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Influence of Radial Fins and Turbulence Promoters on the Enhancement of Charging and Discharging of Phase Change Heat Transfer in Triplex-Tube

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***Abstract*— Latent heat thermal energy storage (LHTS) based on phase change material (PCMs) is an interesting solution to be used for mitigating the mismatch between energy demand and supply that affects various kinds energy systems. One of the serious problems with the operation of PCM storage system is the slow heat transfer from and to the element containing the PCM. This paper presents the results of an experimental investigation on the effects of radial fins and turbulence promoters on the enhancement of charging and discharging during phase change heat transfer. Water is used as the heat transfer fluid. Temperature variations with respect to time were obtained for simple latent heat thermal energy storage system without fins and turbulence promoter, with fins and without turbulence promoter and with both fins and turbulence promoter incorporated together. The results are presented and discussed.**

***Keywords*— PCM, Charging, Discharging, Latent heat storage, Radial fins, Turbulence promoters.**

I. INTRODUCTION

A Phase Change Material (PCM) ideally requires a suitable phase change temperature and a large melting enthalpy. These requirements have to be fulfilled in order to store and release heat efficiently. Suitable phase change temperature is needed to assure storage and release of heat for a specific application. Large phase change enthalpy is needed to achieve high storage density compared to sensible heat storage. Phase change materials, also need cycling stability in order to use the storage material repeatedly for storage and release of heat as required by an application.

During solidification of the Latent Heat Thermal Storage (LHTS) system, conduction is the sole transporting mechanism and during melting natural convection occurs in the melt layer and this generally increases the heat transfer rate compared to the solidification process. Hence for a given configuration in LHTS system, charging is faster than discharging. Also in LHTS system surface heat transfer rate decreases due to increase in thermal resistance of the growing layer of solidified PCM.

Moreover, for extracting heat directly from latent heat storage system a medium is required for heat exchanger which is called as heat transfer fluid(HTF)

PCM based thermal energy storage systems are popular and intense research were carried out in this area during past few decades. The issues regarding these systems were its slow response time. So one of the areas that need research, is the enhancement methods to increase the efficiency of these systems by ensuring a fast response time.

Zhongliangliu (2004), carried out investigations in a vertical annular energy storage system. The thermal and heat transfer characteristics of stearic acid during solidification process were studied. Along with this study a copper fin was designed and fixed in the system to enhance the thermal conductivity of the stearic acid. The result of such a modification was the enhancement of both conduction and the natural convection heat transfer of the PCM, and the enhancement factor of the solidification process was found to be as high as 250%. The fin width is used as the variable, and it was found that the fine fins were the one's which produced more effective enhancement.

Zhongliangliu (2005) investigated, on the heat characteristics of heat pipe heat exchanger in latent heat storage system. Among different types of thermal energy storage systems, latent heat type is the most desirable one because of its large energy storage density, significant reduction in storage volume and most importantly, the isothermal behavior during the charging and discharging process compared with sensible heat storage systems. In this paper a new heat pipe exchanger with latent heat storage was designed and manufactured. The effects of inlet temperature and flow rate of the cold/hot water were studied during charging and discharging process. It was found that the heat exchanger performed the designed functions very well and both storing and releasing of the thermal energy was efficient.

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C Balaji (2011) conducted an experimental investigation of the performance of finned heat sinks filled with phase change materials for thermal management of portable electronic devices. The heat sink act as an energy storage and a heat spreading module and studies were done on the heat sink on which a constant heat load was applied for the both finned and non-finned cases. The effect various types of fin geometry in enhancing the operating time for various set point temperatures and period of latent heat phase were studied. The results lead to the conclusion that operational performance of the portable electronic devices was significantly improved by the introduction of fins in the heat sink containing the PCM.

K.A.R. Ismail (2011) presented the results of an experimental investigation on the effects of the radial fins and turbulence promoters on the enhancement of phase change heat transfer external to a horizontal tube submersed in the PCM with the working fluid flowing through it. The experiment was conducted on bare tubes, finned tubes, and finned tubes with turbulence promoters inserted into the finned tubes. The result showed that the temperature of the working fluid has a strong influence on the solidification process around a radially finned tube. Low temperatures lead to high velocity, more solidified mass and short complete solidification time. The increase of the mass flow rate of the working fluid results in high interface velocity and less time for complete solidification. The effect of mass flow rate was relatively smaller than the working fluid temperature. The use of the turbulence promoter resulted in high interface velocity and small time for complete solidification. Its effects were less pronounced than those due to the radial fins.

Sohif Mat and Abduljalil (2013) conducted a study which dealt with numerical investigation on the melting process in a triplex-tube heat exchanger with PCM RT82. Heating method to melt PCM was done along inner tube, outer tube and both tubes. Three heat enhancement methods namely, TTHX with internal fins, TTHX with external fins, TTHX with both internal-external fins were studied to improve the thermal performance of PCM thermal storage. The result showed that there is no significant difference among the three enhancement techniques in terms of the PCM melting. Effects of fin length were also investigated. Complete melting time with the use of internal-external fins with 42mm fin length was reduced to 43.3% compared with that of TTHX without fin.

Therefore, a large number of studies were done on enhancement of PCM based heat storage systems. The present study is conducted for enhancement of heat transfer during charging and discharging by means of a triplex tube heat exchanger with radial fins assisted by turbulence promoters, which is not tried in the past.

II. Details Of Experimental Setup

For low temperature applications like hot water supply, room-heating paraffin provides an excellent material for storage. Paraffin are available at different temperature ranging from 40-120°C.One can choose the type of paraffin depending on the requirements. Moreover, they do not corrode the ordinary storage containers. Another important aspect is that they are cheap, reproducible and durable over long periods of time. In this study, the maximum temperature obtained is 70°C. Therefore, the latent heat storage material should melt completely at that temperature. After studying the properties of various latent heat materials, paraffin RT60 was chosen. Further RT60 is easily available in the market and it is economical too. The properties of paraffin RT60 is given below. Density of wax = 850 kg/m^3 (Solid), 775 kg/m^3 (Liquid)

Melting point of wax = 58 – 60 °C
Specific heat of wax = 2.9 kJ/kg K

Water is the most commonly used medium as HTF in thermal storage systems. Water has many advantages like availability, cost and low boiling point. Hence after analyzing various advantages, water has been chosen as sensible heat storage material in the present study.

Experimental setupconsists of two concentric cylinders made of galvanized iron whose annulus is filled with paraffin which is sealed on both ends using sheet metal. This setup is enclosed in another concentric PVC cylinder which is insulated with glass wool. Fins are inserted in the annulus and turbulence promoters in the path of water flow in another similar setup. These vertical setup is connected to the water supply through reducers, bushes and valves. Temperatures are measured using LM35 temperature sensors connected to Arduino Leonardo. The LM35 are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±0.25°C at room temperature and ±0.75°C, over a full −55°C to 150°C temperature range.

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As the LM35 device draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. Flow is measured and maintained constant with the help of hall-effect flow sensor. Temperature is measured at 4 points: Water inlet & outlet, and 2 points in the PCM column. A relay circuit is used to control the heater temperature.

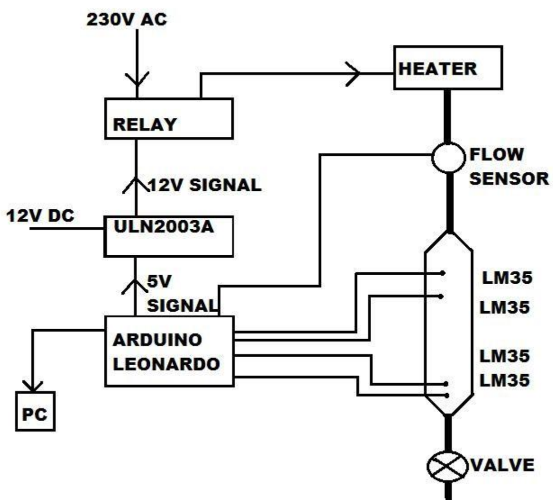

Figure 1. Schematic diagram of Temperature control relay circuit of the system

Two concentric GI pipes (32mm & 82mm) are joined and held in position and the annulus is sealed at bottom using sheet metal. Stands are welded to the annulus storage unit to hold it in a position one & half feet above the ground. Care is taken to operate the system without vibration. Holes are drilled on the outer cylinder to enable the measuring of temperature. The outer PVC pipe has to be held equidistant to the outer GI. Provision is given on the outer GI pipe to hold the PVC pipe in position to enclose the GI pipe. Fins are inserted into the annular region of the second setup. Boundary layer breaker or turbulence promoters are also introduced into the paths of water flow in the same set up. Turbulence promoter consists of long metal wire wound in the form of a spring and inserted into the water paths. PCM is melted and poured carefully into the annular region with the help of a heating coil and funnel. The top portion of the annulus is sealed with a lid made of GI.

Figure 2. Turbulence promoter and fins attached in system

Figure 3. Photograph of the system before attaching control circuit

Outer PVC pipe, having provision for entry of temperature sensor, is introduced enclosing the storage unit. Reducers are used to facilitate the connection of experimental setup with water supply. 110mm PVC pipe is reduced to 50mm using a reducer which is further reduced to 32mm using a plug and it in turn is reduced to 20mm using another reducer. Pipes and reducers are bonded using PVC solvent.

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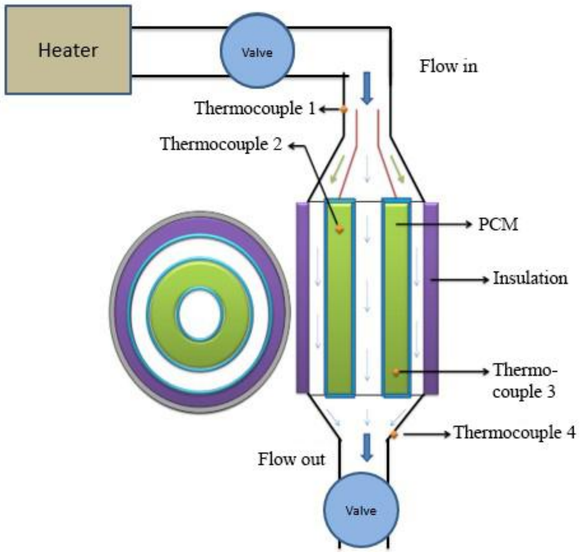

Figure 4. Schematic diagram of the triplex tube system

Probes are introduced into the holes drilled in the setup. LM35 (4 No's) is the temperature sensor used and it is connected to the Arduino board. Points where probes are inserted are sealed with m-seal. Also various joints in the setup are sealed and leak test is conducted. Glass wool (1m) is wrapped around the PVC pipe and is covered using another PVC pipe. The other end of the temperature sensors is connected to the Arduino board. Heater controller circuits are made.

Initially, temperature inside the PCM storage unit is in thermal equilibrium with the surroundings. Water is heated externally with heater to a predetermined value above the melting point of the PCM and is supplied from the top of the setup. First, the heat gets stored as sensible heat and then as latent heat. A constant flow rate is maintained with the help of a gate valve and flow sensor. The temperature is recorded every 2 seconds throughout the experiment, on a PC. Charging is stopped when the PCM temperature rises 1 °C above its melting point, i.e., at 61 °C. This procedure is repeated twice for different flow rates and inlet temperatures.

After charging, temperature inside the PCM unit is above melting point of PCM. This heat can be preserved for some time with the help of insulation material. Cold water is allowed to flow into the apparatus at a fixed rate with the help of gate valve and flow sensor. The PCM loses its heat stored both as sensible and latent heat to the water. Temperature is continuously recorded in every 2 seconds. Temperature of the outlet water increases by absorbing heat from PCM. This process is repeated twice for different flow rates.

Both charging and discharging is repeated in the experimental set up with fin and turbulence promoter. Water flow rate and inlet temperature is maintained identical to the previous cases. The temperature history is recorded for different cases with fin & turbulence promoter. The experiment is repeated after removing the turbulence promoter by keeping only the fins.

III. Result And Discussion

The figure (5) depicts the charging profile of the PCM for water flow rate of 0.86 L/min and inlet temperature fixed at 75 °C. Initially, temperature at the top portion increases at a higher rate than at the bottom portion due to more availability of heat. After the initial increase, temperature variation throughout the PCM is almost uniform. During the early stage of charging process, the heat transferred from the hot water to the triplex tube is mainly used to heat the walls of the tube and, thus to raise the temperature of the tube, which explains the rapid raise of the tube wall temperature during this period. However, as soon as temperature at wall of the tube is higher than the PCM temperature, some of the heat is transferred into the PCM that surrounds the tube and this part of the heat causes increase of the tube wall temperature. The heat transfer through the PCM is by pure conduction, before melting process starts and the temperature increases almost linearly with time afterwards. Due of the low thermal conductivity of the PCM, the temperature near the tube increases very quickly. However, after the temperature of the PCM reaches its melting point and the melting process starts, the rate of increase of PCM temperature is significantly slowed.

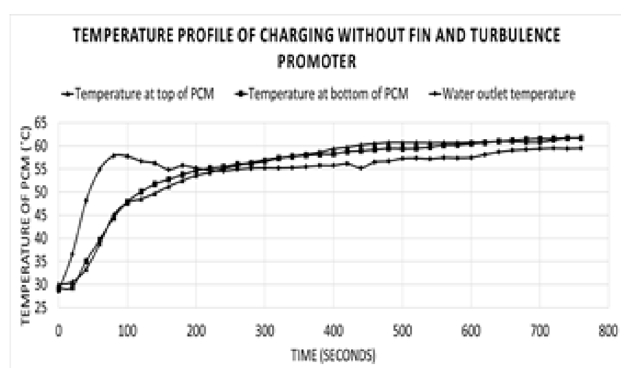

Figure 5. Temperature profile of charging without fin and turbulence promoter

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Figure (6) shows the discharging profile for a flow rate of 1.05L/min and inlet temperature of water 27°C. Temperature of PCM at the bottom portion decreases at a faster rate. This is due to the internal movement of PCM due to difference in density. At the very beginning of the process, the PCM is in the liquid state, and therefore, the effective conductivity of the PCM is well enhanced by the natural convection within the PCM. However, as the process proceeds, solidification of the PCM finally commences. Solidification of the PCM not only restrains the natural convection but produces a solid PCM layer of low thermal conductivity on the tube, therefore, less amount of heat is transferred into PCM when compared to the initial period. This tendency continuous until the process approaches its final steady state as PCM temperature approaches the cold water temperature. After that, that the system will finally acquire its new steady state with new uniform temperature distribution.

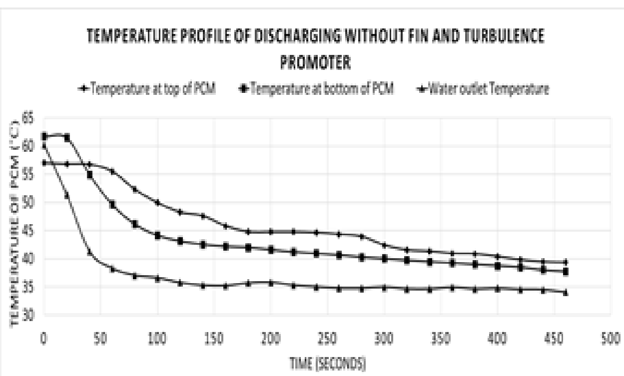

Figure 6. Temperature profile of discharging without fin and turbulence promoter

Figure (7) shows the charging profile of PCM for same inlet temperature of 70 °C and two different flow rates. The influence of the flow rate is much weaker compared with the inlet temperature during charging. This is because increasing the flow rate can only improve the convection heat transfer between the hot water and the wall section of the tube, and the thermal resistance of this convection heat transfer process is less important than the thermal conduction resistance of the PCM due to the very small thermal conductivity of the PCM. However, as the process proceeds, more and more PCM is melted and natural convection within the melted PCM gradually plays a role, and this results in a decrease in the thermal resistance in the PCM.

And this decrease in thermal resistance of the PCM increases the relative importance of the convection thermal resistance between the tube wall and the hot water in the overall heat transfer process, which results in a more apparent influence of the flow rate compared with that in the initial period. From the figure (9) it is clear that the higher flow rate during charging results in higher water outlet temperature. Figure (8) shows the discharging profile for PCM at two different water flow rates. It is clear from the graph that higher flow rate results in faster discharging. It can be seen that the flow rate condition of the cold water has an important influence. That is, under the same flow rate conditions the overall heat transfer coefficient from the cold water to the PCM is basically a constant, and therefore, the heat flow from the PCM to the cold water is directly proportional to the temperature difference between the PCM and the cold water temperature. It is clear that influence of flow rate is stronger on the charging process than on the discharging process. The PCM that is in the solid state will have low effective conductivity when compared to the liquid state. Therefore, the overall thermal resistance of heat transfer process from the hot or cold water from the PCM, is much high during the discharging process than the charging process. Figure (10) shows the profile for charging of PCM at same flow rate and two different inlet temperatures. It is clear that charging time decreases considerably for increase in inlet temperature. The inlet temperature of the hot water has a very strong and direct influence. This is because, the heat flow from the hot water to the PCM is directly proportional to the temperature difference between the hot water and the PCM. Since the initial PCM temperature is the same in these experiments, therefore the heat flow is in direct proportion to the inlet temperature of the hot water to a great extent. Thus we can conclude the time required for complete melting should, decrease directly with the increase of inlet temperature.

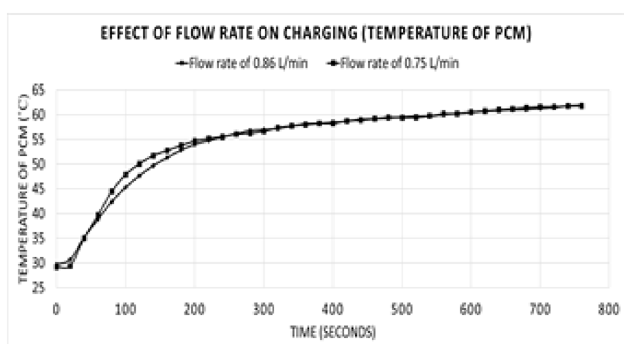

Figure 7. Effect of flow rate on charging (Temperature of PCM)

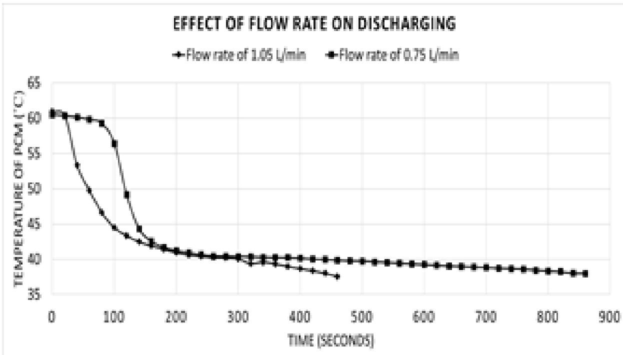

Figure 8. Effect of flow rate on discharging (Temperature of PCM)

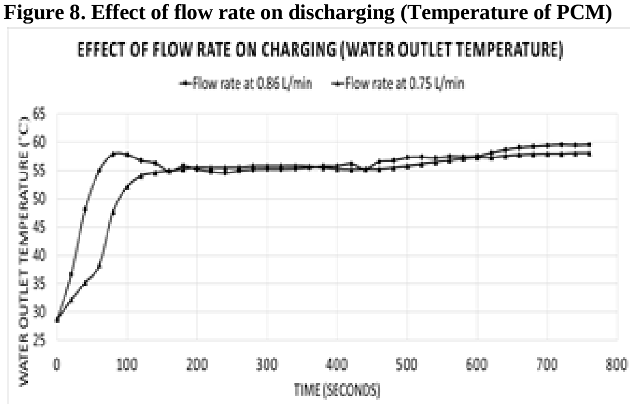

Figure 9. Effect of flow rate on charging (Water outlet temperature)

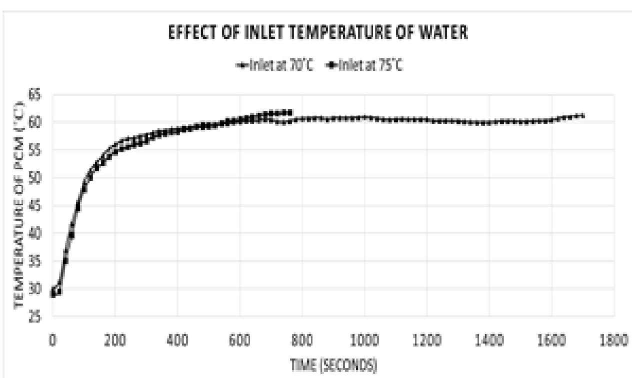

Figure 10. Effect of inlet temperature in charging

Figure (11) shows the charging profile of PCM at same inlet temperature of 70 °C and same flow rate of 0.75 L/min, for different experimental setups. The longest charging time of about 27 min is observed for the model without fin and turbulence promoter. The model with both fins and turbulence promoter gave a charging time of 25 min, and the model with fins and without turbulence promoter gave a charging time of 22 min.

Figure (12) shows the discharging profile of PCM at same inlet temperature of 70 °C and same flow rate of 0.75 L/min, for different experimental setups. The longest discharging time of about 12.5 min is observed for the model with no fin and no turbulence promoter. The model with both fins and turbulence promoter gave a discharging time of 10 min, and the model with fins and without turbulence promoter gave a charging time of 8 min.

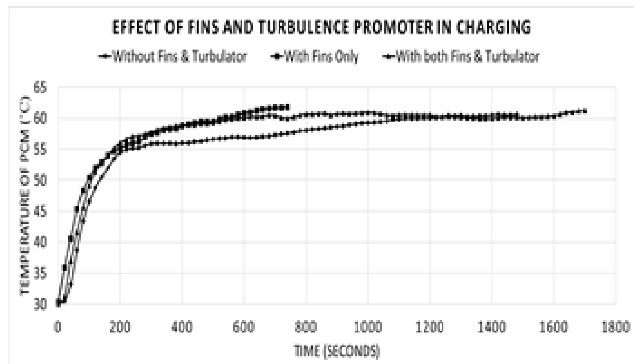

Figure 11. Effect of fins and turbulence promoter in charging

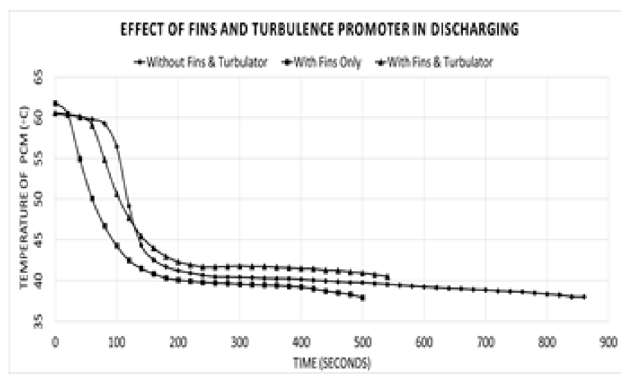

Figure 12. Effect of fins and turbulence promoter in discharging

From the above two graphs of comparison between 3 models, it is evident that fins greatly improve the heat transfer rate, but the turbulence promoter used in the model have in fact, reduced heat transfer rate. Comparing the cases between finned and bare tube it is clear that better enhancements in thermal performance is with the finned tube. It can be concluded that incorporating fins to the tube which is submerged in the PCM lead to enhancement of thermal performance than the case of bare tube as well as that with the turbulent promoter. Similar study conducted on fins and turbulent promoter [4], showed a significant increase in the heat transfer rate by using finned structure when compared to the bare model.

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The arrangement with the fin and turbulent promoter have negligible increase in heat transfer compared with the arrangement with fins.

IV. Conclusion

Results indicate that the heat transfer is enhanced in the finned arrangement. This is due to the reduction in thermal resistance. Fins can thus overcome the drawback of low thermal conductivity of PCM. The present experiment indicates reduction in heat transfer with use of turbulence promoter. This must be due to reduction in heat transfer area. The effect of higher heat transfer coefficient obtained by creating turbulence is lower than the effect of reduced heat transfer area. Thus the present investigation suggests that there is good scope for the use of triplex storage system with fins. The role of the turbulence promoters need further investigation; like optimization of the geometry and pitch.

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