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Experimental Analysis of Phase Change Material inclined at various angles 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. PCMs have been majorly used in various thermal storage systems specifically latent heat thermal storage systems for e.g. Solar Cookers, Heat Pumps, DomesticRefrigeratorandSolar Water Heaters.Thetime required for Melting of PCM is very crucial parameter in the study of energy storage units using PCM. In myproject work an investigation through an experiment iscarriedoutoncharging process of phase change materials (PCM) inclined at various angles.In vertical annular spacethePCM is stored 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 ofeffectof inclination on temperature profile during process of charging PCM and on melting time of PCM.

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

1. Introduction

All over the world the scientists are in search of renewable energy and new energy sources. Out of all options available one option is to develop energy storage devices which are as useful as developing new source of energy. The mismatch between supply and demand is reduced by Energy storage and also performance improvement and energy systemsreliabilitywhichdeliver an important role in conserving the energy. It results into saving of premium fuels and makes the overall system more effective by reduction in the energywastage and emission of CO_2 from the combustion of fossil fuels, particularly in areas where low temperature application are involved. The energy type Solar has a great potential for cooling and heating of building, giving hot water for industrial and domestic purpose, warming greenhouses, cooking and for agricultural crops, etc.moreover, this solar energy is unpredictable,intermittent and readily available only during the daytime. Therefore, its major application needeffective way of thermal energy storage so that the heat collected which is surplus during daytime hours may be stored for use during the night hours. The use of phase change materials in latent heat thermal energy storage has been widely noticed as an effective way to store the thermal energy due to high energy storage density advantages and isothermal operating characteristics. In this type of systems energy is stored at the time of melting and is reused during solidification of PCM.

There is increased interest in projects involving phase change materials over past few years. Atul Sharma [1] presented various applications of PCM in solar e.g., buildings, heat exchangers for thermal storage unit.Dusan*et.al*[2] presented a latent heat storage system using PCM and found that effective heat transfer increases due use of PCM and heat exchanger performance.Akgunet*et.al*[3]Investigates the effect of increased temperature and mass flow rate of HTF on melting and solidification of PCM based shell and tube heat exchanger. Akgunet*et.al*[4]suggested a method 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. H. Zennouhi*et.al*[5] carried out two dimensional simulations in numerical form of rectangular cavity inclined at various angles. JianLU*et.al*[6] studies the inclination effect on heat transfer inside a heat sink. hexadecanol is used as PCM and study is carried out at different pulsed heat loads.Effect of inclination on flow structure and characteristics of heat transfer is studied in details. Wei-Biao Ye *et.al*[8] studied the flow and thermalbehavior of PCM in quadrant cavity. They varied the inclination angle from 0 to 360 and found that inclination affects the melting time and movement of convection currents and it shown that inclination is having various effects on the melting time and melting temperature.

In this project work experiment is done in order to investigate the process of charging of phase change material with effect of various inclinations. This study involves detailed temperature profile analysis during charging process of PCM inclined at various angles. Further to study the details melting pattern inside the inclined PCM unit a CFD study is carried out. The PCM used is this study is paraffin wax because of its lower cost, high energy storage density, and easy availability across the nation. 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	200KJ/kg
Specific Heat(Solid/Liquid)	2.384 KJ/kg°C - 2.44 KJ/kg°C
Melting/Solidification Temp.	55°C
Density	770 Kg/m^3
Kinematic Viscosity	$8.31\times10^{-5} m^2/s$
Thermal Conductivity	0.15W/mk
Weight	4.380 Kg

2. Experimentation

2.1 Experimental Set-up

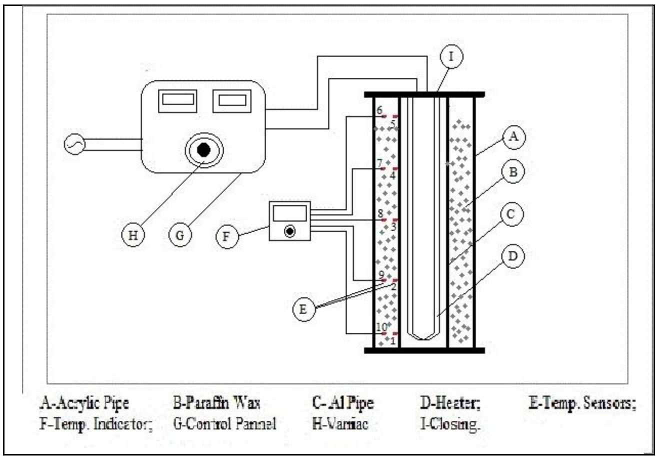

Fig.1 Block Diagram of Experimental Setup

The setup for an experiment consists of twopipesplacedconcentrically of 0.48 m long. The pipe on inner side is made of aluminum with0.062mdiameter and outer pipe is of 0.065mdiameter.The pipe on outer side is made of acrylic material with the 0.144 minnerdiameter and 0.15 mouterdiameter.Acrylicmaterial is working as an insulator. The phase change material (PCM) the technical grade paraffin wax is filled with the annular space between inner heater pipe and outer acrylic pipe.ThisPCM is selected due to good thermo-physical properties, availability and low cost.

Fig. 2 Experimental setup

The heater of tubular shape is used inside pipe made of aluminum for charging of paraffin wax as shown in fig.1There are total eightthermocouplesof K-type used in setup for experiment out of them,firstfour thermocouples (1, 2, 3, 4) were placed inside paraffin wax at middle of annular space and other four thermocouples (T_1, T_2 ....T_4) are placed on pipe surface made of aluminum to measure the surface temperature of Aluminum (Al) at various points. Manually the temperature is recorded at time interval of 10 min. Inclination to PCM unit is given in anticlockwise direction. The control panel consists of Variac, Ammeter, Voltmeter and Mains Switch. The function of Variac or Variable Auto Transformer has same as transformers of regulartypebut handles lower voltage. The working model is as shown in fig.2

*2.2*Procedure

The procedure which is followed while conducting an experiment is consisting of various components which are shown in experimental set- up. In which dimmer stat (variac) is used to give power supply to the heater. By controlling the variac power supply by manual method can be change. With aid of heater the charging of phase change material is done. In storage unit during the process of charging the heat transfers between the heater & phase change material (paraffin wax), PCMTemperature& heater placed at the different locations are recorded at intervals of 15 minutes till PCM complete melting. The readings of charging are taken at various inclination position to PCM unit i.e. 0, 30˚, 60˚, 90˚ with constant heater input of 285 W.

To perform CFD study a set of governing equations are solved in commercial software Ansys Fluent 6.0 shown below.

Continuity equation-

$$\frac{\partial \alpha n}{\partial t} + u_i \frac{\partial \alpha n}{\partial xi} = 0 \qquad (2.1)$$

Momentum equation –

$$\frac{\partial(\rho\ ui)}{\partial t} + \frac{\partial(\rho\ ui\ uj)}{\partial xj} = \frac{\partial 2(ui)}{\partial xj\ \partial xj} - \frac{\partial p}{\partial xi} + \rho g_i + S_i \qquad (2.2)$$

Energy equation –

$$\frac{\partial(\rho\, h)}{\partial t} + \frac{\partial(\rho\, ui\, h)}{\partial t} = \frac{\partial\left(k\, \frac{\partial T}{\partial xi}\right)}{\partial xi} \quad (2.3)$$

where

α_n = n^{th} fluid's volume fraction in the computational cell,

ρ = density,

k = thermal conductivity,

μ = dynamic viscosity,

Si = momentum source term,

u_i = velocity component,

x_i = Cartesian coordinate,

h = specific enthalpy.

The enthalpy can be defined as a

sum of the sensible enthalpy the enthalpy change due to the phase-change γ L,

$$h_s = h_{ref} + \int_{Tref}^{T} Cp\, \partial t \quad (2.4)$$

where

h_{ref}= reference enthalpy at the reference temperature T_{ref}

Cp = specific heat,

L = specific enthalpy of melting (latent-heat of the material),

γ = liquid fraction during the phase-change which occurs over a range of temperatures $Ts< T <T_l$.

Liquid fraction is defined by the following relations,

γ=0 if $T<T_s$

γ=1 if $T>T_l$

$$\gamma = \frac{T-Tl}{Tl-Ts} \text{ if } Ts<T<Tl \quad (2.5)$$

The source term Si in the momentum equation, Eq. (2.2), is

Given by

$S_i = -A(\gamma)\, u_i$

A (γ) is porosity function and it can be defined as,

$$A(\gamma) = \frac{C(1-\gamma)}{\gamma 3+\epsilon} \text{ where} \quad (2.6)$$

Where € = 0.001 is a small computational constant used to avoid division by zero,

C is a constant reflecting the morphology of the melting front. This constant is a large number, usually 10^4–10^7.

3. Results and Discussion

Experiments have been conducted to determine the charging behaviors of the PCM unit under various inclination positions.

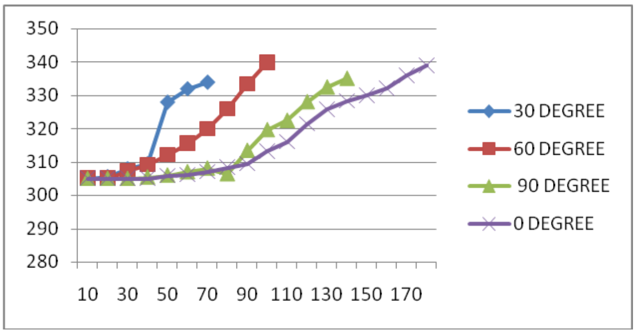

Fig. 3 Melting Time Vs Temperature at thermocouple 1

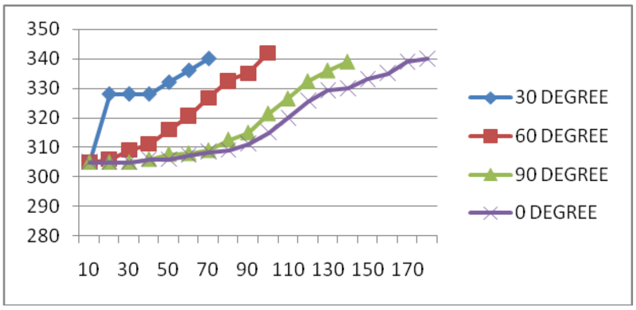

Fig. 4 Melting Time Vs Temperature at thermocouple 2

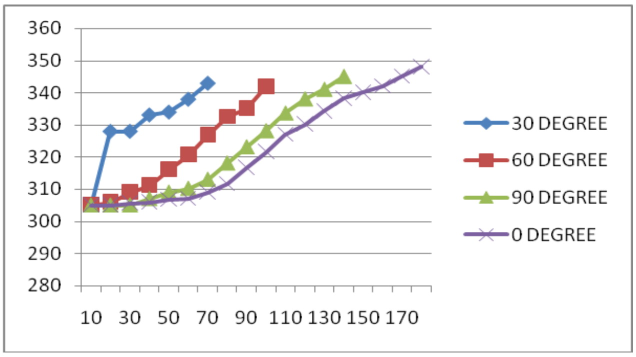

Fig. 5 Melting Time Vs Temperature at thermocouple 3

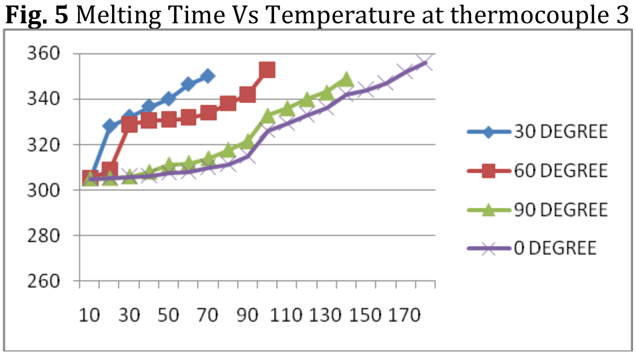

Fig. 6 Melting Time Vs Temperature at thermocouple 4

Fig.3toFig.6 shows typical transient curves of temperatures at different locations in the storage unit. It can be seen from these curves that for 30° of inclination the temperature inside the PCM cavity crosses the melting point temperature very fast. Whereas other inclinationshowrelativelyslow growth towards the melting temperature.At this inclination movement of natural convection currents is faster compared to other three inclinations. Due to this reason for 30° of inclination, the melting time required to melt the PCM unit is very less as compared to other units. At 0° the PCM unit attains the melting temperature very slowly and has shown the most melting time requirement compared to other inclination position.

To study the melting pattern for 30° of inclination of PCM unit, a computational fluid dynamics study is performed (CFD).

CFD study results are compared with experimental results which shows good agreement as shown in fig. 7

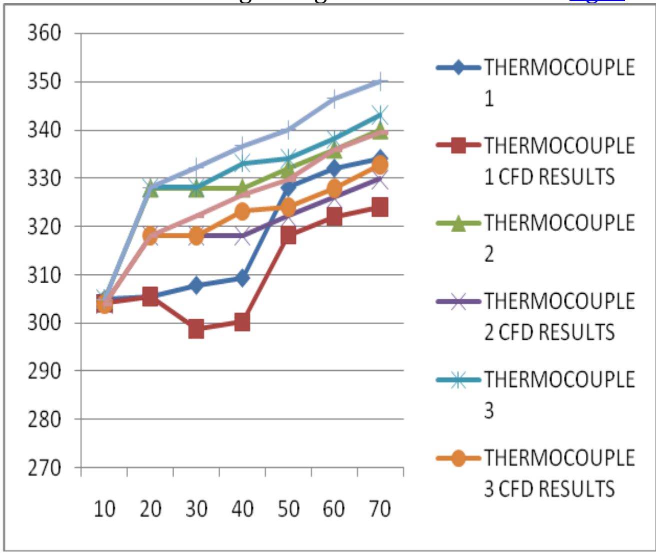

Fig. 7 Comparison between CFD study and experimental study

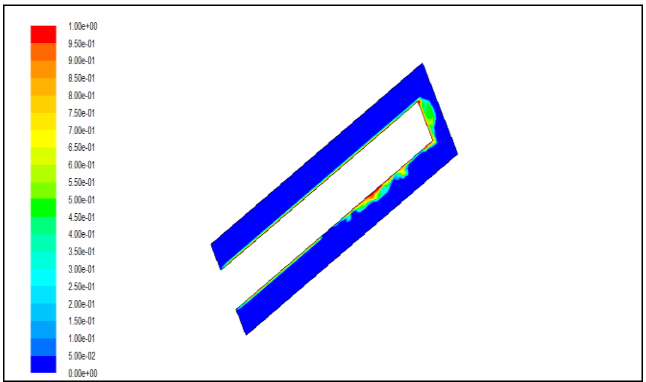

Fig. 8 (a) Results of melt fraction at time 10 min

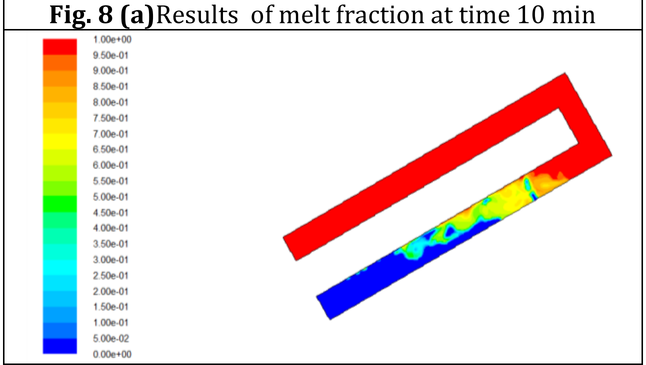

Fig. 8 (b) Results of melt fraction at time 20 min

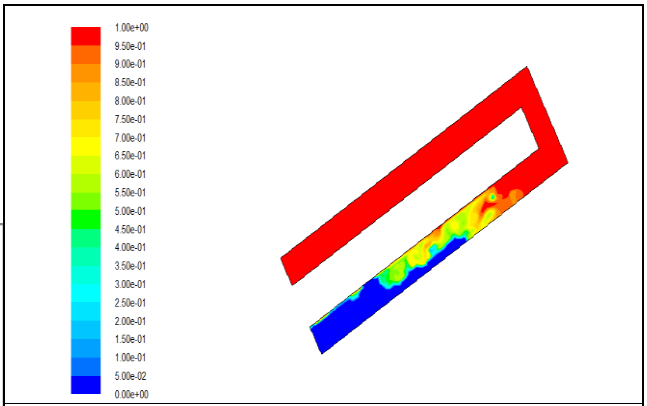

Fig. 8 (c) Results of melt fraction at time 30 min

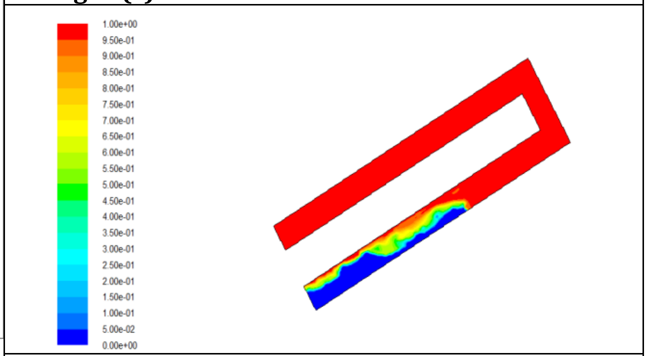

Fig. 8(d) Results of melt fraction at time 40 min

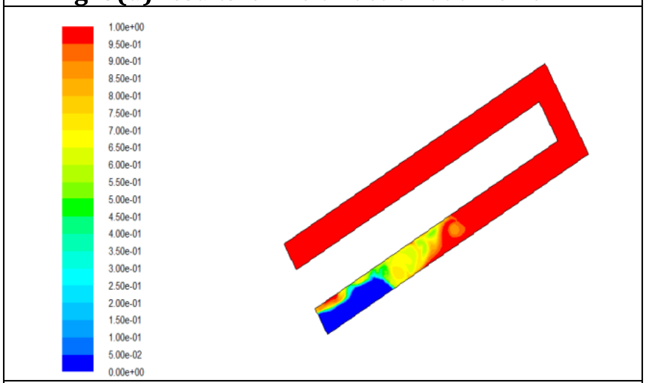

Fig. 8(e) Results of melt fraction at time 50 min

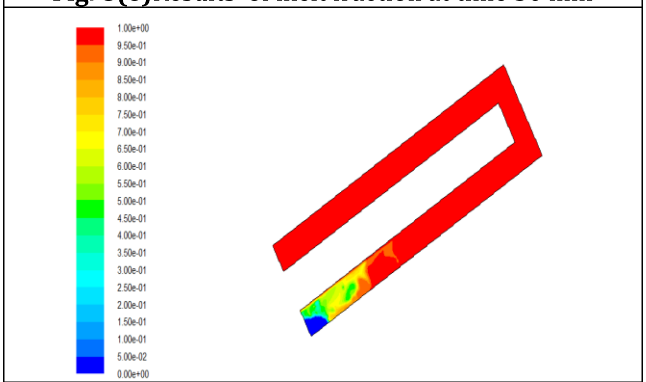

Fig.8 (F) Results of melt fraction at time 60 min

Fig. 8 Melt fraction contours for 30 inclination position

From fig.8 results it can be observed that melting starts immediately in the portion which is close to heater pipe. Molten PCM travels in upper portion of cavity. Due to effect of inclination convection currents move faster in the cavity. Clearly there are two region inside melted cavity i.e. solid PCM and melted liquid PCM. There is difference in densities of solid and liquid PCM which give rise to buoyancy forces. These forces carry molten PCM in the upper region of cavity and solid

PCM in lower region of cavity. These buoyancy forces are assisted by inclination effect of PCM unit which ultimately yields in effective heat transfer inside the cavity reducing melting time. Total melting time for various inclinations is given in table 2.

Table. 2 Summary of Results of melting time

Sr.No	Input Power(w)	Melting Time(min.)
1	90	140
2	60	100
3	30	70
4	0	180

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

$$(Q)_{stored} = (Q)_{sensible} + (Q)_{latent} \text{..........................} (2.7)$$

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

Further study is carried out to find the amount of energy stored in PCM unit inclined at 30 and various heater input.

Table. 3 Summary of Results for heat stored

Sr.No	Input Power(w)	Energy Stored (KJ)
1	120	1280.069
2	140	1289.156
3	170	1278.469
4	205	1289.157
5	245	1297.706
6	285	1319

Conclusions

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

1) The inclination has major influence on total melting time of PCM. With increase in inclination the melting time can be shortened considerably.
2) Inclination at 30 has shown best result yielding minimum melting time compared to other inclination positions.
3) The melting behavior at 30 inclinationsis discussed in detail, melting starts in lower portion near to inner aluminum wall then melted PCM ascended faster in upper region. In this process natural convection currents are assisted by effect of inclination.
4) The amount of energy stored in PCM is calculated the results drawn indicate that significant amount of energy can be stored in PCM unit.

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