCUSSION

This study aims to assess the charging and discharging processes of a LTES system, featuring a TTHX incorporating Paraffin Wax with a melting temperature range of 58-60°C. As depicted in Figure 4, the heater temperature exhibits a continuous rise in the initial 15 minutes. Subsequently, upon nearing 80°C, the heater is automatically cut off to maintain the temperature within the range of 75 to 80°C. This precaution is implemented to prevent potential damage to the heater, adhering to the specified design limitations.

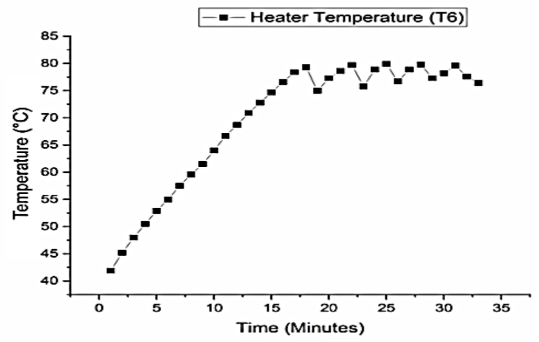

Figure 4: Variation of Temperature in TES tank vs Time

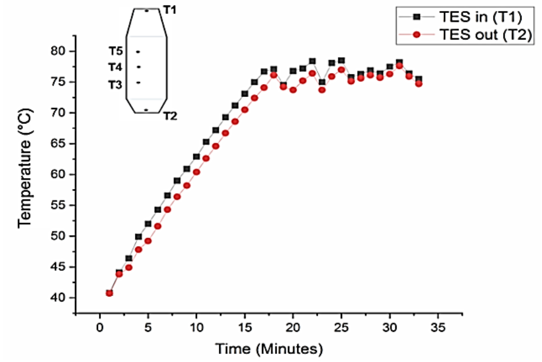

Figure 5: Variation of temperature at inlet and outlet LTES during charging

Figure 5 illustrates the temperature changes at the inlet and outlet sections of the TES. The observed variations indicate that the temperature difference between the inlet and outlet is predominantly influenced by the presence of the Phase Change Material (PCM) within the Triplex Tube Heat Exchanger (TTHX). This graphical representation underscores the continuous absorption of energy by the PCM throughout the experiment. The duration of this experiment was approximately 35 minutes, representing the charging time under the specified conditions.

Figure 6 depicts the temperature variations within the TTHX where PCM is housed. Thermocouples are strategically positioned at uniform intervals along the longitudinal direction within the PCM-filled region of the TTHX. It is assumed that the temperature gradient in the axial direction is minimal due to the thinness of the PCM and the dual-sided heating facilitated by water (heat transfer fluid). Notably, T_4, located in the middle, exhibits the smallest temperature change compared to the other thermocouples.

This phenomenon may be attributed to the lower heat transfer within the PCM, stemming from its low specific heat. Conversely, temperatures T_3 and T_5 align well with both the heater temperature and the TES inlet temperature T_1. The variations in T_3 closely mirror the heater temperature, emphasizing the extended contact time of the PCM with the heat transfer fluid at this specific location.

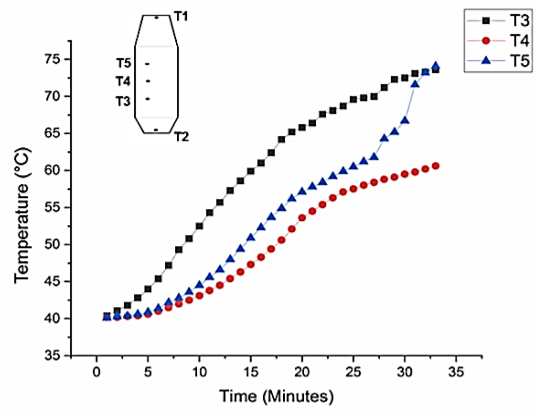

Figure 6: Temperature variations inside TTHX thermal energy storage while charging

Figure 7 displays the changes in inlet and outlet temperatures, denoted as T_1 and T_2, respectively. The discharging process involves incorporating a radiator in this loop, complemented by an exhaust fan to facilitate efficient heat transfer to the surrounding environment.

Notably, there is an initial rapid decline in temperature because of ambient environment. Subsequently, as temperatures descend below 45°C, the variations in temperature exhibit a gradual and diminishing decline.

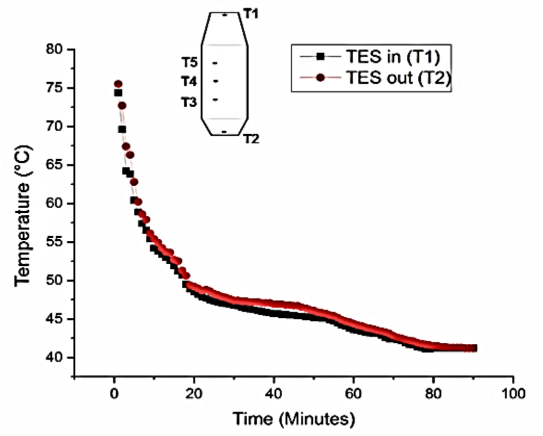

Figure 7: Variation of inlet and outlet temperature in TES during discharging

In Figure 8, the temperature variations within the LTES are illustrated, encompassing the region where the PCM is housed. The depicted curve showcases a sustained decline in these temperatures, signifying the retrieval of energy from the LTES. Notably, the TTHX proves instrumental in facilitating efficient heat retrieval. Like the prior situation, the rate of energy extraction slows down as the temperature contrast between the LTES and its surroundings diminishes. An ongoing observation indicates that the solidification phase of the PCM remains steady during storage, especially when temperatures drop below 55°C.

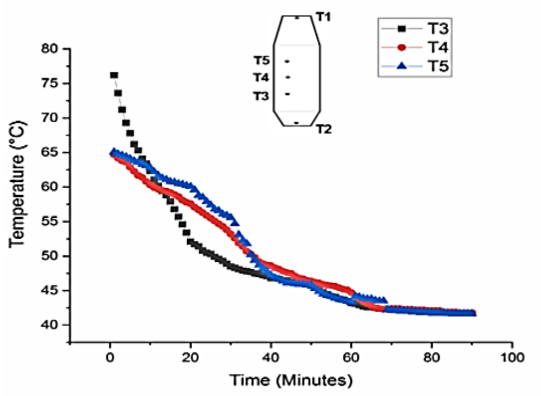

Figure 8: Temperature variations inside TTHX thermal energy storage while discharging

4. CONCLUSION

The current study showcases the charging and discharging processes of a LTES, featuring an adeptly designed TTHX. The TTHX proves its efficiency and effectiveness as a heat exchanger, providing dual-sided heating to the LTES. While existing literature predominantly comprises analytical approaches, this paper introduces an experimental investigation to observe temperature variations within the LTES when coupled with the TTHX. Additionally, the research endeavors to showcase the charging and discharging behavior of the PCM within the system. Water serves as the heat transfer fluid, facilitating the heat transfer during the charging and discharging of the LTES, wherein paraffin wax (transition temperature 58-60°C) acts as the PCM. The future scope of LTES includes enhanced efficiency, integration with renewable energy sources, scalability for grid applications, and advancements in material science for improved performance and cost-effectiveness.

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