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A STUDY ON THE HEAT TRANSFER MECHANISM OF A PHASE CHANGE MATERIAL ALONG THE THREE DIMENSIONAL AXIS OF A SOLAR WAX MELTING CHAMBER

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ABSTRACT
A heat transfer characteristic of paraffin wax by natural convection was studied experimentally. A square wax melting chamber was taken to study the charging/melting characteristics of the PCM. A square wooden block was used to fix the monocouples, which was used to measure the temperature of the pcm radially and axially. DSc was taken for the Paraffin wax used in the study and its thermophysicsal characteristics were studied. Natural convection increases the thermal conductivity of the PCM with time.

keywords: PCMs, Copper turnings, Latent thermal energy storage, Heat transfer, Graphite powder, DSC.

1. INTRODUCTION

Energy storage, especially thermal energy storage (TES), plays an important role in conserving available energy and improving its utilization because the discrepancy between energy supply or availability and demand can be overcome by implementation of a proper energy storage system. Among the various thermal energy storage methods, the latent thermal energy storage employing a phase change material (PCM) has been widely noticed as an effective way due to its advantages of high energy storage density and its isothermal operating characteristics (i.e. charging/ discharging heat at a nearly constant temperature) during the solidification melting processes, which is desirable for efficient operation of thermal systems. In a latent heat storage system, energy is stored during melting and recovered during solidification of a PCM. Paraffin wax is attractive for use in solar heat storage. It has good latent heat and is stable. Embedding aluminum powder in the wax enhances its low thermal conductivity (Eman-Bellah et al. 2007). The solid-liquid PCMs are divided into three main groups: organics, inorganic compounds and eutectics of inorganic and/or organic compound (Zhou et al. 2011).

DSC is a thermo analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Both the sample and reference are maintained at nearly the same temperature throughout the experiment. The basic principle underlying this technique is that when the sample undergoes a physical transformation such as phase transitions, more or less heat will need to flow to it than the reference to maintain both at the same temperature. Whether less or more heat must flow to the sample depends on whether the process is exothermic or endothermic. For example, as a solid sample melts to a liquid it will require more heat flowing to the sample to increase its temperature at the same rate as the reference. This is due to the absorption of heat by the sample as it undergoes the endothermic phase transition from solid to liquid. Likewise, as the sample undergoes exothermic processes (such as crystallization) less heat is required to raise the sample temperature. By observing the difference in heat flow between the sample and reference, differential scanning calorimeters are able to measure the amount of heat absorbed or released during such transitions. The result of a DSC experiment is a curve of heat flux versus temperature or versus time. There are two different conventions: exothermic reactions in the sample shown with a positive or negative peak, depending on the kind of technology used in the experiment. This curve can be used to calculate enthalpies of transitions (Dean, et al. 1995; Pungor et al. 1995; Skoog, et al. 1998).

The quest for new technologies to avert the growing concern about environmental problems, the imminent energy shortage and the high cost of energy and new power plants has been a scientific concern over the last three decades. Central to the problem is the need to store excess energy that would otherwise be wasted and also to bridge the gap between energy generation and consumption. Latent heat thermal energy storage is particularly attractive technique because it provides a high-energy storage density. When compared to conventional sensible heat energy storage systems, latent heat energy storage system requires a smaller weight and volume of material for a given amount of energy. In addition latent heat storage has the capacity to store heat of fusion at a constant or near constant temperature which correspond to the phase transition temperature of the phase change material (PCM) (Francis et al. 2010). Organic and inorganic compounds are the two most common groups of PCMs. Most organic PCMs are Non-corrosive and chemically stable with most building materials and have a high latent heat per unit weight and low vapor pressure. Inorganic compounds have a high latent heat per unit volume and high thermal conductivity and are non-flammable and low in cost in comparison to organic compounds (Élan Zalba et al. 2003). Phase change materials (PCMs) are used with conventional solar water heating systems (AL-Hinti et al. 2010).

2. MATERIALS AND METHODS

A Solar Wax melting chamber of area 0.2601 m^2 was constructed to study the melting /solidification characteristics of Paraffin wax. Commercial grade paraffin wax was used in the experiment. Copper Constantan monojunction thermocouples were used to measure the temperature. Solar radiation was measured using Pyranometer .Polyurethane foam was used for thermal insulation purposes. Two transparent glass plates are used to cover the system.
To study the thermal conductivity of the paraffin wax, copper constantan monocouples are used to measure the temperature of the wax at the radial and axial direction.

T_1, T_2, T_3, T_4, T_5 are the monocouples used to measure the thermal conductivity of the paraffin wax. The distance between the thermocouples T_1 and T_2 was 8cm and T_2 and T_3 was 11cm, T_3 and T_4 was 11cm and T_4 and T_5 was 8cm.

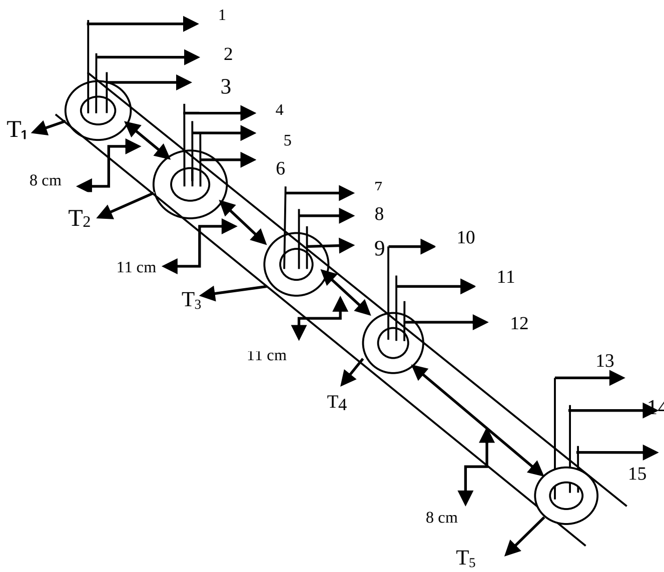

Figure 1 Schematic diagram of the experimental setup 1= T_1^3, 2= T_1^2, 3= T_1^1, 4= T_2^3, 5= T_2^2, 6= T_2^1, 7= T_3^3, 8= T_3^2, 9= T_3^1, 10= T_4^3, 11= T_4^2, 12= T_4^1, 13= T_5^3, 14= T_5^2, 15= T_5^1.

A square wooden block of area 0.196 m^2 was placed in the bottom of the wax melting chamber. Holes are made in the wooden block to fix the monocouples in it which was used to measure the heat transitions in the PCM. First the wooden block was placed on the wax melting chamber. Then the paraffin wax of mass 4kg was laid on it in the form of small pieces. So paraffin melts in the square chamber and took the shape of the container like a square block.

The schematic diagram of the monocouples fixed in the wooden block was shown in the figure 1. Monocouples are fixed radially in the wooden block to study the heat transfer in the radial direction. In the first hole T_1, three monocouples T_1^1, T_1^2, T_1^3 are fixed. These three monocouples are used to measure the axial temperature of the wax at different layers. The thickness of the 4kg wax was 3.5cm, so three monocouples are fixed from the bottom of the wax to the top at the interval of 1cm. At the distance of 1cm from the bottom of the paraffin wax bar T_1^1 monocouple was fixed and at the distance of 2cm from the bottom of the wax T_1^2 monocouple and at the distance of 3.5cm from the bottom T^3, was fixed. So from the T_1 first hole in wooden block, it was able to measure the temperature from the bottom to top layer of the paraffin wax temperature axially. Similarly in the remaining four holes in the wooden block T_2, T_3, T_4, T_5 monocouples are inserted. The monocouples T_1, T2, T_3, T_4 , T_5 measure the radial heat transfer characteristics of the paraffin wax and the remaining monocouples T_2^1, T_2^2, T_2^3 T_3^1, T_3^2, T_3^3 T_4^1, T_4^2, T_4^3 T_5^1, T_5^2, T_5^3 are inserted in their corresponding holes to measure the axial temperature of the wax. Figure 3 shows the enthalpy of the paraffin wax at different phases.

Dsc Thermal Analysis of the Pcm Commercial paraffin and Composite was used as PCM paraffin is an attractive, chemically stable and non toxic material. Melting temperature of paraffin used as PCM was measured by a DSC instrument. The analyses were performed between the temperatures of 30 ˚C and 500 ˚C at 20 ˚C/min heating rate. A 3 mg of sample was sealed in an aluminum pan. The melting temperature range of the sample was taken as peak temperature of DSC curve. The enthalpy was determined from the area under the peak of the DSC curve taken for the paraffin wax, which represents solid-liquid phase change and liquid-gaseous phase change. The thermo physical properties of the ıaraffin used in the study are given in Table 1. Figure 5 .hows the result of DSC analysis for paraffin. Three aks are noted in the Figure 2. The first peak T1 represents the temperature 44.1 ˚C of the partially melted araffin. The second peak T represents the fully melted temperature 60.4 ˚C of the paraffin wax. At Tg 303.7 ˚C the paraffin attains the gaseous state. The values for the equation 1 are taken from the Figure 2 and the enthalpy value was calculated.

$$(dh|dt) \times \frac{(^{\circ}c)}{\left(\frac{dT}{dt}\right)} = enthalpy\ J/g \quad \text{---------} \qquad (1)$$

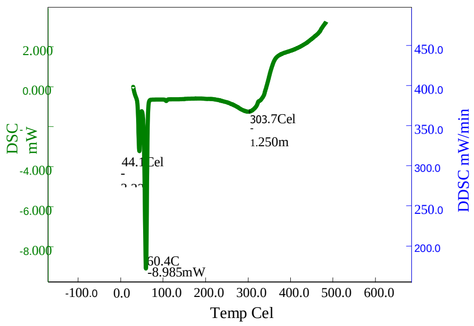

Figure 2 DSC curve of the paraffin wax.

3 RESULTS AND DISCUSSION

The paraffin wax was taken as the phase change material and it was taken in the wax melting chamber. The paraffin wax was melted by absorbing the solar radiation. In this study the charging characteristics of the paraffin wax was only considered. The heat transfer characteristic of the paraffin wax was studied with the monocouple. In the study it was absorbed that paraffin wax first melts in the boundary region, after that due to the natural convection the heat was transferred from the boundary to central part of the paraffin wax. It was also absorbed that paraffin wax in the upper layer melts faster than the paraffin in the bottom of the container. Figure 4, 5, 6, 7, 8 shows the heat transfer characteristics of the paraffin wax in the axial position. The monocouples T_1^1 ,T_2^1, T_3^1, T_4^1 , T_5^1 are fixed at the lowest part of the paraffin wax shows the lowest temperature at the beginning of the charging process and at last due to the natural convection, it reaches the highest temperature. The monocouples T_1^2, T_2^2, T_3^2, T_4^2, T_5^2 are fixed at the middle part of the wax that was at the height of 2cm from the bottom was always at a minimum temperature. The monocouples T_1^3, T_2^3, T_3^3, $T_4^{\,3}$, T_5^3 are fixed at the upper part of the paraffin wax it attains the maximum temperature at the beginning itself. So the heat transfer occurs first at the upper layer of the paraffin wax and by natural convection, heat flow occurs and the region below the upper part also gets melted. Figure 9, 10, 11 shows the heat transfer characteristics of the paraffin wax in the radial direction. T_1^1, T_2^1, T_3^1, T_4^1, T_5^1 are the monocouples measures the bottom layer of the paraffin wax radially. T_1^2, T_2^2, T_3^2, T_4^2, T_5^2 and T_1^3, $T2^3$, T_3^3, T_4^3, T_5^3 measures the middle and upper part of the paraffin wax radially. From figure 13 it was noted that the rate of heat transfer of the PCM increases at the beginning and after 1.00 PM, the rate of heat transfer decreases due to the change of phase of the PCM from solid to liquid phase. So at this point the paraffin observes the heat in the pcm and change to liquid state from solid state. Solar isolation also decreases from 959.458 W/m^2 to 635 W/m^2 at 2.00 PM (figure 17), so it also causes for the decrease of the rate of heat transfer of the paraffin. So the pcm temperature is the sensible temperature at the beginning stage and during the phase transition it absorbed the gained heat and changed from one se to another phase. After that the PCM remain sometime in the latent phase that is, the pcm's temperature remain at constant temperature during the Latent phase.

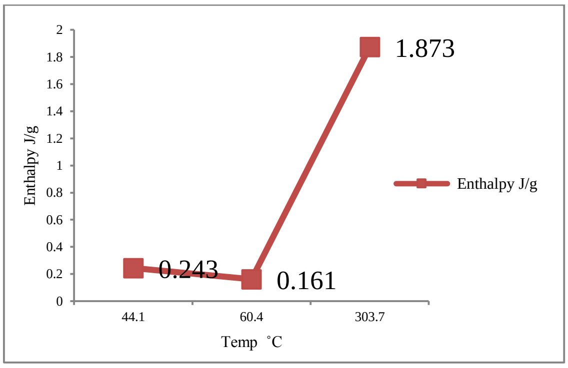

Figure 3 Enthalpy curve of the paraffin wax.

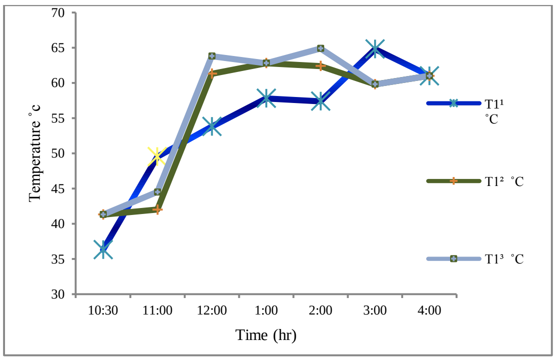

Figure 4 Charging curve of the paraffin wax temperature taken from the first monocouple in the axial direction.

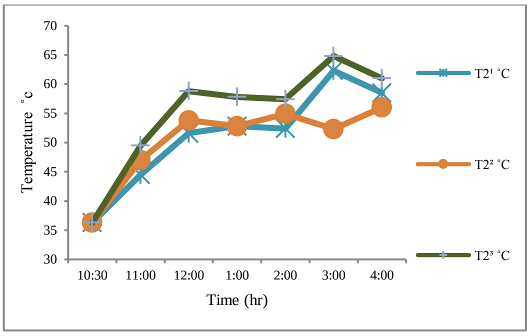

Figure 5 Charging curve of the paraffin wax temperature taken from the second monocouple in the axial direction.

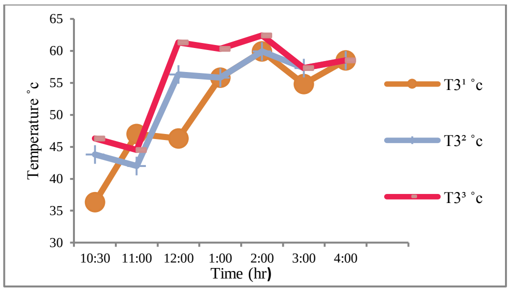

Figure 6 Charging curve of the paraffin wax temperature taken from the third monocouple in the axial direction.

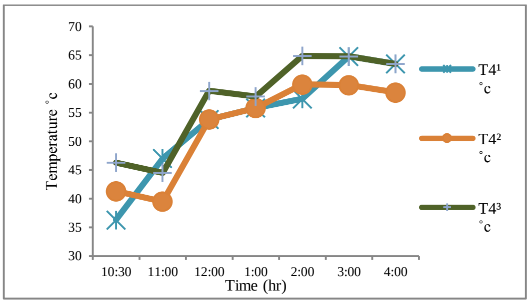

Figure 7 Charging curve of the paraffin wax temperature taken from the fourth monocouple in the axial direction.

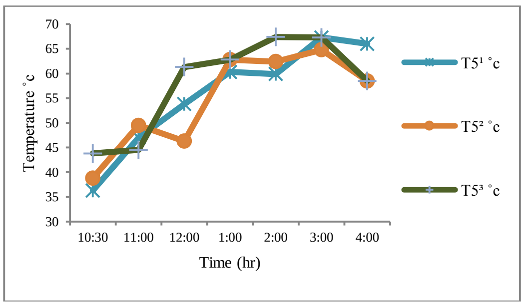

Figure 8 Charging curve of the paraffin wax temperature taken from the fifth monocouple in the axial direction.

From the figure 11, 12, 13 it was noted that the temperature noted from the monocouples T_5^1, T_5^2, T_5^3

attains the maximum temperature radially when compared with the other monocouples this was due to the heat transfer caused by the natural convection.

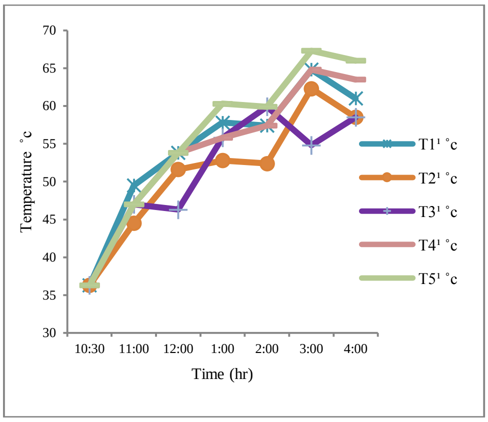

Figure 9 Heat transfer characteristics of the paraffin wax temperature taken from monocouples in the radial direction at 1cm from the bottom of the pcm.

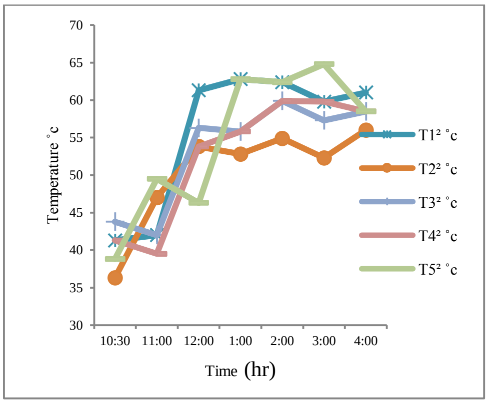

Figure 10 Heat transfer characteristics of the paraffin wax Temperature taken from monocouples in the radial direction at 2cm from the bottom of the pcm.

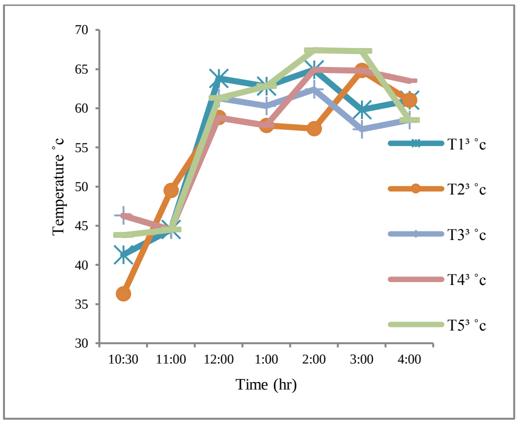

Figure 11 Heat transfer characteristics of the paraffin wax temperature taken from monocouples in the radial direction at 3.5 cm from the bottom of the pcm.

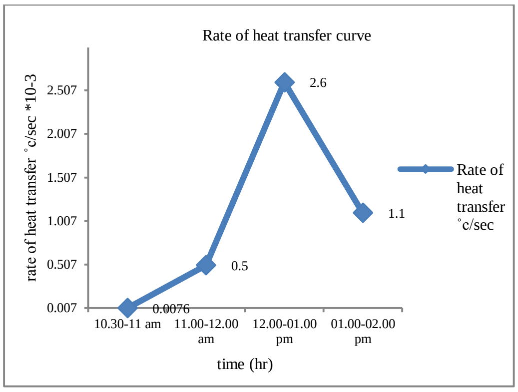

Figure 12 Rate or heat transfer curve for the temperature of the monocouples T_1^1, T_2^1, T_3^1, T_4^1, T_5^1.

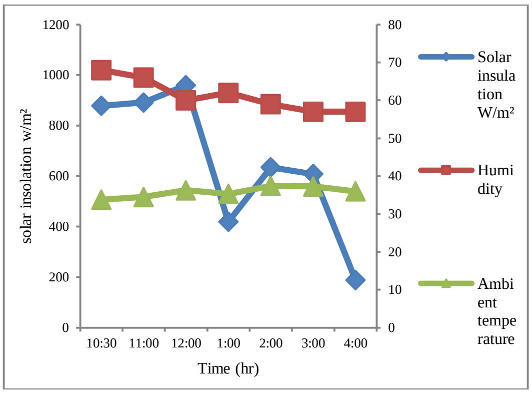

Figure 13 Time versus solar insulation curve.

4 CONCLUSIONS

The charging process is the melting process, as the charging/melting process proceeds, more solid PCM gets melted due to the natural convection effect. Natural convection increases the thermal conductivity of the PCM with time. Thermal resistance of the PCM decreases with time due to the natural convection and due to the Paraffin's (PCM) effective thermal conductivity increases. So by natural convection the heat transfer occurs in the PCM radially inwards. The heat transfers from the boundary layer of the pcm towards the centre and similarly from top to bottom layer of the PCM. The results provide conclusive evidence of the role played by natural convection, contact melting and phase change temperature range on the heat transfer.

Nomenclature	
T^1	partially melted state peak temperature
T	fully melted state peak temperature
T^g	gaseous state temperature
Dsc	differential scanning calorimetry
PCM	phase change material
P	paraffin
dh/dt	heat flow
dT/dt	heating rate

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