Experimental Analysis of Phase Change Material during Charging Process

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Abstract— Storage of energy in latent heat storage devices using phase change materials (PCM) is an efficient way of storing thermal energy and has the advantage of high energy storage and the isothermal nature of the process. PCMs have been vastly used in latent heat thermal storage systems (for eg. Heat Pumps, Solar Cookers, Solar Water Heaters and Domestic Refrigerator). In this project work an experimental study is conducted to investigate the charging process of phase change materials (PCM) inside acrylic cylinder. The PCM is stored in vertical annular space in between an inner aluminium pipe & concentrically placed outer acrylic shell. The paraffin wax is used as PCM because it is cheap, stores high amount of energy & availability. This investigation involves analysis of temperature profile during charging process of PCM and effect of Stefan No. and Grashoffs No. on the charging process of PCM.

***Keywords*:** Phase Change Material, Latent Heat Storage System, Charging Process, Paraffin Wax, Temperature

I. INTRODUCTION

In many parts of world direct solar radiation is considered to be one of the most prospective sources of energy. All over the world the scientists are in search of new and renewable energy sources. One of the options is to develop energy storage devices which are as useful as developing new source of energy. Energy storage reduces mismatch between supply and demand and also improves the performance and reliability of energy systems which plays an important role in conserving the energy. It leads to saving of premium fuels and makes the system more effective by reducing the wastage of energy and CO_2 emission from the combustion of fossil fuels, particularly in areas where low temperature application are involved. Solar energy has a large potential for heating and cooling of building, producing hot water for domestic and industrial purpose, cooking, warming greenhouses for agricultural crops, etc. however, solar energy is intermittent, unpredictable, and available only during the daytime. Therefore, its application requires efficient thermal energy storage so that the surplus heat collected during sunshine hours may be stored for later use during the night. The latent heat thermal energy storage using phase change materials has been widely noticed as an effective way to store the thermal energy due to its advantages of high energy storage density and isothermal operating characteristics. In such a systems energy is stored during melting and is reused during solidification of PCM.

Over past few years there is increasing interest in systems involving phase change materials. Atul Sharma [1] presented review on thermal energy storage with PCM and PCMs for different application (solar egg., buildings, heat exchangers for thermal storage unit). Dusan Madveet *et.al* [2] presented a latent heat storage system using PCM his study is very helpful to find suitable PCM for various purposes and suitable heat exchanger to enhance the heat transfer. Mithat Akgunet *et.al* [3] Investigate melting and solidification process of paraffin wax as PCM in tube in shell-tube heat exchanger also effect of increased temperature and mass flow rate of HTF on melting and solidification. Mithat Akgunet *et.al* [4] proposed a technique to reduce the melting time of the PCM in the storage unit and find out the best orientation of storage unit to reduce the melting time of PCM. S.A.Vijay *et.al* [5]Provide feasibility of storing solar energy using phase change materials (PCM) and utilizing this energy to heating water for domestic application during night time. Robynne Murray *et.al* [6] Gives outline of initial steps in development of solar domestic water heater, melting solidification behaviour of lauric acid inside a cylindrical container with horizontal finned pipe wax examined experimentally and numerically.

In this work experimentation is performed in order to investigate the charging process of phase change material here paraffin wax. This investigation involves detailed analysis of temperature profile during charging process of PCM, to study the effect of Stefans No. on melting time of charging process and to calculate the energy stored during charging process. The paraffin wax is used as a PCM because of its low cost, high energy storage density, and availability. The various properties of chosen technical grade PCM are given below.

Table 1 Properties of Technical Grade Paraffin Wax[7]

PARAMETERS	**VALUES**
Grade	6035
Latent Heat Capacity	206 KJ/kg
Specific Heat(Solid/Liquid)	2.384 KJ/kg°C - 2.44 KJ/kg°C
Melting/Solidification Temp.	56 °C
Density (Solid/Liquid)	833.66 Kg/m^3 - 775 Kg/m^3
Kinematic Viscosity	$8.31\times10^{-5} m^2/s$
Thermal Conductivity	0.15W/mk
Weight	4.380Kg

II. EXPERIMENTATION

2.1 Experimental Set-up

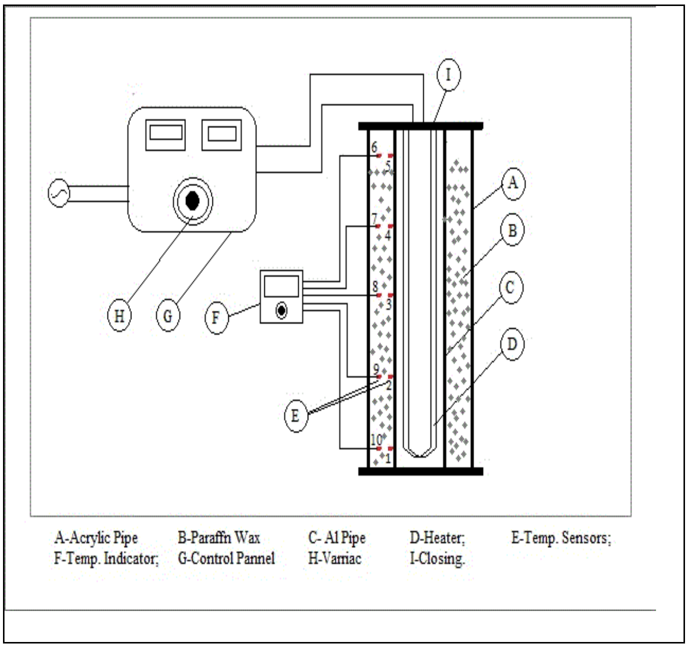

Fig. 1 Block Diagram of Experimental Setup

The experimental setup consists of two concentrically placed pipes of 0.48 m long. The inner pipe is made of aluminum with inner diameter 0.062 m and outer diameter 0.065 m. while outer pipe is made of acrylic with the inner diameter 0.144 m and outer diameter 0.15 m. In order to reduce heat transfer to environment acrylic is selected as outer pipe material, it will act as an insulator. The annular space between inner and outer pipe is filled with the phase change material (PCM) the technical grade paraffin wax is used as PCM due to suitable thermo-physical properties, large scale availability and relatively low cost.

Fig. 2 Experimental setup

The tubular heater is used inside aluminum pipe for charging of paraffin wax as shown in fig.1 There are total ten K-type thermocouples used in experimental setup out of them, five thermocouples (T_{6}, T_7 ….T_{10}) were placed inside paraffin wax at middle of annular space and other five thermocouples (T_{1}, T_2 ….T_5) are placed on aluminum pipe surface to measure Aluminum (Al) surface temperature at various points. The temperature recorded manually at time interval of 15 min. To maintain axisymmetric melting around the inside pipe the test unit is oriented in vertical direction. The control panel consists of Variac, Voltmeter, Ammeter and Mains Switch. Variac or Variable Auto Transformer has the same function as regular transformers but handles lower voltage. The voltmeter is connected parallel with device to measure its voltage while an ammeter is connected in series with a device to measure its current. The working model is as shown in fig.2

2.2 Procedure

The experimental procedure is consisting of various components as described in experimental set- up. In which power supply is given by using dimmer stat (variac) to the heater. By manually controlling the variac power supply can be change. The charging of phase change material is done with aid of heater. During the charging process in storage unit the heat transfers between the heater & phase change material (paraffin wax). Temperature of the PCM & heater at the different locations are recorded at intervals of 15 minutes till complete melting of PCM. The readings of charging process are taken for different heater inputs which are 129 W, 149.5 W, 171.5 W, 204.75 W, 224W, 246.5W, and 294.3W.

III. RESULTS AND DISCUSSION

Experiments have been conducted to determine the charging behaviors of the PCM unit. The experiments are performed for various heater inputs. For the charging experiments, seven different values for the inlet powers of the heater have been tested for Paraffin Wax, which are all set above the melting temperature of the Paraffin Wax.

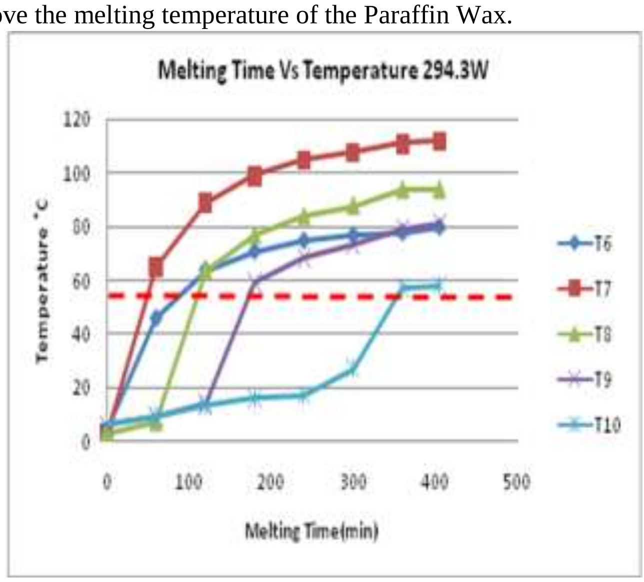

Fig. 3 Melting Time Vs Temperature at 294.3W

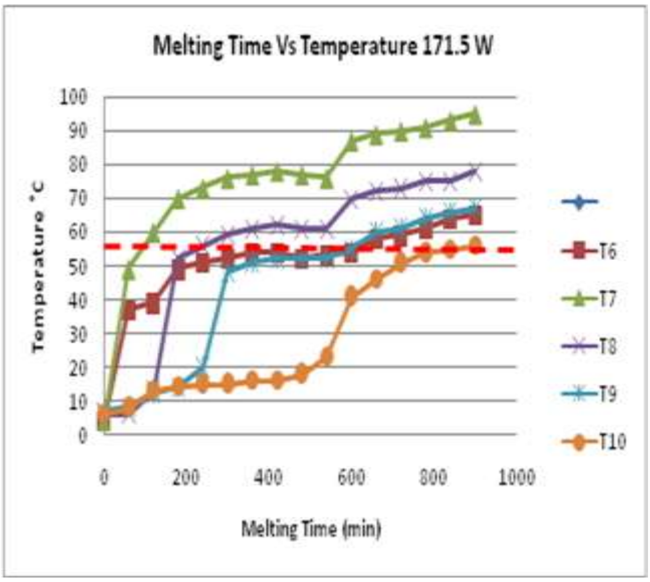

Fig. 4 Melting Time Vs Temperature at 171.5W

Fig.3 and Fig.4 Shows typical transient curves of temperatures at different locations in the storage unit. As expected with increase in input power to storage unit the heat transfer rates inside the unit will increases and as a result of this the melting time reduced considerably.

As observed practically and from values of temperatures, melting starts in lower portion close to the inner aluminium pipe. Further the molten PCM ascends to top portion of the unit as a result of natural convection currents. Due to these two regions coexist during charging process which is the melted PCM (Liquid Phase) and non melted PCM (Solid Phase). When solid melts it gets accumulate at upper portion due to buoyancy forces induced by density gradients as a result of temperature difference. It should be noted that the density of molten PCM is lower than solid PCM. At larger operating times the region of molten PCM covers larger region nearer to aluminium pipe and upper portion of storage unit. The PCM located near to lower outer regions of storage unit remains solid for longer time this is because input energy is not sufficient to achieve complete melting. Therefore the total melting time of the PCM prolongs. Same can be observed from above fig.3 &Fig.4. The thermocouple T-10 located at the bottom takes much time to achieve the saturation temperature of the chosen PCM shown by red dotted line.

In order to have proper melting inside the PCM unit the temperature distribution at different points inside the PCM needs to be studied.

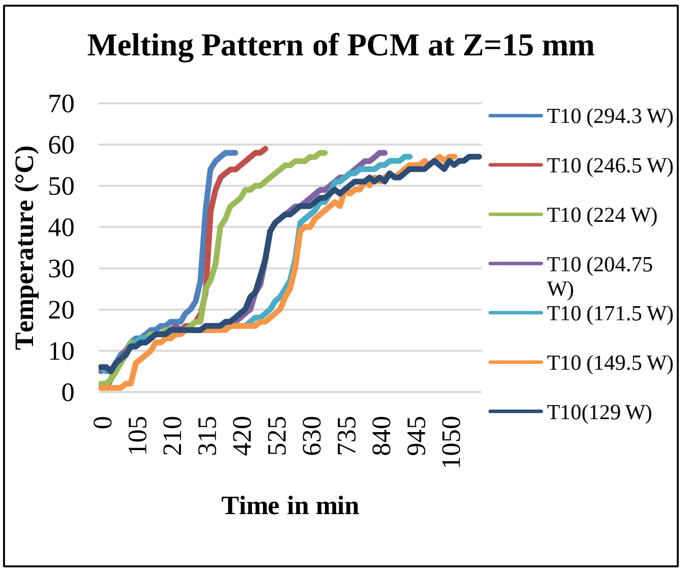

Fig. 5 Melting Pattern of PCM at Z=15mm

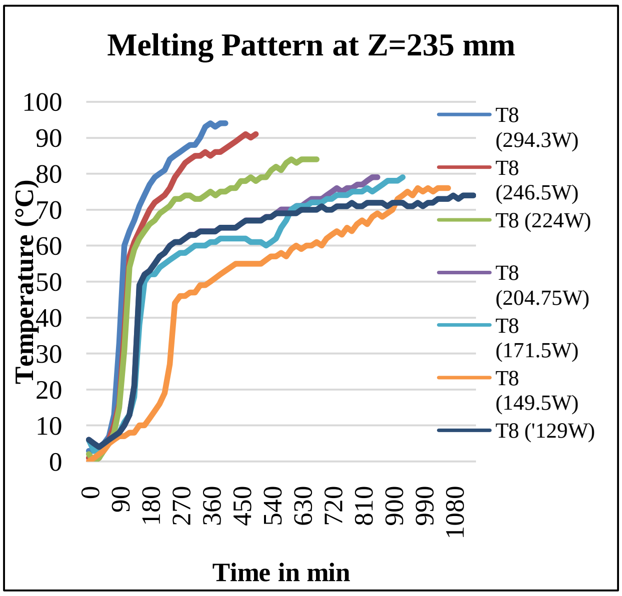

Fig. 6 Melting Pattern of PCM at Z=235mm

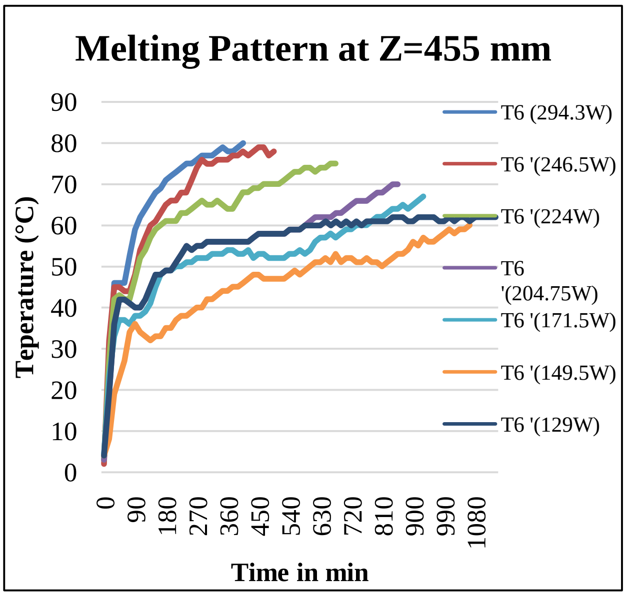

Fig. 7 Melting Pattern of PCM at Z=235mm

Above fig.5, Fig.6 and Fig.7 shows the temperature distribution at various points inside the storage unit. The fig. clearly shows the temperature distribution inside the storage unit is symmetrical which ensures proper melting at every point in the storage unit. Here in this study the symmetrical temperature distributions are obtained because of symmetrical geometry of storage unit and symmetrical boundary conditions.

If in the case proper melting of the PCM is not accomplished, there may be local heating of the PCM due to this the portion where more heating takes place will get melt earlier and due to excessive heating it may affect the properties of the PCM. Such cases prolong the total melting time of the PCM.

Fig.8 and Fig.9 shows the axial temperature variations with time of various axial positions at a various heat flux. During the initial period of heating, the energy transferred by the aluminium pipe is absorbed and stored by the PCM in the form of sensible heat. This heat is used to raise the temperature of the PCM gradually to its melting point.

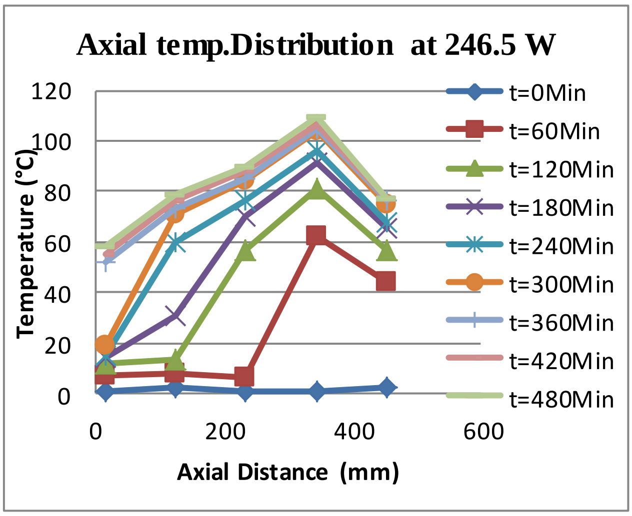

Fig. 8 Axial Temperature Distribution at 246.5 W

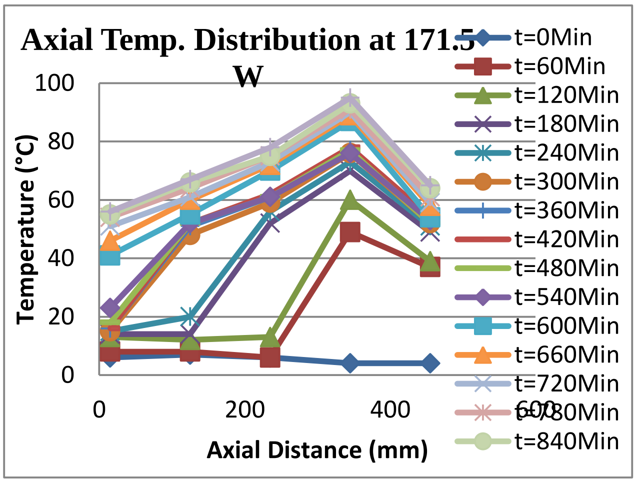

Fig. 9 Axial Temperature Distribution at 171.5.5 W

Initially at time t = 0 min heating of the PCM starts. As soon as T4 reached equal to or higher than the melting point, the melting process starts. Before melting begins, Upto t =60min conduction plays important role in melting of the PCM compared to convection. As time passes melting of PCM near to aluminium pipe starts. and later on natural convection currents dominates the conduction heat transfer.with this actions conductivity of the solid PCM increases and total heat transfer rates increases.
The flow in phase change materials is govern by Stefans No.The requird melting time of PCM is a function of Stefans No.

$$t_m = f(St)St = St * q = \frac{C_s * q_w * \delta}{\rho_s * \alpha_s * L} \quad ....[8]$$

The PCM and storage configuration remains same. The only variable in Stefan's No. is heat flux (Temperature of Aluminium Pipe). Therefore the total melting time is dependent on heat flux supplied.

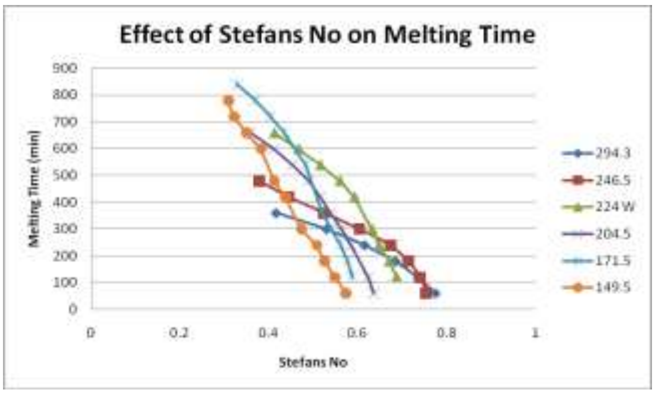

Fig 10 Experimental procedure parameters

The Stefan number is dimensionless number, which is sensible energy divided by the latent energy. From fig.10 we see that increasing the Stefan Number considerably decreases the total melting time. As the Stefan number increases the latent heat decreases. From its definition, the Stefan Number is directly proportional to the difference between the temperature of the aluminum (heating) surface and the melting temperature of the PCM. An increase in the aluminum pipe surface temperature will leads to an increase in the Stefan Number. The higher the aluminum surface temperature is, the higher the heat transfer rates.

Experimental investigation of PCM shows PCM (Paraffin Wax) has significant potential to store the energy. PCM stores the energy in the form of sensible energy and latent energy. The energy stored in PCM is calculated as

$(Q)_{stored} = (Q)_{sensible} + (Q)_{latent}$……………………….[7]

$$(Q)_{stored} = [m\, C_p\, (T_s - T_{pcm})] + [mH]$$

Table. 2 Summary of Results

Sr.No	**Input Power (w)**	**Melting Time (min.)**	**Energy Stored (KJ)**
1	129	1140	1280.069
2	149.5	1080	1289.156
3	171.5	930	1278.469
4	204.75	855	1289.157
5	246.5	675	1297.706
6	294.3	495	1319

IV. CONCLUSIONS

On the basis experimental results obtained and discussion given above, the following conclusions are made.

1) The heating flux (inner pipe wall temp.) has major influence on total melting time of PCM. With increase in heat flux the melting time can be shortened considerably.
2) The melting behavior is discussed in detail, melting starts in lower portion near to inner aluminium wall then melted PCM ascended to the top part of storage unit due to natural convection currents and two region coexist in storage unit i.e. melted PCM(Liquid phase) and non melted PCM(Solid phase)
3) Effect of Stefans No. on melting time of PCM is studied and it has observed that with as Stefans No. increases the required melting time decreases.
4) Finally amount of energy stored in PCM is calculated the results show that significant amount of energy can be stored in PCM unit.

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