# PERFORMANCE TEST ON ENCHANCEMENT OF HEAT TRANSFER USING COPPER TUBES IN THERMAL ENERGY STORAGE SYSTEM

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## ABSTRACT

This paper presents the enhancement of heat transfer and analysis of thermal performance in thermal storage system. Number of phase change materials (PCM) were analysed and paraffin was chosen in this paper. PCM storage unit was designed and developed to enhance the heat transfer rate to store heat energy in PCM storage tank. PCM storage unit consist number of copper tube filled with PCM materials. This PCM storage unit has kept in well insulated storage tank called PCM storage tank. It carries minimum of 45 litres capacity of water with glass wool insulation. Copper has high thermal conductivity and hence in order to increase enhancement of heat, bundle of copper tube was used to transfer heat from solar tank to PCM storage tank, PCM storage tank receives hot water from solar tank which has integrated with evacuated glass tube collector. Solar energy absorbed and stored in PCM storage unit as latent heat. Large quantity of solar energy can be stored in day time and the heat can be retrieved for later use. The tank was instrumented to measure inlet and outlet water temperature. Flow meters were used to measure the mass flow rate at different intervals of time. Using the observed data heat transfer rate and system effectiveness were calculated.

**Keywords:** PCM storage unit, solar collector, thermal storage system, Copper tubes.

## I. INTRODUCTION

Efficient and economical technology that can be used to store large amounts of heat in a reduced volume is a subject of research for a long time. PCM plays an important role in energy conservation, which is very attractive because of its high storage density with small temperature swing. It has been demonstrated that the development of a latent heat in thermal energy storage system which can store heat during peak power operation and release the same during reduced power operation. Phase change material is one of the many thermal storage devices average. Thermal energy storage system enhanced by encapsulating with suitable PCM materials can absorb or capture solar energy directly or thermally through natural convection. The amount of stored heat energy depends on the specific heat of the medium, the temperature change and the amount of storage material. Latent Heat Storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice - versa. This system provides a valuable solution for correcting the difference between the supply and demand of energy. Latent heat storage is a new area of study and it received more attention during early 1970s and 1980s. Many phase change materials have been studied and tested for different practical uses by many scientists. This paper attempts to analyse the application of PCM in thermal storage system. The present work mainly concentrates enhancement of heat transfer from solar tank to PCM storage tank.

Efterkhar et al. (1984) have experimentally studied a different heat transfer enhancement methods for melting of paraffin by constructing a model that consists of vertically arranged fins between two isothermal planes which not only provides additional conduction paths but also promotes natural convection with the molten PCM. Ananthanarayanan et al.(1987) developed a computer model for the estimation of temperature profiles of the solid and the fluid along the length of the packed bed of self-encapsulated Al-Si PCM shots as a function of distance along the bed and time during a series of heat storage and utilization cycles. Air was used as HTF in their study. Chen and Yue (1991) developed an ID porous medium model to determine the thermal characteristics of ice-water cool storage in packed capsules for air conditioning. Comparisons of this theory with experimental data of temperature profiles of PCM (water) and coolant (alcohol) for various porosities flow rates and different inlet coolant temperatures showed good agreements. Lacroix (1993) has presented a theoretical model for predicting the transient behaviour of a shell and tube storage test, in which annular fins were externally fixed in the inner tube with the PCM on the shell side and the HTF flowing inside the tube. The numerical results have also been validated with experimental data for various parameters like shell radius, mass flow rate inlet temperature of the HTFL.C.Chow.et al (1996) studied about two thermal conductivity enhancement techniques. the first technique focused on placing encapsulated PCM of various shapes in a liquid metal medium. The second technique involved a metal / PCM composite. Velraj et al. (1997) have presented the theoretical and experimental work for a thermal storage unit consisting a cylindrical vertical tube with internal longitudinal fins and it was concluded that this configuration which forms a v-shaped enclosure for the phase change material gives maximum benefit to the fin arrangement. I. M. Bugaje(1997) studied thermal response of paraffin wax contained in plastic tubes and used in latent heat storage systems and observed the heat of enhancement by the use of metal matrices. R.Velraj et al. (1999), investigated the different heat transfer enhancement methods for the latent heat thermal storage system and proved that enhancement can be achieved with fin configuration by using Lessing rings to increase the storage capacity. Ismail et al. (2002) represented a model for simulation of the process of heat transfer (charging and discharging) of a latent heat storage system of packed bed of spherical capsules filled with PCM. They were developed and solved numerically using a finite difference approach and moving grid technique. The numerical grid was optimized and the predicted results were compared with experimental measurements to establish the validity of the model V. Arun prasad Raja et al (2005) developed numerical simulation method and studied the enhanced heat transfer rate for water and air, in which numerical solutions were obtained for constant properties. Forced convection heat transfer in fully developed flow were compared with thermally developing laminar flow and was found that heat transfer coefficients were higher due to small channel spacing and developing laminar flow. E. Assis et,al.,(2006) presented the process of melting of a phase-change material (PCM) in spherical geometry. Nallusamy et al. (2006), dealt with the experimental evaluation of thermal performance of a packed bed latent heat Thermal Energy Storage (TES) unit integrated with solar flat plate collector, in which TES unit contained paraffin as phase change material (PCM) filled in spherical capsules, which were packed in an insulated cylindrical storage tank. Water used as heat transfer fluid (HTF) to transfer heat from the solar collector to the storage tank also acts as sensible heat storage material

The objective of the present work is to enhance the heat transfer performance in thermal energy storage system using PCM filled copper tubes, integrated with solar collector water heating system. Parametric studies were carried out and the effectiveness of the storage unit was calculated.

## II. CLASSIFICATION OF PHASE CHANGE MATERIALS (PCM)

PCMs are generally divided into two main groups' organic and inorganic compounds as shown in

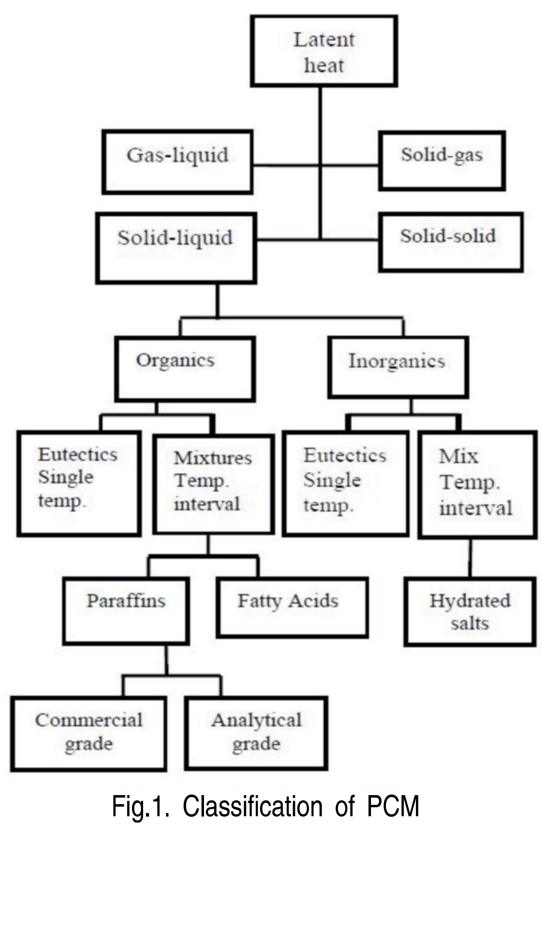


Fig.1. Classification of PCM

Fig.1.Organic compounds present several advantages like ability of congruently melting, self-nucleating properties, non-corrosive behaviour and compatibility with conventional materials of construction. Sub-groups of organic compounds include paraffin and non-paraffin organics.

## III. PHASE CHANGE MATERIALS AND ITS CHARACTERISTICS

Phase Change Material is the latent heat storage material as the source temperature rises, the chemical bonds within the PCM break up and the material changes its phase from solid to liquid. During the charging process, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished as illustrated in Fig.2.

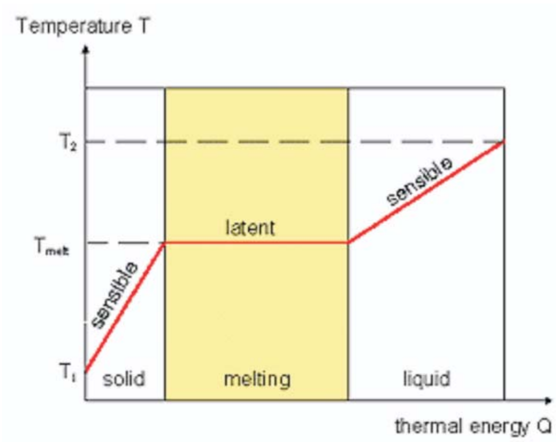


Fig. 2. Charging Process of PCM

The Fig.2 shows the heat stored during the phase change process (melting process) of the material is called Latent Heat. It takes isothermal behaviours during charging and discharging process. Here paraffin is used as PCM in which the latent heat storage can be achieved through solid-solid, solid-liquid, solid-gas and liquid-gas phase change. However, the only phase change used for PCM is the solid-liquid change. Liquid-gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials in their gas phase. Liquid-gas transitions do have a higher heat of transformation than solid-liquid transitions. Solid-solid phase changes are typically very slow and have a rather low heat of transformation. Initially, the solid-liquid PCM behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCM reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant raise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCM are available in any required temperature range from – 5°C up to 190°C and more. Within the human comfort range of 20° to 30°C, some PCM are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry, or rock.

Paraffin has an excellent stability concerning the thermal cycling, i.e. a very high number of phase changes can be performed without a change of the material's characteristics. On the other hand they are flammable and their melting enthalpy and density are relatively low compared to salt hydrates. The problem with salt hydrates is their corrosiveness and the cycling stability. The PCM undergoes a phase change by absorbing latent heat. Excess heat can be stored as sensible heat. Important characteristics of paraffin are listed below have listed out in the following steps

(i) Suitablemeltingtemperature

(ii) High melting enthalpy per volume unit [kJ/m$^3$]

(iii) High specific heat [kJ/(kg.K)]

(iv) Low volume change due to the phase change

(v) High thermal conductivity

(vi) Cycling stability

(vii) Not flammable, not poisonous

(viii) Not corrosive

## IV. PCM STORAGE UNIT AND COPPER TUBE SPECIFICATION

The experimental PCM storage unit is a concentric cylinder 75cm length. The inside cylinder 30 cm and outer cylinder 37 cm in diameter made of stainless steel. Copper tube bundle containing 50 tubes 60 cm in length 1.5 cm in diameter and 1.5mm thick as shown in Fig.3 is fitted in the inner cylinder. Each copper tube in the bundle was packed with 100 gms of PCM. In order to reduce the heat transfer to the environment the storage tank is thermally by filling the annulus with glass wool. Water was used as the heat transfer fluid (HTF) and was circulated over the copper tubes. The storage tank is designed as adiabatic one with no heat transfer. The PCM storage tank containing numbers of copper tube, each tube carrying minimum of 100gm PCM, totally 5kg PCM were used, and the entire setup kept in well insulated stainless steel tank with45 litres capacity of water. The heat transfer during sunlight, i.e. the active phase, hot fluid heats the PCM, the PCM melts and the heat is stored in the absences of sun light, i.e. eclipse phase the PCM solidifies and the stored heat is delivered to the cold fluid.

Fig. 3. Copper tubes

Copper possesses very good thermal conductivity and is also available easily; hence copper materials can be used effectively in thermal storage systems. Insulation is an important factor in thermal storage systems. Hence proper capping in each of the copper tube was done after installing the PCM material, for effective insulation work. Proper insulation and high thermal conductivity of these copper tubes provide secure thermal storage system which retains heat for long time and reduce energy wastage.

## V. SPECIFICATION OF SOLAR COLLECTOR AND SOLAR TANK

Solar tank of 100 litres storage capacity containing 15 numbers of evacuated glass solar collectors each of length 138cm, breadth 100cm and 4cm clearance were used. Height of the solar tank from


Fig. 4. Solar collector and solar tank

the base of the collector was ensured to be 65cm. The maximum permissible working pressure maintained for the solar water heater with evacuated tube collector was 0.4kg/cm$^2$.The PCM storage unit was integrated with the solar collector and tank as shown in Fig.4.Each of the solar collector is concentric and is made of borosilicate glass tubes. The outside surface of inner glass tube is coated with special solar selective coating, which absorbs and converts the maximum amount of solar radiation into heat. The space between outer and inner glass tubes is evacuated and permanently sealed off, the vacuum acts as an excellent insulator

## VI. EXPERIMENTAL SETUP

The experimental set-up consists of two storage tanks one is a solar tank having a capacity of 100 litres and the other a PCM storage tank (fabricated storage tank) having a capacity of 45 litres as shown in Fig. 5& 6 respectively. Instrumentation of the tank with thermocouple arrangement was done to measure


Fig. 5. Experimental setup

inlet and outlet water temperatures. Temperature was noted for 10 minutes of time interval. For later use hot water was drained and cold water was supplied to PCM tank , where the cold water absorbs heat from the PCM and releases hot water continuously. The experiment was stopped when PCM and water temperatures were the same.

Fig. 6. Experimental setup with Thermocouples

## VII. RESULTS AND DISCUSSIONS

Heat transfer and effectiveness by natural convection for this specific geometry was calculated and the results are represented in Figures 7, 8 and 9. The results show that PC materials like paraffin increases heat transfer rate when cooled down the 60°C to 45°C on pouring the cold water after draining the hot water (which assures a complete solidification of the PCM). Among the thermal energy storage concepts, latent heat thermal storage is regarded as a promising technology. Here volumetric expansion during melting is negligible.

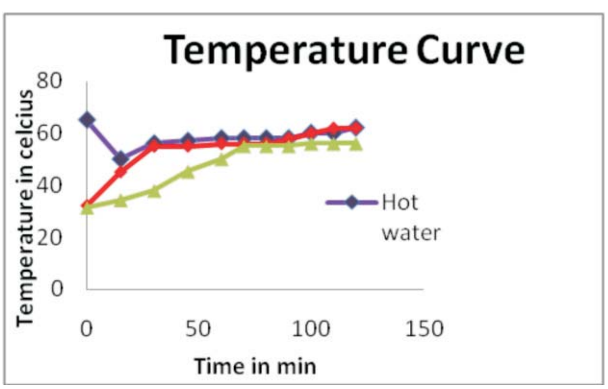


Fig. 7. Temperature Curve

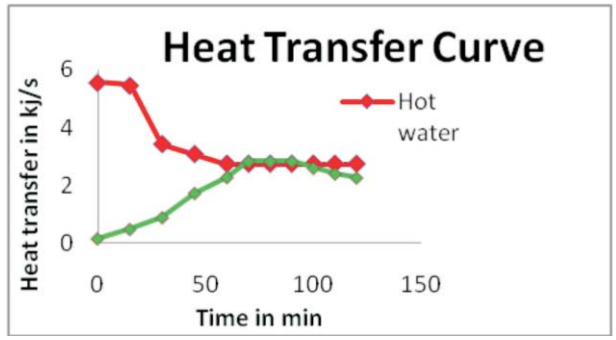


Fig. 8. Heat Transfer Curve

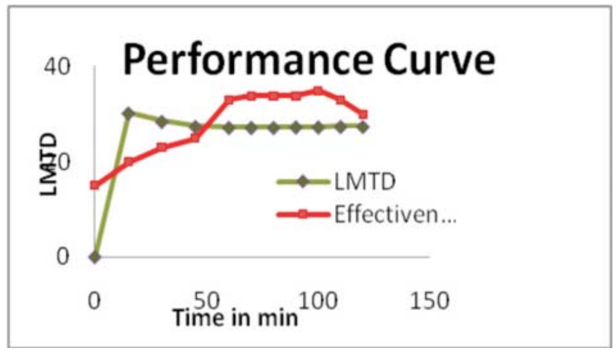


Fig. 9. Performance Curve

Fig-7 & 8 shows the increase in temperature is higher in water than in the PCM as more quantity of heat is absorbed by the water than the amount of heat it gives to the PCM. This is due to the higher resistance offered by the solid PCM for heat flow. A stage is reached when the entire heat in the HTF (hot water) is transferred to PCM by convection. Hence beyond this stage, hot water temperature also remains nearly constant, also copper tubes are having high thermal conductivity hence in short time it heat was transferred from the hot water to PCM materials.Fig.9 shows the LMDT curve in which the difference of temperature between HTF and PCM is considerably less hence it becomes constant after a long time duration. With respect to time variations effectiveness is also found varying due to the energy loss. Hence the analysis proved that PCM tank would keep hot water for a longer time, in which a lot of energy can be stored as latent heat and stored heat can be retrieved later.

## VIII. CONCLUSION

The insulated thermal storage tank contains number of copper tubes with PCM materials which absorbs available heat during peak hour periods of day time and heat is stored in encapsulated PCM tubes and it can be retrieved from the tank during off peak hours. Hence hot water can be had even in the absence of sun rays. The use of PCM in a water tank working with a solar system allows a lot of energy to be stored. An experimental work was designed and carried out to determine heat transfer. The results proved that the technical potential of PCM increases heat storages in encapsulated copper tubes. Also the PCM modules can be used to store energy in a reduced volume. However with design modifications and replacement of Parrafin with higher latent heat capacity PCMs the heat carrying capacity of the proposed system can be achieved in future.

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