EXPERIMENTAL STUDY AND THERMAL CHARACTERIZATION OF NANO COMPOSITE PHASE CHANGE MATERIAL

Giriswamy B G*, Eswarmoorthy M², Yellappa M¹ and Satyamurthy N¹

*Corresponding Author: Giriswamy B G, gvc2005@yahoo.co.in

INTRODUCTION

Global warming and green house effects can be reduced by active utilization of renewable energy sources. Thermal energy storage plays a key role in the application of renewable energy sources and thus it contributes to the reduction of global CO2 emissions. Thermal energy storage is commonly based on the sensible- or latent-heat-storage techniques. Latent-heat thermal storage is based on the absorption or release of heat when a storage material is changing phase. The thermal-storage materials suitable for latent-heat storage are called Phase-Change Materials (PCMs). PCMs have considerably higher thermal-energy-storage densities than the sensible-heat-storage materials and they are able to absorb large quantities of energy in a small range of temperatures during the phase change. A phase-change material (PCM) is a substance...
with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa thus, PCMs are known as latent heat storage (LHS) units. Phase change materials have wide range of applications which include thermal energy storage, Conditioning of buildings such as ice-storage, Cooling of food, beverages, coffee, wine, milk products, Medical applications, Heating water and Cooling, Heat systems, Solar plants, Spacecraft thermal systems, Thermal comfort in vehicles, Thermal protection of electronic devices, Thermal protection of food, transport, Textiles industry, Computer cooling, Telecom sectors, etc. Organic and inorganic materials are two most common groups of PCMs. Most organic PCMs are noncorrosive and chemically stable, and have little or no subcooling. But, they have disadvantages of low thermal conductivities, high changes in volume on phase change and flammability. In contrast, inorganic materials have a high latent heat per unit volume and high thermal conductivities, and are non-flammable and low in cost in comparison to organic materials. However, they are corrosive to most metals and suffer from decomposition and subcooling, which can affect their performance in heat storage systems. New techniques of utilizing phase change material (PCMs) and improving the properties and thermal performance of PCMS in thermal energy storage system has been developed and being studied by some researchers in and around the world. The optimum design of thermal energy storage systems, which run with phase change material slurry, requires a good knowledge of flow and heat transfer characteristics of two-phase slurry involved in phase change, in order to reduce the capital cost, system size, and energy consumption. The thermal properties of PCMS are crucial for the LHS system design. Thermal conductivity is one such property which is of prime importance which decides the performance of PCMS in latent heat storage systems. Due to low thermal conductivity, the performance of PCMs has been hindered. So an effort is made in developing an apparatus for investigating the thermal conductivity of phase change materials and enhancing the thermal conductivity of PCMS by adding normal and nano Al2O3 in different weight ratios. Comparison of thermal conductivity for different specimens prepared is made and variation of thermal conductivity with temperature is studied for analyzing the thermal performance of phase change materials.

**PHASE CHANGE MATERIALS**

A phase-change material (PCM) is a substance with a high heat of fusion which on melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. PCMs are classified as latent heat storage (LHS) units.
Characteristics
PCMs’ latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid–gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation. Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from -5 up to 190 °C. Within the human comfort range between 20–30°C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

**PCM MEETS SEVERAL CRITERIA**
Release and absorb large amounts of energy when freezing and melting. This requires the PCM to have a large latent heat of fusion and to be as dense as possible.

**Classification of PCMs**
Have a fixed and clearly determined phase change temperature (freeze/melt point)
The PCM needs to freeze and melt cleanly over as small a temperature range as possible. Water is ideal in this respect, since it freezes and melts at exactly 0 °C (32 °F). However, many PCMs freeze or melt over a range of several degrees, and will often have a melting point that is slightly higher or lower than the freezing point. This phenomenon is known as hysteresis.

Avoid excessive super cooling
Super cooling is observed with many eutectic solutions and salt hydrates. The PCM in its liquid state can be cooled below its freezing point whilst remaining a liquid. Some salt hydrates can be cooled to 50 °C (122 °F) below their freezing point without crystallisation occurring. This can be beneficial, for example in hot packs where a 48 °C (118.4 °F) PCM is kept as a super cooled liquid at room temperature until the hot pack is required and super cooling is broken by mechanical or chemical nucleation. However for most applications, super cooling must be kept to a minimum by the addition of suitable nucleating agents to the PCM.
Remain stable and unchanged over many freeze/melt cycles

PCMs are usually used many times over, and often have an operational lifespan of many years in which they will be subjected to thousands of freeze/melt cycles. It is very important that the PCM is not prone to chemical or physical degradation over time which will affect the energy storage capability of the PCM. Some eutectic solutions may be susceptible to microbiological attack, so must be protected with biocides. Long term stability can be a problem in some salt hydrate PCMs, unless they are modified to prevent separation of the component materials over successive freeze/melt cycles.

Be non-hazardous

PCMs are often used in applications whereby they could come in contact with people, for example in food cooling or heating applications, or in building temperature maintenance. For this reason they should be as safe to use as possible. Ideally a PCM should be non-toxic, non-corrosive, non-hazardous and non-flammable. There are many substances that behave excellently as PCMs but cannot be used due to issues over safety.

Be economical

It doesn’t matter how well a substance can perform as a PCM is if it is prohibitively expensive. PCMs can range in price from very cheap (e.g. water) to very expensive (e.g. pure linear hydrocarbons). If the cost of the PCM outweighs any benefit obtained from using the PCM, its use will be very limited.

ENCAPSULATED PCM PRODUCTS

1) Flat ICE Containers

These containers are constructed of blow moulded HDPE and can be filled with positive or negative temperature PCMs, although high temperature PCMs may be unsuitable due to softening of the plastic. Each container holds approx 3 litres of PCM and due to their design they can be stacked on top of each other to achieve a large bulk volume of PCM for, e.g., building temperature control applications. When stacked there is a small gap between each container, allowing either air or water to flow easily over the containers while providing a large PCM surface area for heat transfer.

2) Tube ICE

These containers operate on a similar principle to the FlatICE containers, and are supplied as fully sealed PCM-filled HDPE tubes. The tubular design enables them to be stacked effectively in both rectangular and cylindrical tanks with minimal void space. Once installed, a series of ridges around the circumference of the tube mean that air or water can pass freely between the containers allowing excellent heat exchange properties.

3) Ball ICE

This technology is only available for use with our positive temperature organic range of PCMs, and involves the PCM being directly incorporated into a plastic or rubber matrix. This is then moulded to produce standard sized balls, although any shape or size can be moulded if required. This concept is ideal for heat storage applications such as solar, waste heat, hot water, and domestic/commercial heating tanks.

4) Eutectic Plates

This catalogue acts as an introductory guide to the methods of encapsulation available for our sub-zero eutectic PCMs, and their typical modes of application and uses. Our standard Eutectic plates are in four sizes starting from 500mm x 250mm x 32mm down to small ice
pack of 150mm x 80 mm x 30 mm can be filled any of our Eutectic solutions between -62°C and +89°C but any other dimensional shape, fitting and temperature requirements can be supplied as a custom-made product together with full application support.

5) PCM Pouches
The bulk of the range of our PCMs can be supplied prefilled in a wide variety of flexible metallic or non-metallic pouches, available in a number of different sizes for use in temperature critical transport applications. Alternatively, we can fill majority of our Plus ICE range PCM solution in our customer's own pouches as well as develop custom-made sizes using special materials for a variety of temperature range applications.

6) Transport Eutectic Plates
A wide range of metallic eutectic plates manufactured by FIC (Italy) are available in a number of different sizes, and filled with several standard eutectic solutions to cover a multitude of conventional applications and operational temperature ranges. However, if any special application is required, we can fill them with any of our Plus ICE PCM solutions to suit the application. Both standard carbon and stainless steel with or without a cooling coil fitted versions can be used with or without a refrigeration circuit.

7) Passive Cooling
A passive cooling energy storage application designed to work the natural difference between the cooler night and warmer day time ambient temperatures and by storing the cold energy over-night, the daily heat gains both internally and externally can be handled without any mechanical refrigeration, thereby providing maintenance free passive cooling’s

8) Eco Pack Box
Another passive cooling application, this time targeted at maintaining operational temperatures in temperature sensitive areas such as computer rooms, telecoms shelters, or any enclosed space containing electrical equipment capable of generating heat. Many such pieces of equipment are specified not to be used in ambient temperatures greater than 45 °C (113 °F). The Eco Pack BOX design complements, or eliminates altogether, the need for mechanical cooling in such spaces.

MATERIALS AND METHODOLOGY

Selection of Phase-Change Materials
Phase-change materials can be chosen from both organic and inorganic materials. The organic phase change materials melt and freeze repeatedly without a phase-change segregation and crystallize with little or no-supercooling. The organic phase-change materials, e.g. the paraffin’s, are compatible with metals without any risk of corrosion. The paraffin’s have a rather poor thermal conductivity and they are flammable. The melting point of the alkanes increases with an increased number of carbon atoms. The inorganic PCMs are compatible with plastics and their storage capacity is higher than the capacity of the organic PCMs due to their higher density. The in-organic PCMs, e.g., salt hydrates, are incompatible with uncoated metals. The salt hydrates are important PCMs because of the high heat of fusion and a small volume change during the process of melting and solidification. The main disadvantages of salt hydrates are their poor nucleating properties that result in super cooling. Suitable PCMs from both organic and in organic groups are available for applications
in the latent-heat storage technology. Many phase-change materials cannot be used as latent-heat-storage mediums because of the problems with their chemical stability, toxicity, corrosion, volume change and price. The phase-change materials should meet the following thermodynamic and economic criteria.

**Thermodynamic Criteria**
- high heat of fusion
- melting range in the desired operating-temperature
- range
- high specific heat
- high thermal conductivity
- high density and low volume change

**Economic criteria**
- availability in the required quantities;
- Low cost.

**Some of the Important Properties Required for PCM**
- High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy.
- High specific heat that provides additional sensible heat storage effect and also avoid sub cooling.
- High thermal conductivity so that the temperature gradient required for charging the storage material is small.
- High density, so that a smaller container volume holds the material.
- A melting point in the desired operating temperature range.
- The phase change material should be non-poisonous, non-flammable and non-explosive.
- No chemical decomposition, so that the (LHTS) system life is assured.
- No corrosiveness to construction material.
- PCM should exhibit little or no super cooling during freezing.

**Methods Done to Improve Thermal Conductivity**
Most PCMs have low thermal conductivity, which prevents them from overcoming problems of rapid load changes in the charging and discharging processes. To overcome this obstacle and to obtain excellent thermal properties, studies have proposed various techniques for enhancing the thermal conductivity of PCMs, such as
- adding metallic or non-metallic particles with high thermal conductivity.
- inserting fins
- incorporating porous or expanded materials
- inserting fibrous materials
- Incorporating macro-, micro-, and nano-capsules.

The above mentioned methods for enhancing the thermal conductivity of PCM involve adding high-conductivity materials to improve the thermal conductivity of PCMs as the most simple and feasible method. Metals have excellent thermal conductivity; therefore, they can be expected to enhance the thermal conductivity of PCMs significantly. However, metal materials oxidize, and their application to PCMs can degenerate and reduces the thermal conductivity of PCMs in the long run. Although adding metal oxides or minerals to PCMs to enhance thermal conductivity is worth considering, the thermal conductivity of such additives must be higher than that of the PCM if they are to enhance the thermal conductivity of PCMs. Moreover, a poor combination of additives to PCMs can increase interface thermal resistance and
sedimentation and reduce the performance of the thermal storage without enhancing the thermal conductivity of PCMs. With the development of nanotechnology, the size of the additives can be reduced to a nanometre scale, and the reduced size can enhance the suspension performance, specific surface area, and heat transfer performance of the additives. In some studies, carbon nanotubes (CNTs), carbon nanofiber (CNFs), Cu nanoparticles, and Ag nanoparticles were added to form nanocomposite-enhanced phase-change materials (NEPCMs) as a technique to enhance the thermal performance of PCMs. However, CNTs, CNFs, and Ag are expensive; therefore, the extensive use of these nanoparticles can reduce the economic benefits of PCMs for TES. Paraffin is a material of low cost and toxicity that can be decomposed by bacteria. Therefore, it was chosen as the PCM thermal storage material for this study. Furthermore, the melting point of paraffin is approximately 55°C to 65°C, which makes it suitable for thermal storage in non-concentrating solar collectors.

**Design for Fabrication of the Experimental Setup**

**Design of Container with Respect to Volume of Paraffin**

The dimension of the container is estimated as follows. Calculations

Volume of cylinder

We know that

\[
\rho = \frac{m}{V}
\]

\[
V = \frac{m}{\rho}
\]

\[
= \frac{0.140}{900}
\]

\[
= 1.545 \times 10^{-4} \text{ m}^3
\]

Here

\[
m = \text{mass of wax i.e. 140gms}
\]

\[
\text{Density of wax i.e. 900Kg/m}^3
\]

Volume of wax = volume of cylinder

\[
= \text{area of cylinder} \times \text{length of cylinder}
\]

\[
\text{Length of container} = 71 \text{ mm}
\]

\[
\text{Inner Dia of container} = 53 \text{ mm}
\]

**Drawing of Container**

![Figure 3: Draft Drawing of Copper Container](image)

Dimensions must include diameter of container, its length, selection of material and etc. for current work container dimensions considered are, Ø 53x71x1.5. These dimensions are considered for a mass of 140gms of wax, but actual mass of wax taking for experiment is 100gms only. Fully refined paraffin wax served as the base material in this study alumina nano powder of 350nm size with different volume % are added to base PCM in order to alter its properties.
CONDUCTION OF EXPERIMENT

The experiment investigates the effects of Al2O3 of 400 mesh and Al2O3 nano powder on the paraffin to evaluate the heat storage performance. Figure above shows the test apparatus used for the heat conduction performance of nano composite PCMs. The 100 gm of solid paraffin wax is poured into the copper container. The setup is provided with five thermocouples, out of which three thermo couples are installed in a copper container at different locations within the container, one is provided to measure ambient temperature and remaining one to measure temperature of heater. The temperature change was recorded by Temperature indicator with channel selector (UNIVERSAL, 6 channels and temperature range up to 0-12000c). The heat input is measured by ammeter and voltmeter readings. Readings are taken at an interval of time of 2 min up to the point that the paraffin wax gets melt during charging. Then set up i.e. container allowed to cooling for discharging. The same is repeated for various volume fractions of alumina i.e. Al2O3 of 400 mesh and nano Al2O3 added to base PCM.

Table 1: Design Considerations and specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Material</th>
<th>Diameter</th>
<th>Height</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>Copper</td>
<td>53</td>
<td>71</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2: Components of Equipment

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description</th>
<th>Quantity</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Heater</td>
<td>01</td>
<td>Band type heater, range 0-350 G I material, power 360W</td>
</tr>
<tr>
<td>02</td>
<td>Container</td>
<td>01</td>
<td>Copper material 53 x 2 x 71</td>
</tr>
<tr>
<td>03</td>
<td>Insulation</td>
<td>01</td>
<td>Glass wool Range 540 sections</td>
</tr>
<tr>
<td>04</td>
<td>Voltmeter</td>
<td>01</td>
<td>Digital Voltmeter Range 0-750V Accuracy +/- 1</td>
</tr>
<tr>
<td>05</td>
<td>Ammeter</td>
<td>01</td>
<td>range 20A 220V, Accuracy +/- 1</td>
</tr>
<tr>
<td>06</td>
<td>Temperature indicator</td>
<td>01</td>
<td>Range 0-12000c6channals</td>
</tr>
<tr>
<td>07</td>
<td>Autotransformer</td>
<td>01</td>
<td>Range 0-270 volts 2 Amps</td>
</tr>
<tr>
<td>08</td>
<td>Thermocouples</td>
<td>05</td>
<td>Range up to 600°</td>
</tr>
</tbody>
</table>

Composite Cylinders

Consider system of composite cylinders as shown in Figure
A cylinder of radius R1 and thermal conductivity of k1 is covered with another layer of radius R2 and thermal conductivity K2. R2 is covered with layer of radius R3 and thermal conductivity K3 and R3 is covered with the layer of radius R4 and thermal conductivity of K4. There is a perfect thermal contact at the interface between the two layers, i.e. there is no temperature drop at the interface. Assumptions: (i) Steady state conduction (ii) One dimensional heat conduction in r direction only (iii) No internal heat generation (iv) Perfect thermal contact between layers.

EFFECT OF VARIABLE THERMAL CONDUCTIVITY

In general it is assumed that thermal conductivity; k to be constant, i.e. k did not change with temperature. However, this assumption may not be always true. When the k of a material varies rapidly with temperature or when the temperature range of operation is large, it becomes necessary to take into account the variation of k with temperature.

GLASS WOOL INSULATION

Insulation is added to a surface to reduce the heat loss from the surface to ambient, if the surface is hot, or to reduce the heat loss into the surface from ambient, if the surface is cold. Either way, the aim is to reduce the heat loss. Generally, addition of insulation does reduce the heat loss.

PROCEDURE FOR CONDUCTING EXPERIMENT

Charging Mode
1) Check for power supply and proper connection.
2) Measure 100 grams of paraffin wax by electronic weighing machine.
3) Fill the cleaned copper container with calculated amount of wax i.e. 100gms.
4) Close the container lid with thermocouples properly placed in position.
5) Switch on the power supply to the equipment.
6) Regulate the heat input to the heater by slowly controlling the auto transformer to give a constant heat input of 40v and 0.29 amps.
7) Wait till the heater temperature rises to around 70 – 75 °C.
8) Place the container with paraffin inside the heater.
9) Take initial reading at time equal to zero min.
10) Note the different thermocouple reading at regular time interval of 2 minutes using stop watch as the heat flows across the container radially.
11) Take the thermocouple readings till the temperature of paraffin wax is greater than its melting temperature.
12) Switch off the heat supply and stop the stop-watch.
13) Carefully take out the container from heater for discharging mode.
14) Repeat the experiment for different weight ratios of alumina and PCM.

DISCHARGING MODE

1) Carefully remove the hot container from the heater and is placed in open air without disturbing the thermocouples.
2) Take the initial temperature at time equals to zero.
3) Note the different thermocouple reading at regular time interval of 5 minutes using stop watch as the container cools due to free convection.
4) Take the thermocouple readings till the temperature of paraffin wax reduces to around room temperature.
5) Stop the stop watch and switch off the power supply.
6) Remove the thermocouples from the specimen.
7) Specimen is removed from the container and is preserved.
8) The same is repeated for different weight ratios of alumina and PCM

**Note:** Different temperature readings

T1 = Heater temperature / temperature at the outer surface
T2 = Temperature at the radius R1
T3 = Temperature at the radius R2
T4 = Temperature at the radius R3
T5 = Temperature at the radius R4

**Calculations Formulae Used**

1. Heat input = \[ Q = \frac{\Delta T}{R} \]  
   \[ \text{Eq 3.1} \]
   Where \( Q \) = heat input  
   \( \Delta T \) = temperature difference  
   \( R \) = thermal resistance

2. \[ R = R_1 + R_2 + R_3 \]  
   \[ \text{Eq 3.2} \]

\[ R = \frac{\ln \frac{r_1}{r_2}}{2\pi k_1} + \frac{\ln \frac{r_2}{r_3}}{2\pi k_2} + \frac{\ln \frac{r_3}{r_4}}{2\pi k_3} \]  
\[ \text{Eq 3.3} \]

where

R1 = thermal resistance of copper container
R2 = thermal resistance of wax
R3 = thermal resistance of inner cylinder

Thermal resistance of copper container

\[ R_1 = \frac{\ln \frac{r_1}{r_2}}{2\pi k_1} \]

Thermal resistance of wax

\[ R_2 = \frac{\ln \frac{r_2}{r_3}}{2\pi k_2} \]

Thermal resistance of inner cylinder

\[ R_3 = \frac{\ln \frac{r_3}{r_4}}{2\pi k_3} \]

r1 = outer radius ie container radius = 28mm
r2 = inner radius of container = 26.5mm
r3 = outer radius of inner copper tube = 8mm
r4 = inner radius of inner tube = 6.5mm

Heat input \[ Q = V^*I \]  
\[ \text{Eq 3.4} \]

Q = 40*0.29  
Q = 11.6 watts
Since there is a gap between heater and container, let us assume that there may be 30% loss in supplied heat from heater to container.
Then actual heat input ($Q_{\text{actual}}$) is 70% of supplied input ($Q$).

\[
Q_{\text{actual}} = 11.6 \times 0.7
\]
\[
8.12 = \frac{83 - 32}{R}
\]
\[
R = \frac{51}{8.12}
\]
\[
R = 6.280
\]

\[
R = \frac{\ln \frac{r_1}{r_2}}{2\pi \ln k_1} + \frac{\ln \frac{r_2}{r_3}}{2\pi \ln k_2} + \frac{\ln \frac{r_3}{r_4}}{2\pi \ln k_3}
\]
\[
R = \frac{\ln \frac{28}{16.5}}{2\pi \times 0.065 \times 387.6} + \frac{\ln \frac{2b.8}{8}}{2\pi \times 0.065 \times k_2} + \frac{\ln \frac{8}{6.5}}{2\pi \times 0.065 \times 387.6}
\]
\[
= 1.658 \times 10^{-3} + \frac{2.932}{k_2}
\]

\[
\frac{\Delta T}{8.12} = 1.658 \times 10^{-3} + \frac{2.932}{k_2}
\]
\[
\frac{23.80}{K_2} = \Delta T - 0.01346
\]
\[
K_2 = \frac{23.80}{\Delta T - 0.01346}
\]
\[
K_2 = \frac{23.80}{(T_h - T_i) - 0.01346}
\]
\[
K_2 = \frac{23.80}{(75 - 32) - 0.01346}
\]
\[
K_2 = 0.54 W/m°C
\]
The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax. From the graph it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 305 K to 335.33 K, thermal conductivity decreases 0.54 W/mK to 0.412 W/mK. Hence thermal conductivity is the function of temperature.

Above graph shows charging curve of pure paraffin wax and 10% Al₂O₃ of size 400 mesh it shows the variation of temperature of paraffin wax with time. This graph shows the time required to raise the temperature of paraffin wax to a particular temperature i.e. to store thermal energy.

The above graph shows dis-charging curve of pure paraffin wax with 5% normal Al₂O₃ of size 400 mesh, it shows the variation of temperature of paraffin wax with time. This graph shows the time required to dis-charge the stored heat energy of paraffin wax with 5% normal Al₂O₃ of size 400 mesh.

The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax with 10% Al₂O₃ of size 400 meshes. From the graph it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 306 K to 342.67 K, thermal conductivity decreases 0.613 W/mK to 0.527 W/mK. Hence thermal conductivity is the function of temperature.
Above graph shows charging curve of pure paraffin wax and 5% normal Al₂O₃ of size 400 mesh, it shows the variation of temperature of paraffin wax with time. This graph shows the time required to raise the temperature of paraffin wax to a particular temperature i.e. to store thermal energy.

Above graph shows dis-charging curve of pure paraffin wax with 5% normal Al₂O₃ of size 400 mesh, it shows the variation of temperature of paraffin wax with time. This graph shows the time required to dis-charge the stored heat energy of paraffin wax with 5% normal Al₂O₃ of size 400 mesh.

The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax with 5% normal Al₂O₃ of size 400 mesh. From the graph it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 306 K to 336.67 K, thermal conductivity decreases 0.597 W/mK to 0.463 W/mK. Hence thermal conductivity is the function of temperature.

Above graph shows charging curve of pure paraffin wax with 10% nano Al₂O₃, it shows the variation of temperature of paraffin wax with time. This graph shows the time required to raise the temperature of paraffin wax to a particular temperature i.e. to store thermal energy.
Above graph shows dis-charging curve of pure paraffin wax with 10% nano Al2O3, it shows the variation of temperature of paraffin wax with 10% Al2O3 with time. This graph shows the time required to dis-charge the stored heat energy of paraffin wax with 10% nano Al2O3.

The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax with 10% nano Al2O3 of size 350nm. From the graph it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 305 K to 333.67 K, thermal conductivity decreases 0.667 W/mK to 0.567 W/mK. Hence thermal conductivity is the function of temperature.

Above graph shows charging curve of pure paraffin wax with 5% nano Al2O3 of size 350nm, it shows the variation of temperature of paraffin wax with 5% nano Al2O3 with time. This graph shows the time required to raise the temperature of paraffin wax to a particular temperature i.e. to store thermal energy.

Above graph shows dis-charging curve of pure paraffin wax with 5% nano Al2O3 of size 350nm, it shows the variation of temperature of paraffin wax with 5% nano Al2O3 of size 350nm with time. This graph shows the time required to dis-charge the stored heat energy of paraffin wax with 5% nano Al2O3 of size 350nm.
The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax with 5\% nano alumina Al₂O₃ of size 350nm. From the graph it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 306 K to 336.67 K, thermal conductivity decreases 0.61 W/mK to 0.476 W/mK. Hence thermal conductivity is the function of temperature.

**Comparison Graphs**

Comparison between pure wax, wax and 5\%Alumina, wax+5\% nano Alumina

This shows the comparison of variation of thermal conductivity with temperature for pure paraffin wax, paraffin+5\% normal alumina and paraffin +5\% nano alumina. From this we can see that thermal conductivity of paraffin wax has been improved by adding alumina.

Comparison between pure wax, wax and 10\% Alumina, wax +10\% Nano Alumina

This shows the comparison of variation of thermal conductivity with temperature for pure paraffin wax, paraffin+5\% normal alumina and paraffin +5\% nano alumina. From this we can see that thermal conductivity of paraffin wax has been improved by adding alumina.

Comparison between pure wax, wax 5\% Alumina, wax +10\% Nano Alumina

This shows the comparison of variation of thermal conductivity with temperature for pure paraffin wax, paraffin+5\% normal alumina and paraffin +5\% nano alumina.
From this we can see that thermal conductivity of paraffin wax has been improved by adding alumina of 10% weight ratio than 5%.

**CONCLUSION**

**Conclusion**

In the experimental study and thermal characterization of nano composite phase change material, the following conclusions are drawn from experimental results. The thermal conductivity decreases with increase in temperature and upon the addition of Al2O3 to paraffin the thermal conductivity was significantly enhanced. By addition of normal Al2O3 the thermal conductivity increases by 10.55% and 13.51% for weight ratios of 5% and 10% respectively. It is seen that addition of nano Al2O3 increases the thermal conductivity by 12.9% and 23.51% for weight ratios of 5% and 10% respectively. The effect of normal Al2O3 and nano Al2O3 on thermal conductivity of PCMs are plotted on the graphs. The results show that nano Al2O3 has significant effect on thermal conductivity of PCMs, which enhances the thermal conductivity of PCMs more than that of normal Al2O3. Also we derived the equation using curve fitting technique which will give thermal conductivity for temperature variation within the limit.

<table>
<thead>
<tr>
<th>Table 3: Equations From Curve Fitting Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight ratios of wax and Al2O3</td>
</tr>
<tr>
<td>100% wax 0% Al2O3</td>
</tr>
<tr>
<td>95% wax and 5% normal Al2O3</td>
</tr>
<tr>
<td>90% wax and 10% normal Al2O3</td>
</tr>
<tr>
<td>95% wax and 5% nano Al2O3</td>
</tr>
<tr>
<td>90% wax and 10% nano Al2O3</td>
</tr>
<tr>
<td>Equation obtained from curve fitting technique</td>
</tr>
<tr>
<td>y = -0.005x + 2.088</td>
</tr>
<tr>
<td>y = -0.004x + 2.103</td>
</tr>
<tr>
<td>y = -0.003x + 1.589</td>
</tr>
<tr>
<td>y = -0.005x + 2.193</td>
</tr>
<tr>
<td>y = -0.004x + 0.810</td>
</tr>
</tbody>
</table>

**Scope for Future Work**

- Studies can be carried out to compare experimental results with finite element analysis.
- The present investigation can be extended to study the microstructure of composite specimen.
- Investigation can be carried out by developing the specimen samples through other techniques and results can be compared and analyzed with the present data.
- Microencapsulation techniques can be employed to further improve the thermal conductivity and performance of phase change materials.

**REFERENCES**


4. A Heinz and W Streicher, application of phase change materials and pcm-slurries for thermal energy storage.


