EXPERIMENTAL STUDY OF HEAT TRANSFER ENHANCEMENT IN LATENT HEAT THERMAL STORAGE SYSTEM DURING CHARGING AND DISCHARGING PROCESSES

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ABSTRACT

The objective of the present study was to investigate the thermal characteristics of paraffin in fabricated storage tank during charging and discharge processes. Experiments were performed with phase change materials in which PCM storage unit was designed and developed to enhance heat energy in PCM storage tank. PCM storage unit consisting number of copper tube each tube filled with PCM materials. During charging process heat energy can be stored in copper tube as latent heat, the same heat can be recovered during discharging process by applying cold water .This PCM storage unit kept in well insulated storage tank called PCM storage tank. It carries minimum of 45 litres capacity of water with glass wool insulation. Copper having high thermal conductivity hence in order to increases enhancement of heat, bundle of copper tubes were used to transfer heat from solar tank to PCM storage tank, PCM storage tank received hot water from solar tank, solar tank integrated with evacuated glass tubes collector. Solar energy has absorbed and stored in PCM storage unit as latent heat. Large quantity of solar energy can be stored in a day time and same heat can be retrieved for later use. The tank was instrumented to measure inlet and outlet water temperature. Flow meters are used to measure the mass flow rate at different interval of time. Then performance of charging and discharging as discussed.

Keywords: PCM storage unit, solar collector, thermal storage system, Copper tube, LHTSS

I. INTRODUCTION

Thermal energy storage plays an important role in an effective use of thermal energy and has applications in diverse areas, such as building heating/cooling systems, solar energy collectors, power and industrial waste heat recovery. Among several thermal energy storage techniques, latent thermal energy storage is a particularly attractive technique that provides a high storage capacity per unit mass (and also per unit volume generally) and has the property of storing heat as the latent heat of fusion at a constant temperature, i.e. the phase change temperature. Phase change materials (PCMs) that are used as storage media in latent thermal energy storage can be classified into two major categories: inorganic compounds and organic compounds. In organic PCMs include salt hydrates, salts, metals and alloys, whereas organic PCMs are comprised of paraffin, fatty acids/esters and polyalcohol's. Paraffin is taken as the most promising phase change material because it has a large latent heat and low cost and is stable, nontoxic and not corrosive. However, paraffin waxes suffer from a low thermal conductivity and liquid leakage when they undergo the solid–liquid phase change. These drawbacks reduce the rate of heat storage and extraction during the melting and solidification cycles and restrict their wide applications, respectively.

Energy storage leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy. In most systems, there is a mismatch between the energy supply and consumption of energy. The energy storage can even out this imbalance and thereby helps in saving of capital costs. Increasing energy demands, shortages of fossil fuels, and concerns over environmental impact have provided impetus to the development of renewable energy sources. Solar energy, a major renewable energy resource, is of intermittent nature and its effective utilization is in part dependent on efficient and effective energy storage systems. If no energy storage is used in solar energy systems, the major part of the energy demand will be met by the back-up or auxiliary energy and therefore the annual solar load fraction will be very low. The thermal energy can be stored when energy is abundantly available and used as and when required. However, it is clear that if solar energy is to become an important energy source, efficient, economical and reliable solar thermal energy storage devices and methods will have to be developed. The idea to use phase change materials (PCM) for the purpose of storing thermal energy is to make use of the latent heat of a phase change, usually between the solid and the liquid state. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes. The successful usage of PCMs is on one hand a question of a high energy storage density, but on the other hand it is very important to be able to charge and discharge the energy storage with a thermal power, that is suitable for the desired application. One major drawback of latent thermal energy storage is the low thermal conductivity of the materials used as PCMs, which limits the power that can be extracted from the thermal energy storage. In the work presented in this paper different ways of the integration of PCMs into thermal energy storage were investigated. Different PCM materials, with and without enhancement of the thermal conductivity, were used, and their performance concerning the resulting charge/discharge power of a storage tank was tested experimentally. Here some relevant literature reviews are as follows: Efterkhar et al. (1984) have experimentally studied a different heat transfer enhancement method 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 functions 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 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 are investigated the first technique focuses on placing encapsulated PCM of various shapes in a liquid metal medium. The second technique involves 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 was enhanced by the use of metal matrices R.Velraj et al. (1999), In this paper a detailed investigation of the different heat transfer enhancement methods for the latent heat thermal storage system has been carried out, Enhancement has been done with fin configuration and by Lessing rings are used 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 was developed and solved numerically by 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, he has enhanced heat transfer rate for water and air, computational fluid dynamics software (FLUENT) used. In which numerical solution were obtained for constant properties, forced convection heat transfer in fully developed flow were compared with thermally developing laminar flow, it was found that heat transfer coefficients were higher due to small channel spacing and developing laminar flow. The author E. Assis et,al.,(2006) presented the process of melting of a phase-change material (PCM) in spherical geometry has been explored experimentally and numerically. Melting temperature of the PCM was incorporated in the simulations along with its other properties, Nallusamy et al. (2006), deals with the experimental evaluation of thermal performance of a packed bed latent heat TES unit integrated with solar flat plate collector. The TES unit contains paraffin as phase change material (PCM) filled in spherical capsules, which are packed in an insulated cylindrical storage tank. The 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 same author did the work of thermal energy storage system for the use of hot water at an average temperature of 45ºC for domestic applications using combined sensible and latent heat storage concept. The objective of the present work is to enhance the heat transfer performance in thermal energy storage system using PCM filled copper tubes, the storage unit integrated with solar collector water heating system. The storage tank contained encapsulated copper tubes surrounded by hot water. Parametric studies were carried out and the effectiveness of the storage unit performed

II. REQUIREMENTS OF LATENT HEAT THERMAL ENERGY STORAGE

A good design of latent heat thermal energy storage requires the knowledge of PCMs and the heat exchange processes especially the melting and solidification processes in a containment. Thermal energy storage (TES) is an advanced energy technology that has recently attracted increasing interest for thermal applications such as space and water heating, cooling and air-conditioning. TES system has enormous potential to facilitate more effective use of thermal equipment and large scale energy substitutions that are economic. TES appears to be the most appropriate method for correcting the mismatch that sometimes occurs between the supply and demand of energy. It is therefore a very attractive technology for meeting society's needs and desires for more 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 is 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 being stored as sensible heat, important characteristics have listed out in the following steps

(i) Suitable melting temperature

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

(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

III. PCM STORAGE UNIT AND COPPER TUBE SPECIFICATION

The PCM storage tank contains PCM storage unit, the storage unit having 50 numbers of copper tube, each tube carries minimum of400 gm PCM, totally 20 kg of PCM were used, and the entire setup kept in well insulated stainless steel tank with45 litres capacity of water. The heat transfer fluid flows by convection through the copper tubes. The storage tank accurately considered as adiabatic no heat transfer. The experimental test unit consisted of two concentric cylinder with 75 cm lengths. The inside cylinder with inner diameter of 30 cm and outer diameter of 37 cm was made of stainless steel (304 L), inside the tank the number of copper tubes has kept with dimension of length 60 cm, 1.5 cm diameter and thickness of 1.5 mm. In order to reduce the heat transfer to the environment the storage tank was thermally well insulated as glass wool. Water was used as the HTF and it circulated throughout the tank between the copper tubes. The tube was filled with the PCM.

Copper posses very good thermal conductivity and is also available easily, so copper materials can be used effectively in thermal storage systems. A bundle of 50 copper tubes were fabricated for the purpose of installing PCM materials. 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.

IV. SPECIFICATION OF SOLAR COLLECTOR AND SOLAR TANK

Storage capacity of solar tank has 100 litres, Solar collector having 15 numbers of evacuated glass tube, Length of the collector tube 138 cm, Breadth of the solar collector 100 cm, Height of the solar tank from the base of the collector 65 cm, Gap between the tubes 4 cm, The maximum permissible working pressure of solar water heater with evacuated tube collector is 0.4 kg/cm^2.Solar collector having the evacuated glass tube. the evacuated tube solar collector are the key component of solar water heater, two concentric borosilicate glass tubes configure each of them, 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.

V. EXPERIMENTAL SETUP

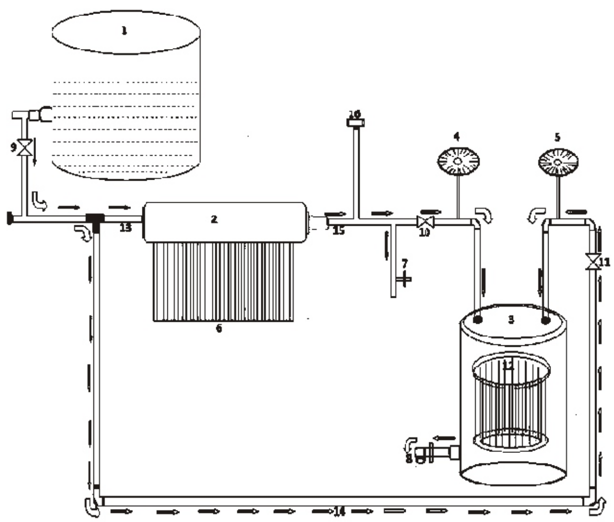

Fig. 1. Experimental Setup

Fig-1 shows the experimental setup and connectivity of the points.1-Cold Water Tank, (capacity 1000 Litres); 2-Solar Water Tank (capacity 100 Litres); 3-Fabricated Storage Tank (capacity 45Litres); 4 & 5-Flow Meter; 6-Solar Collector (evacuated tube); 7 & 8-out let tap; 9,10 & 11-Valves; 12-Bundle Of Copper Tubes; 13-Pipe (cold water towards solar water tank); 14-Pipe (cold water towards fabricated storage tank); 15-Pipe (hot water towards fabricated storage tank) The experimental set-up having two storage tanks one is solar tank having storage capacity of 100 litres and another one is PCM storage tank (fabricated storage tank) having capacity 45 litres with height of 65 cm and 30 cm diameter. The PCM storage tank was instrumented to measure temperature and flow rates, which is connected to solar tank integrated with evacuated glass tube collector. PCM copper tubes were introduced in the PCM storage tank and the performance of the system was tested. The tank was instrumented to measure inlet and outlet water temperature with thermocouples arrangement. The differences of temperature with respect to time have been noted during charging and discharging processes. for later use hot water is drained and cold water is supplied to PCM tank these cold water absorb heat from the PCM and releasing hot water continuously. The experimental work consisted on introducing the module containing melted PCM at $58-64°C$ into the cold water tank to evaluate the heat transfer phenomenon. The experiment was stopped when PCM and water temperatures were the same.

VI. RESULTS AND DISCUSSIONS

As the charging process proceeds, energy storage is achieved by melting the PCM at a constant temperature. The energy is then stored as sensible heat in liquid PCM. Temperatures of the PCM and HTF at different locations of the TES tank as shown in following figures. The charging process is continued until the PCM temperature reaches the value of 76°C.

A. Charging process

The temperature variation of heat transfer fluid (HTF) inside the storage tank at different interval of segments at $x=$ 0.25, 0.50, 0.75 and 1.0 were noted and corresponding temperature of PCM also noted and plotted graphs for both HTF & PCM. It is observed from figures 2 & 3 that the temperature of HTF at all segments increases gradually until it reaches temperature of 76°C in case of PCM temperature at different intervals the temperature is gradually increases until it reaches the temperature of 58°C and then it remains nearly constant at 58°C for a period of 90 minutes, during the time enormous heat can be absorbed by PCM and undergoes phase change at 58°C. After that the PCM temperature increases up to 76°C. As the charging process proceeds, energy storage is achieved by melting the PCM at a constant temperature. Also it is noted from the Fig-2 that the PCM in the initial stages is gradually increases after that a certain period it is maintained for isothermal process. The charging process is terminated when the PCM temperature in all the segments reaches 76°C. It is also observed from both the figures 2 & 3 that there is significant temperature difference between each segment from top to bottom of the storage tank during charging process of HTF and solid PCM. The reason is that the water temperature in the storage tank increases gradually in accordance with inlet temperature of HTF supplied from the solar tank and the PCM temperature also increases gradually along with HTF temperature.

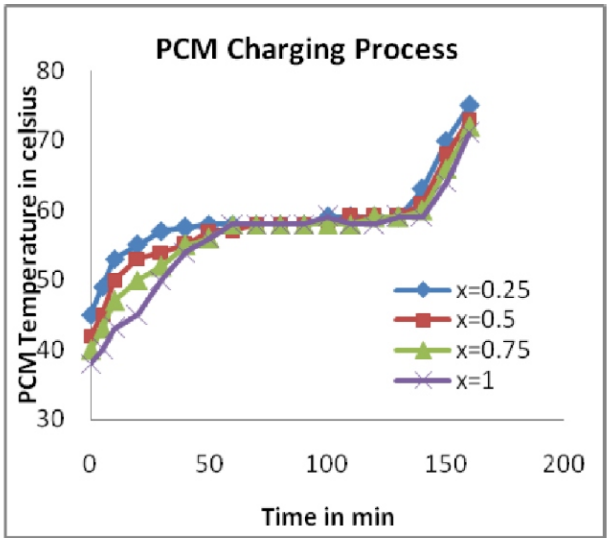

Fig. 2. Charging Process of PCM

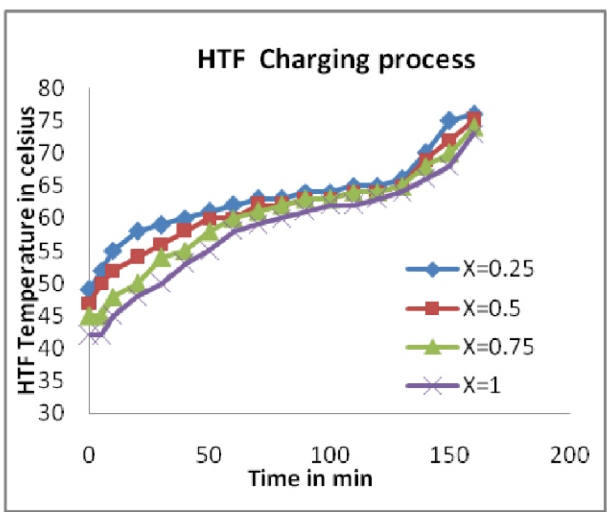

Fig. 3. Charging process of HTF

Also the effect of flow rate of HTF can be obtained by varying the mass flow rate as 2kg/min, 4kg/min, and 6kg/min during the charging process of storage tank. The fig-4 shows increase in mass flow rate has a significant difference between them since large influence on the phase transition process of PCM. As the flow rate increases the time required for the complete charging becomes smaller. This is because an increase in surface heat transfer coefficient between the HTF and PCM capsules. Hence mass flow rate has significant effect on the time for charging the storage tank.

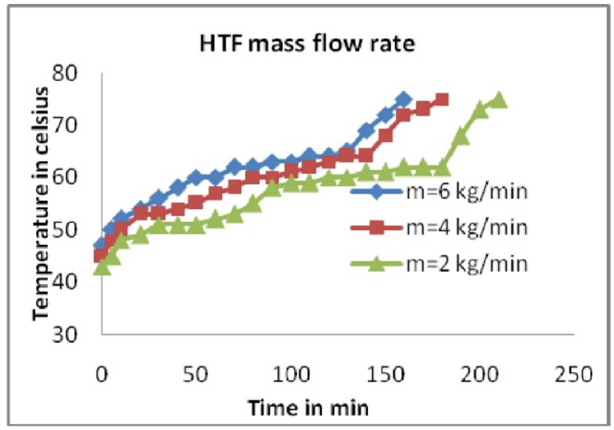

Fig. 4. HTF Mass flow Rate

B. Discharging process

The temperature variation of HTF and PCM during discharging process as noted and plotted graph for both HTF and PCM as shown in the fig 5 & 6, after unloading the hot water discharging process was carried out by applying cold water at 32°C to storage tank then allowing time to release latent heat from PCM to cold water then the cold water is converted to hot water by absorbing heat from PCM It is seen from the figure 5 at the beginning the temperature drop is large until the PCM reaches its phase transition temperature, After that the temperature drop in the PCM is negligible for a long duration as the PCM releases its latent heat. In the case of discharging process the PCM temperature is nearly constant for duration of 150 minutes. After complete solidification of the PCM, its temperature starts decreasing however the rate of temperature drop is not as high as in the beginning of the discharging process. This is due to low temperature difference between the PCM and cold water inlet temperature It is shown in the fig that a comparative study was made between the charging and discharging process in which the discharge process PCM temperature is maintained for long duration up to that we can retrieve hot water continuously from PCM storage tank. The same procedure has repeated for various mass flow rate of cold water until the PCM temperature coincidence with cold water (inlet water) temperature.

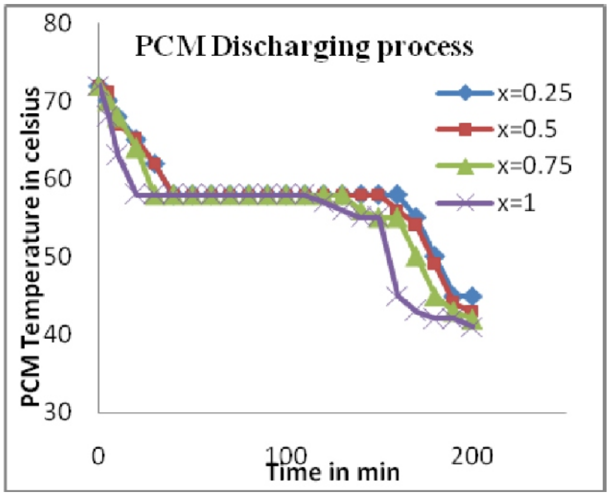

Fig. 5. Discharging Process of PCM

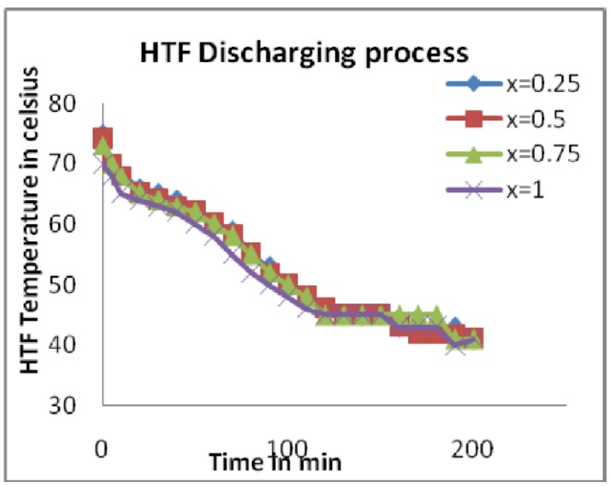

Fig. 6. Discharging Process of HTF

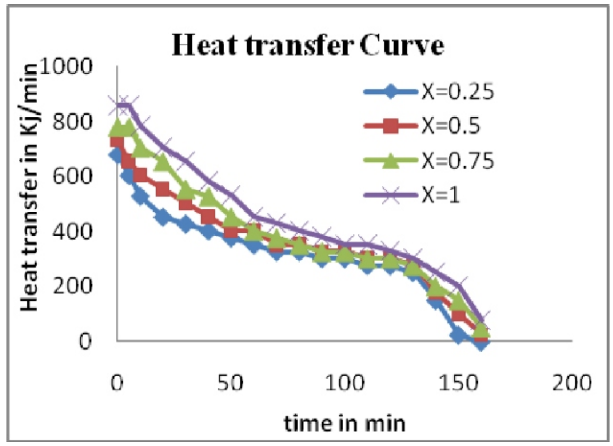

Fig. 7. Heat Trasfer Curve for HTF

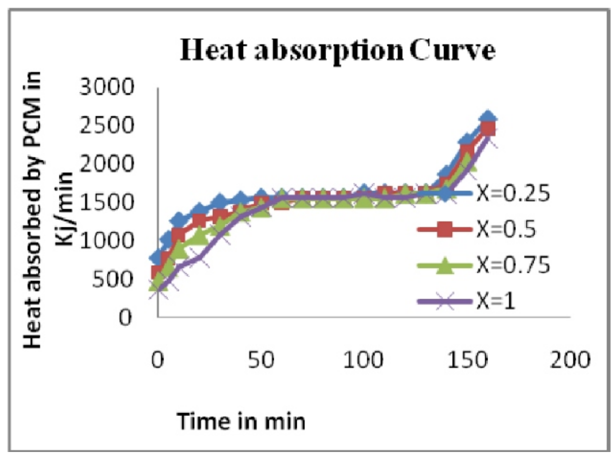

Fig. 8. Heat absorption Curve for PCM

Since the below graph shows great difference between the ordinary storage and storage with PCM materials, the experimental results showed PCM materials like paraffin increases heat transfer rate when cool down the PCM from 76°C to 45°C when pouring the cold water after drained the hot water (which assures a complete solidification of the PCM). Hence Efficient and reliable thermal storage systems are an important requirement for many applications due to non-coinciding heat demand. Among the thermal energy storage concepts, latent heat thermal storage is regarded as a promising technology.

A Phase Change Material (PCM) is used for latent heat thermal storage. In Fig. 8 shows their use in Domestic Hot Water tanks would keep hot water for a longer time. In such a system, a lot of energy can be stored as latent heat, but it should be able to be transferred from the PCM to the water when needed, therefore heat transfer within the PCM and to the water is of high interest .The increase of the heat transfer rate obtained by using encapsulation PCM tubes inside water tanks. These PCM modules are used to store energy in a reduced volume

VII. CONCLUSION

The idea to use phase change materials for the purpose of storing thermal energy is to make use of the latent heat in the phase change materials. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes The use of PCM in a water tank working with a solar system allows a lot of energy to be stored during charging process, while discharging process it is necessary to transfer this energy during demand. An experimental work was designed and carried out to determine heat absorption. The results proved the technical potential of PCM increases heat storage systems using PCM. The Heat carrying capacity of the PCM tank is increased by two to three times for the same size of the heating vessel. It is possible to increase the heat carrying capacity in future with the help of little design modifications and changing the PCM with higher Latent heat capacities.

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