EXPERIMENTAL STUDY OF SOLIDIFICATION OF PARAFFIN WAX IN SOLAR BASED TRIPLE CONCENTRIC TUBE THERMAL ENERGY STORAGE SYSTEM

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This paper addresses an experimental investigation of a Solar based Thermal Energy Storage system to meet current energy demand especially for milk industry in Tamilnadu, India. A solar based energy storage system has been designed to study the heat transfer characteristics of paraffin wax where it is filled in the middle tube, with cold heat transfer fluid flowing outer tube, inner tube, and both tubes at a time during solidification process in a horizontal triple concentric heat exchanger. In this study, main concentrations are temperature distributions in the energy storage materials such as paraffin wax during solidification process and total solidification time. And three heat recovery methods were used to solidify paraffin wax from the inside tube, outside tube and both tubes methods to improve the heat transfer between heat transfer fluid and phase change materials(PCM). The experiment has been performed for different heat transfer fluid mass flow rates and different inlet temperatures and predicted results shows that solidification time is reduced.

Keywords*: Thermal energy storage, phase change materials, paraffin, solidification*

1. Introduction

Rapid industrial and economic growth in developing countries have increased the need for sustainable energy sources in recent years. Considering environmental protection, and also the great uncertainty over future energy supplies, there is a strong focus on the utilization of sustainable energy sources and energy conservation methodologies. The energy demand pattern in the commercial, industrial and utility sectors varies on a daily, weekly and seasonal basis. Energy storage units, integrated into the energy management networks of commercial and industrial buildings, can make better use of local waste heat energy sources, reducing the mismatch between the heat supply and demand. Thermal Energy Storage is one of the key technologies for energy conservation and has recently been developed to a point where it can have a significant impact on modern technologies. Thermal energy storage is the temporary storage of high or low temperature energy for later use, and it is the most appropriate method to reduce the mismatch between the energy supply and energy demand. Solar thermal energy is the cheapest and widely available renewable energy that often replaces fossil-fuelled or electrical water heating, reducing utility bills and greenhouse gas emissions. All the developed nations are in the process of promoting the use of solar energy for various applications.

In many engineering sectors, circular tubes are used commonly for heat transfer. Maximum heat transfer-minimum weight thermal dissipation systems are imperative in new applications such as electronic systems, compact heat exchangers as well as well-known automotive and aerospace industries etc.The heat transfer enhancement techniques are commonly used in areas such as process industries, heating and cooling r, thermal power plants, air conditioning equipment's, refrigerators, radiators for space vehicles and automobiles, etc.

Till date, a large number of attempts have been made to make the heat exchanger compact and achieve a high heat transfer rate with minimum pumping power.Very few researchers have now started to focus in triple tube arrangements useful for various products that are found in the dairy, food, beverage and pharmaceutical industries. Basal et al. [1] A new type thermal energy storage system consisting of a triple concentric-tube arrangement is investigated, an annulus shaped PCM layer that is in contact with the heat transfer fluid from both inner and outer surfaces provides a larger heat transfer area and numerical investigations conducted by using an enthalpy method. Abduljalil et al [2] have investigated the application of a triplex tube heat exchanger with a phase-change material (PCM) (paraffin wax RT 82) in the middle tube to power a liquid-desiccant air-conditioning system. The PCM temperature gradients in the radial, angular, and axial directions were analyzed. Abduljalil et al(2014) [3] have investigated the PCM charging process under steady and non-steady heat transfer fluid (HTF) inlet temperature and the influence of the mass flow rates on the PCM melting process. Abduljalil et al(2013) [4] heat transfer enhancement technique by using internal and external fins for PCM melting in a triplex tube heat exchanger (TTHX) was investigated numerically. A two-dimensional numerical model is developed using the Fluent 6.3.26 software program, and pure conduction and natural convection are considered in the simulation.

The objective of the present work is to investigate temperature distributions in the energy storage materials such as paraffin wax during solidification process and total solidification time. And three heat recovery methods were used to solidify the paraffin wax from the inside tube, outside tube and both tubes methods to improve the heat transfer between heat transfer fluid and phase change material (PCM). The experiment has been performed for different heat transfer fluid mass flow rates and different inlet temperatures.

2. Experimental Procedure

Schematic diagram of the experimental apparatus is shown in fig.1. It consists of triple tube heat exchanger, 100 l solar water heater, temperature indicator- k type thermocouples, rotameter, and solar power meter. The Experimental setup consists of three pipes placed concentrically. In this work the paraffin wax used as phase change material. The PCM is placed in annular space of the heat exchanger. There are eight k types thermocouples are used to find the temperature distributions in the PCM and inlet and outlet temperatures of fluid and each placed in equal distance of the tube. The various properties of the phase change material are shown in the table below. 100 l evacuated tube collector solar water heater is connected with triple tube concentric heat exchanger to supply hot water to melt the PCM during the day time. The control valve is used to change the flow rate of the heat transfer fluid and rotameter is used to measure different flow rates of fluid. Paraffin wax is filled in the middle tube and heat transfer fluid is circulated through inner and outer tube to transfer the heat and melt PCM to reduce time compared with the base model that is double tube arrangements. The mass flow rates, time, solar radiation and temperatures are measured at equal time of intervals until steady state reached. Section of PCM mainly consider below mentioned properties to apply wherever required to meet.

Storage Medium (PCM)	-	Paraffin Wax
Mass of PCM	-	0.5 kg
Heat Transfer Fluid (HTF)	-	Water
HTF & Storage tube	-	Copper &Mild steel
Insulation	-	Glass Wool
Outer Cladding	-	Aluminum

Table 1.Properties of paraffin wax

S. No	**Properties**	**Value**
1	Melting Temperature,·C	58-60
2	Heat of fusion,kJ/kg	214
3	Thermal Conductivity,W/m-k	0.24
4	Density,kg/m^3	910
5	Specific heat capacity,kJ/kg K	1.85

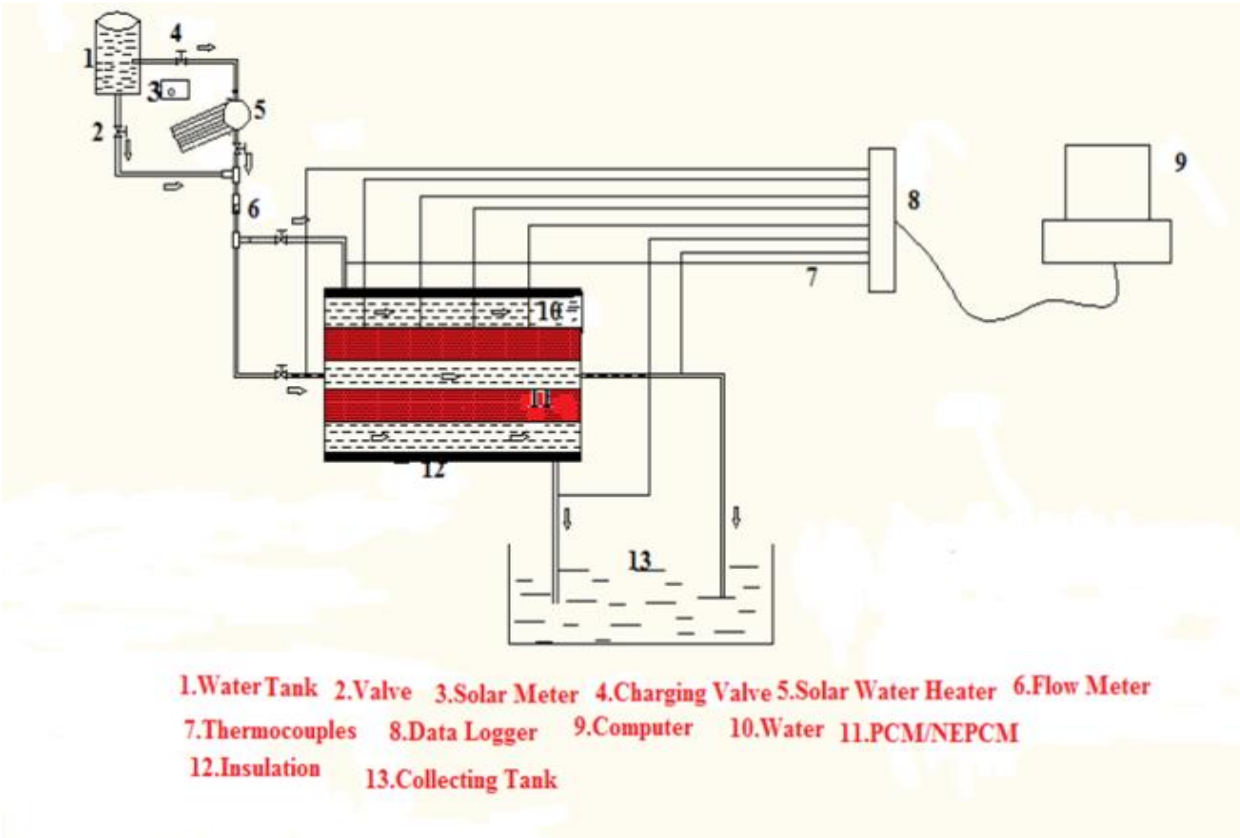


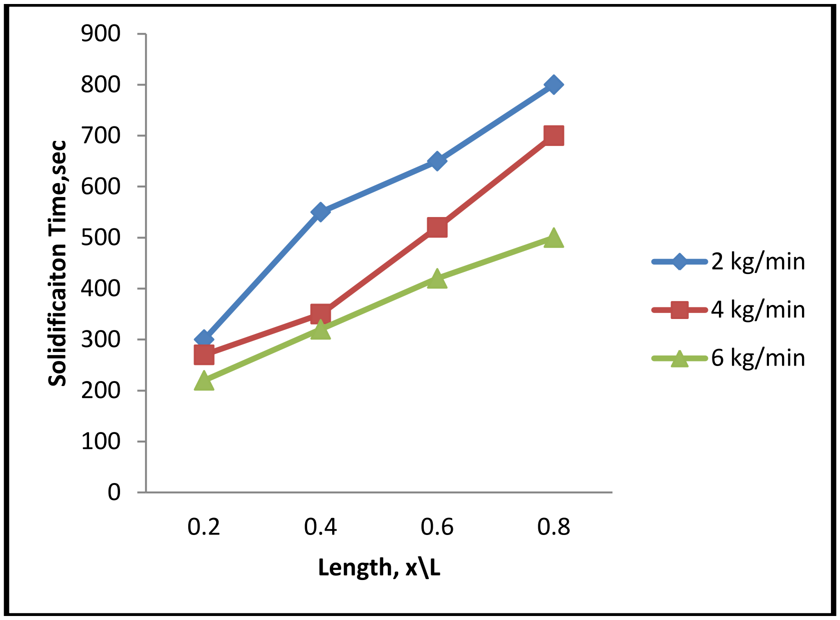
Figure 1. Schematic layout of the experimental setup

3. Results and Discussion

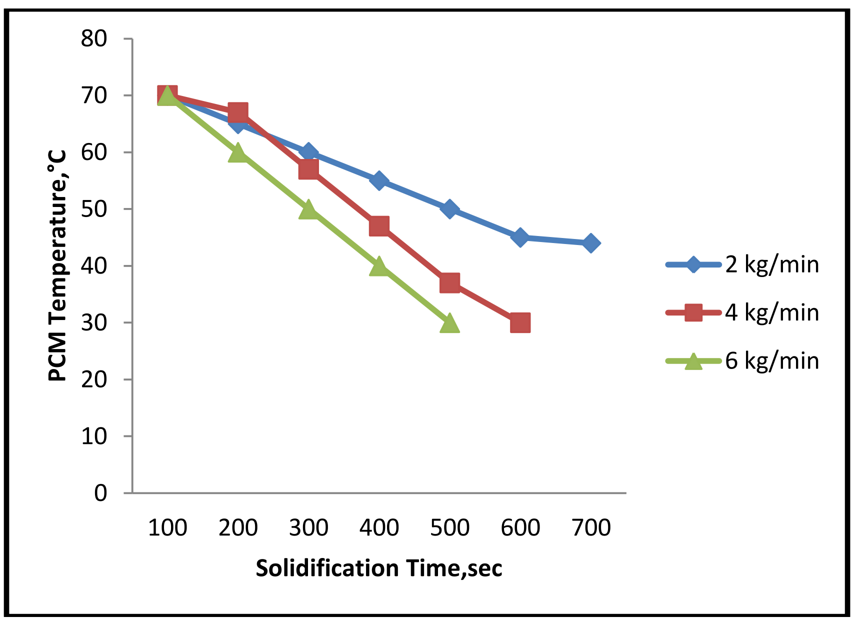
The purpose of the experimental investigation is to study the temperature variation inside the storage tank during the discharging process**.** The solidification process of PCM totally depends on the low temperature of HTF. The operating mass flow rates and inlet water temperatures for this PCM were taken 2 kg/min, 4 kg/min and 6 kg/min and 30 °C.Three methods of retrieval of energy from PCM, one by one method is trialed in a number of experiment and readings are taken to compare at equal times of different days in Nagapattinam.

First both side energy retrieval methods that are low-temperature heat transfer fluid is circulated between both side inlet of the triple pipe concentric pipe is trailed in different mass flow rates and it is measured by the rotameter (0 to 10 l/min) and before that the experiment is started to melt the PCM completely in the storage tank, utilizing the solar radiation of different days. Figure 3.1(a) shows the variation of the solidification time at various lengths in the storage tank during the discharging process. The location of the thermocouple in the storage tank at various length, with respect to the length of the storage tank is given on the horizontal axis. x/L = 0 indicates the initial and x/L=1 end location of the storage tank. If the mass flow rate of HTF is increased the solidification time is reduced and it varied for different length position of storage pipe. It is observed from Figure 3.1(b) that the temperature of the thermocouples located at near position increases at a faster rate. The thermocouple location is very close to the entry of the low heat transfer fluid, and hence, the increase in temperature is at a faster rate. Further, the constant temperature of the HTF, during the phase transition, decreases the temperature gradient between the PCM and the front region, and the HTF in the initial of the tank is maintained at a lower temperature. Then the second method of outer side discharging method that is low-temperature heat transfer fluid is circulated only through the outer side of the pipe to retrieval the stored energy. Figure 3.2(a) shows the variation of the solidification time with respect to the length of the storage pipe for various mass flow rates of the low-temperature HTF.When the mass flow rate is 2 kg/min the solidification time is very low and for 4 kg/min it is appreciable but in the case of 6 kg/min it shows a faster rate of solidification. This is due to the less convective mass flow in the case of the 2 kg/min, and the heat has to be transferred only through diffusion to the end side. This reduces the heat transfer to the end of the storage tank at a lower mass flow rate during the initial phase. At a higher mass flow rate of 6 kg/min the convection heat flow is predominant, from the beginning of the discharging process. Then the last method of inner side discharging is followed to retrieval the energy through circulating low temperature in inner side of the storage pipe with different mass flow rates and it shows in figure 3.3 (a&b)

In this methods it shows longer solidification times compared to the other two methods in different mass flow rates**.**It is seen from figures 3.1,3.2&3.3 that the higher mass flow rates reduces the phase change duration appreciably, during all methods of discharging processes. This shows that the mass flow rate has a significant effect, which is due to the higher variation in the heat capacity of the HTF used in the present investigation. It is also observed the variation in the instantaneous heat transfer with respect to time is very low during all this discharging processes at the lower mass flow rate whereas at higher mass flow rates, initially the heat transfer is very high, and it decreases at a faster rate with respect to time. It is seen from the figure that as the length distance increases, the time required for the phase change increases for all methods of solidification. This is due to the decrease in the temperature difference between the HTF and the PCM at the higher length location. Further, it is observed that the increase in time required for the phase change along the length is appreciable at a lower mass flow rate. This is due to the higher variation in temperature of the HTF along the flow direction, at lower mass flow rate, due to its low heat capacity. Hence, the time required for the phase change is very high at the end of the storage tank, at a lower mass flow rate, due to the very low temperature difference between the HTF and the PCM.

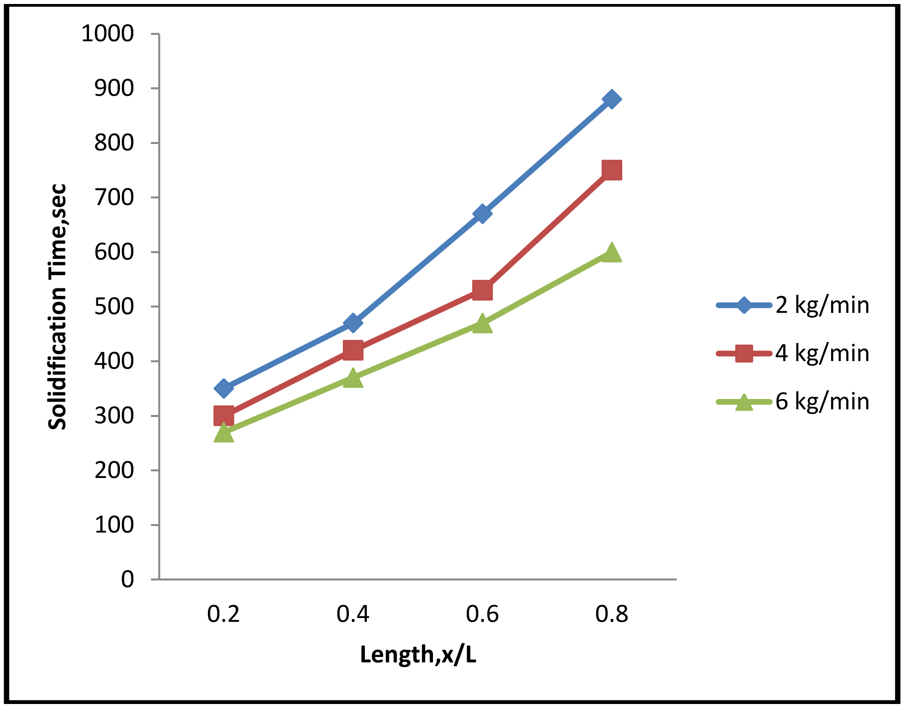


(a)



(b)

Figure 3.1 Effect of mass flow rate in both side discharging methods with
(a) Solidification time &length, x/L
(b) Solidification time & PCM temperature



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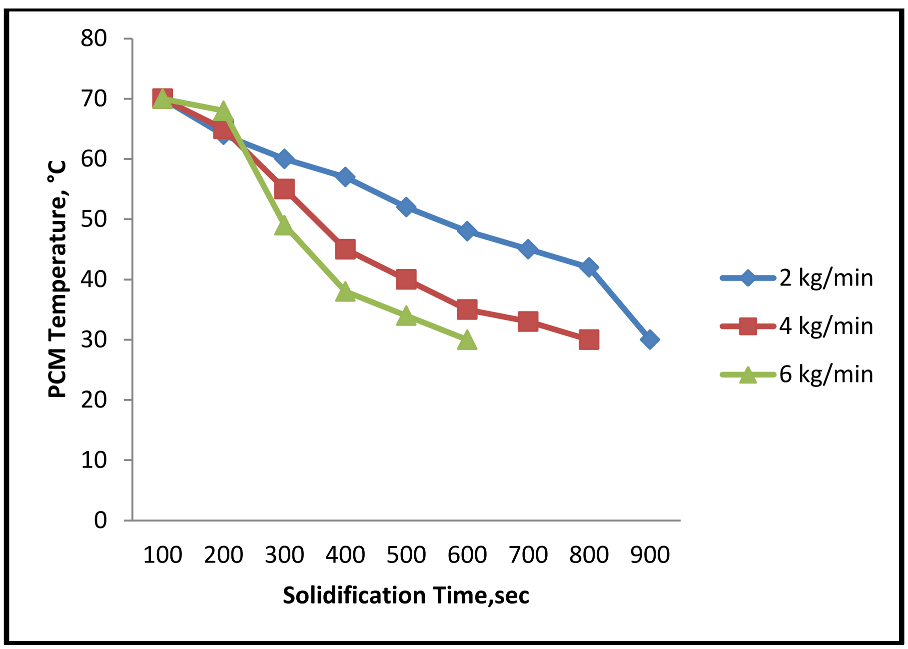
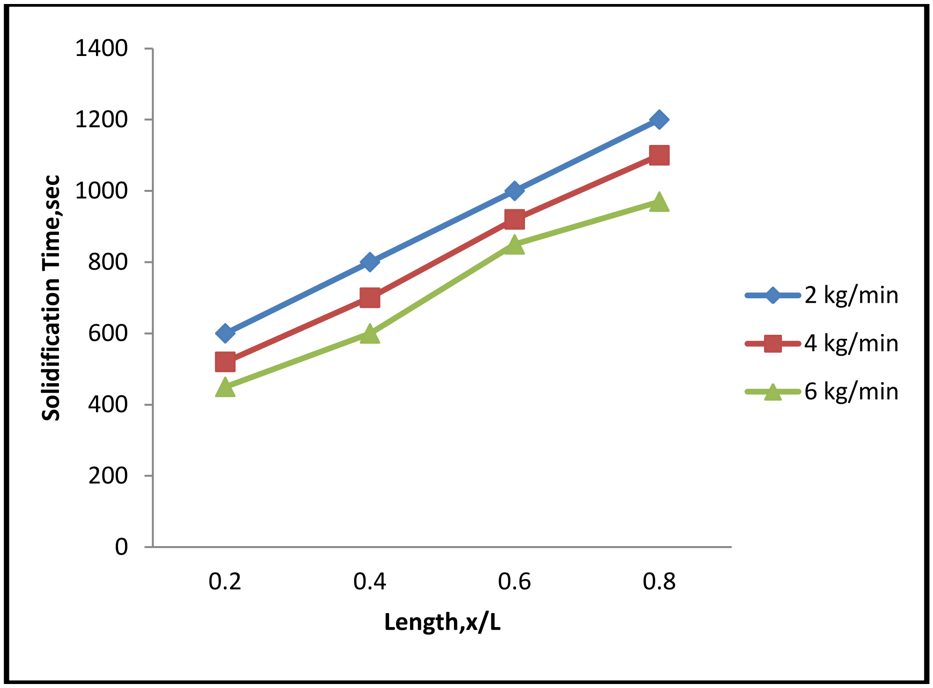


(b)

Figure 3.2 Effect of mass flow rate in outer side discharging methods with
(a) Solidification time &length, x/L
(b) Solidification time & PCM temperature



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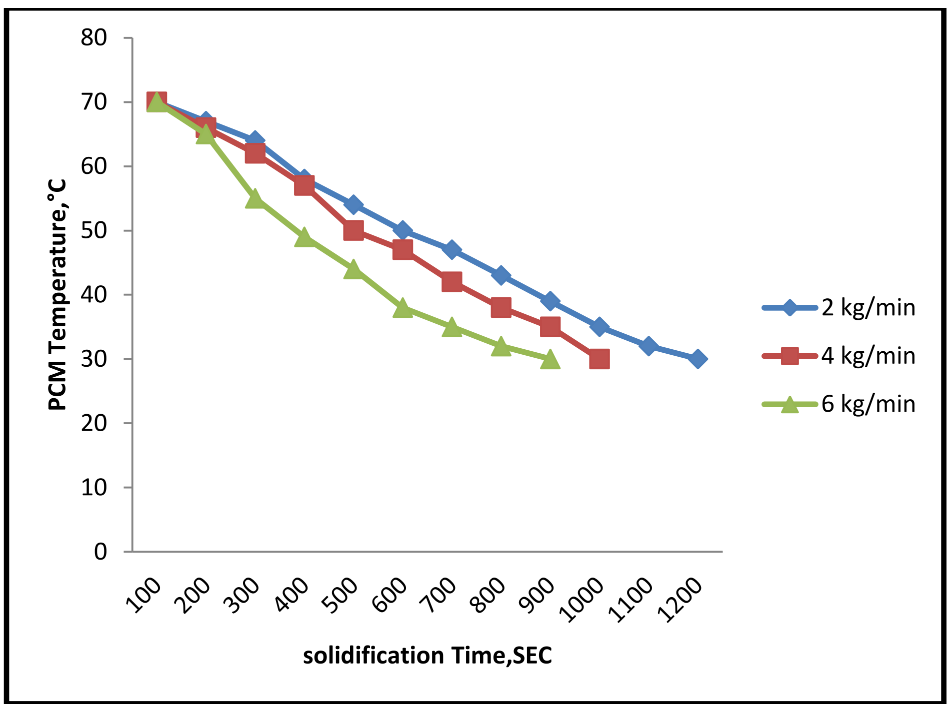

(b)

Figure 3.3 Effect of mass flow rate in inner side discharging methods with
(a) Solidification time &length, x/L
(b) Solidification time& PCM temperature

4. Conclusions

Based on this three discharging cases of PCM in triple tube concentric solar thermal energy storage system the following conclusions could be drawn, during both side discharge methods PCM solidification required a low temperature and a short time compared to outside and inside discharge methods. The effect of mass flow rate of low temperature heat transfer fluid at 6kg/min at various inlet temperatures is best compared to others to save time. Paraffin wax is good PCM for thermal energy storage system due to commercial and cheap and also it does not show any sub cooling. Charging within short periods of available solar energy in triple tube concentric solar thermal energy storage system is more effective than using only one charging surface.

Nomenclature

T	–	Temperature, [C]
l	–	Length, [m]
k	–	Thermal conductivity, [$Wm^{-1}K^{-1}$]
t	–	Time, [s]
d	–	Diameter, [m]
ρ	–	Density, [kgm^{-3}]
m	–	Mass flow rate, [kg/min]
T_m	–	Melting point of PCM, [K]

Abbreviations

PCM	–	Phase change material
TES	–	Thermal energy storage
HTF	–	Heat transfer fluid

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