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A Study on Phase Change Material (PCM) For Insitu Solar Thermal Energy Collection and Storage

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ABSTRACT: An experimental study is conducted in order to investigate the paraffin as a phase change material. The PCM was loaded in GI (Galvanized iron) pipes and arranged in a criss cross manner to form a grid shape and the whole setup was laid one over the other and was used as a heat storage unit. Water is pooled as heat transfer fluid (HTF) surrounding the GI pipe, to collect the heat from the heat exchangers. This arrangement focuses on the possibility of the heat transfer enhancement in the heat storage unit. The thermophysical characteristics of the paraffin used in the experiment was determined using the Differential Scanning Calorimeter (DSC) analysis. The dimensionless numbers such as Rayleigh number, Nusselt number of the PCM are calculated. It is observed that the natural convection between the melted paraffin wax (oil) and the unmelted solid wax has enhanced the melting process. The overall efficiency of the system has been calculated are reported.

KEYWORDS: PCM; HTF; DSC; Latent heat; sensible heat .

I. INTRODUCTION

The discrepancy between energy supply or availability and demand can be overcome by important role in conserving available energy and improving its utilization. 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. The charging/ discharging of heat at a nearly constant temperature during the melting solidification processes, which is desirable for efficient operation of thermal systems. In a latent heat storage system, energy is stored during melting process and recovered during the solidification process of a PCM. Practical difficulties usually arise in applying the latent heat method, due to its low thermal conductivity, density change, and stability of properties under extended cycling and sometimes phase segregation and sub cooling of the PCM [1]. Over the last decade, a number of studies have been performed to examine the overall thermal behavior and performance of various latent heat thermal energy storage systems. These studies focused on the melting/freezing problem of the PCM and on the convective heat transfer problem of the HTF used to store (melt) and/or retrieve energy (solidification) from the unit [1]. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade [2]. The heat transfer rate of the PCM depends on the geometrical shape of the Latent thermal energy storage system [3]. Spiral thermal energy storage unit was used as the heat exchanger. Paraffin wax PPW-20 was used as the low temperature latent heat thermal energy storage material. This paraffin has the characteristics feature that phase change transition occurs not isothermally but rather over a finite range of temperature. Heat exchangers should ensure high effective heat transfer rate to allow rapid heating or cooling of a phase change material [4]. Charging only and discharging only modes, using heat pipes as the heat transfer elements stores the thermal energy efficiently, it stores and releases the heat independently. Natural convection is stronger in the charging process and it becomes weaker in the discharging process. The charging only operation is actually a melting process. As the process proceeds, more solid PCM is melted and the thermal conductivity of the PCM increases with time due to the enhanced natural convection effects. The

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discharging only operation is a process of solidification and the solid phase PCM on the heat pipes increases with time. So heat pipe heat exchangers with latent heat storage material have stronger influence on the discharging/charging process than the flow rate [5]. The studies of the latent storage system with the solar flate-plate collector are used to eliminate seasonal variation in thermal efficiencies. Cylindrical storage units are used for TES using PCM to reach the high thermal conductivity. This will help to eliminate seasonal variation in thermal efficiency [6]. During the melting of the PCM, the melting occurs non-isothermally but on the other hand solidification of the PCM occurs isothermally. Initially the PCM temperature increases with time and it began to melt. From the start of the heating process the PCM begin to change from solid to liquid state due to the conduction. During the phase transition both conduction and natural convection in liquid phase occurred. As melting proceeded, natural convection enhanced. Solid particles of PCM dropped down and melted liquid particles rose, causing faster melting at the top of the tube. At the end of the melting process a more rapid increase of PCM temperature was occurred. During the discharge of heat from the PCM, heat transfer has been governed by natural convection from the start to beginning of the liquid-solid phase transition. A sharp initial temperature drop was observed at the start of the cooling process, until the paraffin started to solidify. The temperature remained constant until the end of solidification and then another temperature drop occurred. Paraffin has an isothermal phase change temperature and no sub cooling property [7]. Thermal analysis of thermal energy storage was performed by using paraffin and stearic acid as phase change material (PCM). The PCM was filled in the spherical container of various sizes and its temperature distributions, melting, solidification, characteristics were studied and it was found that paraffin takes shorter duration for the complete melting process when compared with the steric acid [8]. The paraffin wax was used as the latent heat storage material which was encapsulated in small aluminium containers packed in conventional water storage tank. Paraffin wax was found to have the melting temperature that enables it to store the excess energy available in day time hours as latent heat and then release the stored heat to maintain the water temperature in an acceptable range for most domestic applications [9]. The thermal conductivity of the heat exchanger container material doesn't have any effect on the thickness of the heat exchanger container material. The boundary wall temperature plays an important role during the melting process and has a strong effect on the melt fraction [10]. In the present study PCM encapsulated GI pipes were used to store heat in a reduced volume of the solar collector chamber. Using the PCM filled GI pipe modules a study has been made to solve the problem of slow heat transfer rate from the PCM to the water and increase the availability of the energy.

II. MATERIALS AND METHODS

A Solar Paraffin Wax melting chamber of area 0.22 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. Polyurethane foam was used for thermal insulation purposes. Galvanized iron (GI) pipes are of diameter 0.019 m and length 0.30 m were chosen as the heat exchangers (pipe). Each pipe was filled with 115 grams of paraffin wax. Four layers of pipes are arranged one over the other inside melting chamber of area 0.22 m^2 in criss cross manner. Each layer contains 10 wax encapsulated GI pipes, so 40 GI pipes have been used to construct the four layers which form the heat exchangers in the wax melting chamber. A monojunction thermocouple was fixed on the outer surface of the GI pipe arrangement to study the pipe temperatures. Similarly another thermocouple was inserted inside the GI pipe and well sealed to study the Paraffin wax temperature in the pipe during charging/discharging process. Like that one pipe was placed in each layer as one among the 10 pipes, to study the pipe temperature and PCM temperature (T) in each layer. The heat collection cum storage unit was covered with two glass layers. The empty pipes were stacked as four layers figure 1 one over the other each layer containing 10 sealed GI pipes in order to sealed GI pipes filled with PCM material. So that the HTF will flow in contact with the pipes, so the heat exchangers filled with PCM increases the heat storage capacity of the HTF.

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TABLE 1
Efficiency for various layers of PCM encapsulated in heat exchanger

S.No	Description	Efficiency %
1	1 layer of pipe without water and without Paraffin wax	4 %
2	2 layer of pipe without water and without Paraffin wax	5 %
3	3layer of pipe without water and without Paraffin wax	8 %
4	1 layer of empty pipe in 4 liters of water	30 %
5	1 layer of pipe with 1.15 kg of Paraffin wax without water	16 %
6	1 layer of pipe with 1.15 kg of Paraffin wax in 4 liters of water	28 %
7	Plain water of 12 liters	38 %
8	2 layers of pipe filled with 2.3kg of Paraffin wax in 8 liters of water	35 %
9	4 layers of pipe with 4.6 kg of Paraffin wax in 12 liters of water	43 %
10	4 layers of pipe filled with 4.6 kg 0f Paraffin wax in 13 liters of water	22 %

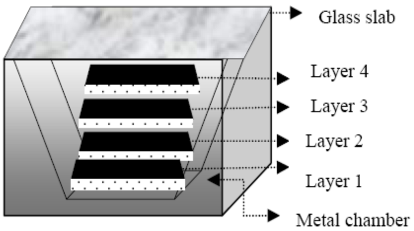

Fig 1: Wax melting chamber

Total heat gain of the system has been estimated as given below,

$Q_{Total} = Q_{Sensible} + Q_{Latent} + Q_{Sensible} + Q_{Water} + Q_{Pipe}$

$Q_{Sensible} = M \times C_{P,\,PCM} \times (T_{LIQUID,\,PCM} - T_{SOLID,\,PCM})$

$Q_{Latent} = M \times L_{PCM}$

$Q_{Pipe} = M \times C_{P,\,PIPE} \times (T_{INITIAL} - T_{FINAL})_{PIPE}$

$Q_{Water} = M \times C_{P,\,WATER} \times (T_{INITIAL} - T_{FINAL})_{WATER}$ (1)

Efficiency of solar paraffin wax melting chamber is,

$Q_{Total}/ A*I*t$ where “A” is the area of aperture and “I” is the average solar radiation, t is the total time of collection of solar energy.

III. RESULT AND DISCUSSION

A. DSC Thermal Analysis of the PCM

In this study commercially available paraffin wax was purchased and used as PCM. Differential scanning calorimeter (DSC) analysis has been made to study the phase change characteristics of the available paraffin wax. Paraffin is an attractive, chemically stable and non toxic material. A 3 mg of sample was sealed in an aluminum pan. The DSC analyses were performed on the sample PCM in the temperature range from 30 ˚C to 500 ˚C at 20 ˚C/min heating rate. The different phase changes of the PCM have been studied from peaks obtained in the DSC curve reported in Figure 2. Three peaks were noted in the Figure 2. The first peak noted at the temperature of 44.1˚C reveals the paraffin gets partially melted. The second peak represents the process of fully melted stage of paraffin wax at the temperature 60.4 ˚C and becomes paraffin oil. At 303.7 ˚C the paraffin attains the gaseous state. The DSC analysis made on the PCM have clearly represents the phase change properties occurring at 44.1˚C, 60.4 ˚C and 303.7 ˚C where solid, liquid and vapour phases of the PCM has been identified.

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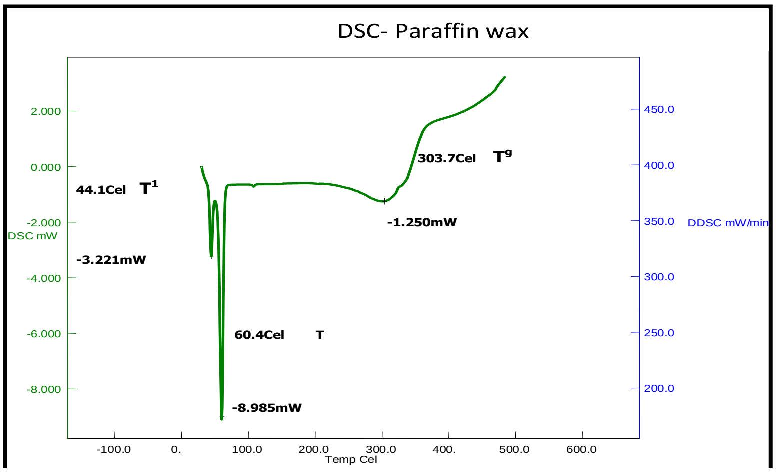

Fig 2: DSC curve of the paraffin wax.

During the melting process thermal resistance of the PCM decreases as reported in figure 2 and there is an increase in the temperature of the PCM. Until the melting process completes the temperature of the PCM is increase with the temperature of the heat exchanger and reaches the peak temperature at the end of the melting process. During the solidification process the loss of heat from the PCM was very slow, so the rate of heat loss proceeds slowly, due to this the HTF also remain in the reasonable temperature which is useful for house hold applications.

*B. **Studies on Paraffin wax Encapsulated GI Pipes as Heat Exchanger in a Solar Collector cum Storage Chamber.***

4 liters of water was taken in the wax melting chamber. The solar heat collection and heat storage capacity of the water was studied from 10.00 AM to 5 PM and the efficiency of the heat storage system was calculated as 10%. When the system was loaded with the paraffin wax of mass 1.15 kg alone encapsulated in G.I pipes and laid as a single layer. The heat storage efficiency of the solar thermal energy storage of the system was calculated as 16%. The heat storage capacity of the empty pipes surrounded by 4 liters of HTF was taken in the wax melting chamber are studied. Its efficiency was found as 30%. From these observations it has been found that the G.I pipes and the water was found to be a good thermal energy storage combination. The pipes were used to encapsulate the paraffin wax and it has acted as the heat exchanger. So the heat transfer fluid charges the wax in the pipe during the morning hours in the presence of sunlight and the melting of the PCM proceeds which leads to the storage of thermal energy. A single layer of pipe (10 pipes) encapsulated with 1.15 kg of paraffin wax laid a pool of 4 liters of water. It was subjected to collect solar energy heat storage capacity was estimated and its efficiency was calculated as 28%.

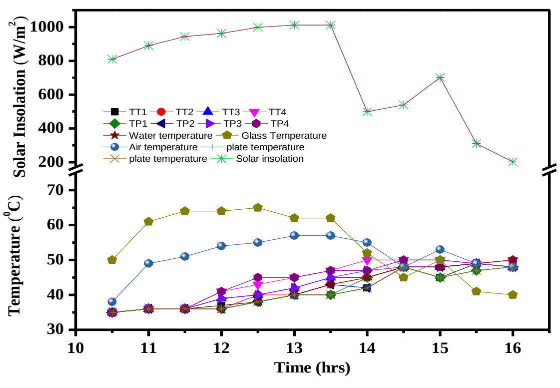

Fig 3: Heating curves of the heat exchangers (TT-pipe temperature), PCM (TP-paraffin temperature), HTF.

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The heat transfer characteristics of the single layer GI (10 pipes) of heat exchangers with and without PCM in the presence of HTF and in the absence of HTF are studied and its efficiencies are calculated. The dimensionless numbers of the paraffin such as Rayleigh number, Nusselt number are calculated as, Ra = 0.9 X 10^5, Nu=9.3 and from the observation it was found that the heat transfer took place in the paraffin was laminar. The efficiencies of the fabricated heat exchangers loaded with PCM and without PCM have been studied and the results are tabulated in table .1 for various descriptions of the experimental setups arranged.

Then the PCM was loaded in and various amount of water was used as the heat transfer fluid to study the maximum efficiency of the system. From the figure 3, it was absorved that 508 C of water was able to produce from the heat storage unit loaded with heat exchangers filled with PCM. The Thermal Energy Storage (TES) capacity of the heat storage unit was analysed by loading the heat storage unit with 12 liters of plain water and from the observed results the system efficiency was calculated as 38%. The heat storage unit with 4 layers (40 pipes) of heat exchangers filled with PCM (4.6 kg) is loaded with 12 liters HTF from the results its efficiency was calculated as 43%. The efficiency calculation includes the contribution of the sensible heat of solid and liquid phases and the latent heat of the solid liquid transitions

IV. CONCLUSION

Latent heat storage technique has been applied to solar energy storage systems, where heat is required to be stored during the day for use at night. A thermodynamic analysis of latent thermal energy storage system employing multiple pipes loaded with PCM has been reported. Relative merits of the thermal energy storage system using four layers of GI pipes loaded with PCM have been investigated. The energy collection efficiency of the system is has been significantly improved while using the PCM encapsulated modules. It is noted that the overall efficiency of the thermal storage system was increased varies with the increase in the number of heat exchangers loaded with PCM used in the system. The analytical results have provided the needed guidance in the selection of appropriate number of heat exchangers loaded with PCM and the number of layers to maximize the system efficiency for the practical design of solar thermal storage systems.

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