Experimental comparison of longitudinal and annular fins using PCM for Thermal energy storage

Mohammed Shahid Afridi, Alfred Anthony, P Sundaram*, Sunil Babu

Department of Mechanical Engineering, SRM University, Kattankulathur, Chennai - 603203, Tamil Nadu, India
Corresponding Author: *vpsundaram@gmail.com

Abstract. This work deals with comparative study of longitudinal and annular fin using PCM in a thermal energy storage unit experimentally and numerically. The TSU under analysis Consists of paraffin wax as PCM with melting Temperature of 55°C to 60°C. Liquid heat transfer fluid passes between the tubes to charge and discharge the storage unit. Thermal storage tank is connected to the experimental setup which consists of hot and cold-water tanks and experiment is carried our initially charging and discharging by Longitudinal fin process by passing heat transfer fluid similarly the charging and discharging by Annular Fin process by passing heat transfer. The experimental results show that usage of Longitudinal fin and Annular fin for charging and discharging has different heat transfer rate. Even efficiency is increased around 6% for the longitudinal finned heat exchanger than the Annular finned heat exchanger.

1. Introduction

The increase in the degree of ozone depleting substance discharges and the hiking in fuel costs are the primary driving force behind endeavors to more effectively use different sustainable power source. One of the alternative is to develop energy storage devices which are as essential as growing new sources of energy. The energy storage in appropriate structures which can typically be changed over into the required shape which is a present-day confrontation to the technologists. Energy storage prompts sparing of premium fuels and makes the framework more practical by lessening the wastage of energy and capital cost. Thermal energy is stored as an internal energy changes of a material and as thermo-chemical materials.

Double pipe helical exchanger was numerically modelled for various laminar flow rates and tube sizes. The exploratory outcomes demonstrate that by expanding the inlet HTF temperature, theoretical efficiency in charging and discharging procedures ascends individually [11]. Various designs of LHTS (latent heat thermal storage) with similar volume and surface area of heat exchange were numerically examined. The comparative investigation on the total melting time of a PCM (phase change material) loaded in three different containers of rectangular, round and hollow and shell and tube shows that...
cylindrical containers took the lesser time for equal amount of energy storage, and with an increase in the mass of the PCM the geometric effect is more pronounced to increase the heat transfer during melting [2]. The effect of multiple PCMs was examined in shell and tube heat exchanger at various melting temperatures. They utilized two PCMs framework (LHSU2) and single PCM framework (LHSU1) amid charging process and compared the thermal performances of the LHSU. The result outcomes demonstrated that when the mass flow rate expands, the two PCMs framework were effective for bringing down HTF inlet temperature. Hence, multiple PCMs unit is more proficient for low estimations of mass flow rate and inlet temperature of HTF [3]. The effect of inlet temperature in a shell and tube heat exchanger on melting process with HTF (heat transfer fluid) was numerically and experimentally studied. They observed that the melting front shows up close to the HTF tube and advances at various rates outwards, at the shell. They deduced that by expanding the inlet temperature, the time taken for melting reduced [4].

The solidification of PCM Paraffin C18 was performed for thermal storage of co-axial tubes with horizontal fins of inner and outer side for conditioning systems with dual air entries. The numerical approach expects to ponder the effect of natural convection, which is happening in the liquid stage, the solidification time of PCM and the transient advancement of the solidification front. This paperwork likewise examines the impact of fins number on heat transfer enhancement [5]. An experimental investigation of a PCM storage unit is performed by various researchers to store the latent heat produced during the phase change. The different types of paraffin are employed as PCM and water is used as a heat transfer fluid. With this model the effect of various thermo-physical parameters on the performance of HE are studied and concluded as the flow rate of HTF has a considerable impact on charging phase comparative to the discharging phase, the inlet temperature plays an important role in enhancing the performance of the heat exchanger and the addition of engine oil to paraffin acts as a catalyst for charging and discharging process [6-9]. On a numerical investigation of a latent heat storage unit loaded with PCM. Water flows through the inner tube by forced convection and exchanges the heat to PCM. A few numerical examinations were led to keeping in mind the end goal was to look at the effect of the key parameters: mass quantities of PCM utilized, number of coil passed and the mass flow rate of the water. This work establishes an exploratory investigation of a PCM storage unit for heat storage applications. A few tests were considered subject to shifting flow rates of the HTF and the inlet temperature of HTF. The utilization of PCM enhances the thermal storage capacity of Solar Thermal Accumulators due of its high energy storage density the latent heat of Solid to Liquid phase changes at consistent temperature [10].

From the above journals, came to know that using of fins increases the heat transfer coefficient of the tube, with increasing surface area more heat is dissipated into the surrounding and they observed that change in inlet temperature changes the heat transfer rate, all the journals are concentrated on the charging mainly and then they observed the discharging process so now we considered giving different types of fins. The present work have decided to use longitudinal and annular fin to determine which one is more efficient

2. Methods and Methodology

2.1 Fabrication of experimental setup
Hot water reservoir is located at the upper section of the setup. It consists of 9KW heater which is connected to the thermostat to govern the temperature of the hot reservoir tank by using thermocouple inside which is insulated by the rubber material. Cold water tank is situated at the bottom of the setup and centrifugal pump is located at the lower section beside the cold water reservoir. Inlet of centrifugal pump is connected to the Hot water reservoir and cold water tank by using T- section with two shut off valves so we can close and open either of the inlet according to our needed.

Outlet of the pump is initially coupled to the Hot water reservoir which is connected to the inlet of the thermal storage unit setup through shut off valve by T- section and another side of T – section placed in the hot water tank through shut off valve.

Flow control valve is presented at the right side of the hot water tank which is connected from pump to hot water tank which is used to control the flow enters to the thermal storage unit. Thermal storage unit consists of one Central copper Longitudinal/Annular finned tube has 8cm and 2cm diameter. Three thermocouples were placed at different places in the thermal storage tank. It consists of an insulated stainless steel in which heating coils are dipped in water similar to water heating iron dipped in a bucket of water. It's only that the bucket has outlet which is attached to you tap. The below photographic image shows the experimental setup which is connected to the storage tank.

| Description         | Dimensions            |
|---------------------|-----------------------|
| Shell (Stainless steel) | 32mm x 8mm x 9mm |
| Tube (copper)       | 42mm x 2mm x 2mm     |
| Hot water tank      | 500mm x 500mm x 500mm|
| Cold water tank     | 600mm x 400mm x 400mm|

A thermocouple is a device used for measuring the temperature, it consists of two different metals which are made to contact each other at two junctions. One of the junction is placed in the body whose temperature is to be determined and the other one is kept in maintained at a known reference temperature, due to the difference in temperature at the junctions voltage is produced by the thermocouple.

2.2 Experimental Trial

Switch on the electric power supply so heater will switch on automatically set the required temperature by using thermostat and maintain the temperature of the hot water reservoir with the help of thermocouple connected to it. Connect the outlet of pump to the inlet of the hot water reservoir which passes over through the inlet of thermal storage unit and place the outlet of the thermal storage unit to the bottom cold water storage tank. Initially stir the water from hot water reservoir to cold water tank with the help of pump to get the stable temperature. After getting the stable temperature open the shut
off valve at the inlet of thermal storage tank and set the flow rate required. Digital thermometers are used at the inlet and outlet of the thermal storage tank to know amount of heat absorbed.

Now the hot water valve is closed and the bottom cold water tank is filled with cold water. The cold water is circulated through the thermal storage unit to get the hot water by absorbing the heat energy of the PCM.

![Figure 1. Schematic diagram of Experimental Setup.](image)

### 3. Results and Discussion

The PCM in the thermal storage tank initially around the room temperature when the water is passed through the thermal storage tank with flow rate of $7.145 \times 10^{-5} \text{ m}^3/\text{s}$ readings were observed for every 5 min.

| Table 2. Physical Parameters

|                      | Longitudinal Fins | Annular Fins |
|----------------------|-------------------|--------------|
| Volume of Shell      | $16.1 \times 10^{-4} \text{ m}^3$ |              |
| Volume occupied by Tube | $1.0053 \times 10^{-4} \text{ m}^3$ |              |
| Volume occupied by Fins | $1.152 \times 10^{-4} \text{ m}^3$ | $1.131 \times 10^{-4} \text{ m}^3$ |
| Functional Volume    | $13.94 \times 10^{-4} \text{ m}^3$ | $13.96 \times 10^{-4} \text{ m}^3$ |
| Mass of PCM          | 0.878 Kg          | 0.879 Kg     |
| (70% of functional volume) |                   |              |

| Table 3. Fin Properties |
The above graphs depicts that, at the beginning the sensible heat is charged at a faster rate in the inner most layer near to the HTF tube than the outer most layer where the heat is transferred at a lower rate due to low thermal conductivity of PCM. For another time period of 22 minutes the latent heat is charged where the outer most layer are charging at the higher temp than that of the inner most layer. Before the sensible heating resumes in its liquid state the PCM has to be bought to a complete steady state and to do so the outer most layer loose a little bit of heat energy to the interior layers and then reaches back to higher energy state in order to bring all the three layers to a constant steady state and the system reach the sensible storage state of 74°C.
As soon as the cold water starts flowing the PCM closer to the HTF tube starts transferring its heat to the cold water and the outer most layer is still in the molten stage and then the inner most layer are held constantly at 46-44°C for a time period of 15 min where the latent energy is dissipated to the water, after the 15 min the latent heat discharge from the closest layer of PCM to the pipe then to the further layers of the PCM dissipates remaining latent heat to reach a complete solidus steady state with other layers. The effect of the copper tube and fins show that the PCM away from the pipe has lower heat conducting effect, this is mainly caused due to the difference in thermal conducting properties of the materials used in the system.

The above graphs depicts that the charging properties that are shown by the PCM while using annular fins are different compared to the way the temperature gradient has changed thought the process. In the initial 3 minutes the annular fins are able to transfer heat much more efficient to the outer most layers.
of the heat exchanger compared to that of the longitudinal fins causing the PCM to reach a constant state of charging the latent heat and after a constant charging time of 19 minutes the complete setup of PCM has achieved solidus state. The total time taken for the PCM to reach a steady state has reduced by 12%. The annular fins due to a higher influence in the total heat flux flow keeps the PCM in the latent heat charging rather than the layers closer to the pipe start sensible charging of heat.

Figure 5. Discharging in Annular Fin HE

The above graphs show that during the discharge of heat energy from the annular fins to the cold water the heat transfer rate between the fins to the PCM is lesser than that of longitudinal even while consisting of the same total area of fins. An initial high heat transfer rate is observed due to the high diving potential in the beginning and evidently the HTR reduces gradually as the driving potential reduces as more energy is dissipated. As a heat exchanger the annular fins are more efficient as a storage unit due to its low thermal conductivity and even flow of energy but in comparison for the fins the longitudinal fins are able to dissipate out or in more heat that the annular making it more useful in exhausting excess heat.

Figure 6. Solidification and melting of PCM in Longitudinal finned and Annular finned HE
The above graph shows the charging and discharging of PCM with respect to time from this it can be inferred that in longitudinal fin discharge time is comparatively greater than the discharge time of the annular fin.

**Table 4. Experimental result summary**

| Description       | Longitudinal Finned HE | Annular Finned HE |
|-------------------|------------------------|-------------------|
| Mass of PCM(M)    | 0.74448 kg             | 0.71118 kg        |
| Heat transfer rate| 2.09366 kw             | 2.0945 kw         |
| Efficiency        | 58%                    | 52%               |

Thus, Longitudinal Fin is more efficient in transferring heat compared to that of annular fin.

4. Conclusion
The charging process from longitudinal finned heat exchanger has higher heat transfer rate than that of the charging rate of annular finned heat exchanger. During discharging process, the annular finned heat exchanger depicts a higher heat transfer ability compared to that of longitudinal fins with control of mass flow rate of discharge of water. The efficiency of longitudinal fin has a 6% higher efficiency at transferring heat from the water to PCM compared to annular fin, this loss is created between the two heat exchangers due to their structural difference in their fin design.

5. References

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