Enhancement of thermal conductivity of PCM using filler graphite powder materials

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Abstract. The thermal conductivity of paraffin wax which is a phase change materials is enhanced by adding filler particle Graphite powder to the paraffin matrix. Praffin wax is melted in a heating mantle to its melting point of 60°C. Graphite particles are slowly added while the mixture is continuously stirred. The mixture is taken into the mould and cooled to get the composite. The time taken for melting the paraffin wax and solidifying it is noted down for each and every composition. Nielsen equation is used to calculate the thermal conductivity value analytically. SEM analysis is done to check the interaction between the matrix and the filler particles. The necessary graphs were plotted between the solidification time vs volume fraction, melting time vs volume fraction, thermal conductivity vs volume fraction. In the end we observed that the thermal conductivity value of the paraffin wax is significantly increased. The highest thermal conductivity is obtained for the paraffin wax with 60% composition and the value is found to be 7.1 w/mk.

Keywords: Thermal conductivity, paraffin wax, Graphite powder, SEM analysis, Nielsen equation, volume fraction

1 Introduction:

Phase change materials make use of the latent heat that can be stored or released from a material over a particular temperature range. The best advantages of using latent heat, rather than sensible heat are decrement in the temperature variation, thermal energy storage and more efficient way to transfer heat over a small temperature difference. [1]
Latent heat storage is done through various phase change transformations. However, only solid→liquid and liquid→solid phase changes are practical for PCMs. Although liquid–gas transitions have a higher efficiency than solid–liquid transitions, liquid→gas phase changes are not preferred for thermal energy storage. Solid–solid phase changes are typically very slow and have a relatively low heat of transformation.

| PROPERTY                      | VALUE         |
|-------------------------------|---------------|
| Latent heat of fusion         | 214kJ/kg      |
| Specific heat capacity (solid)| 1.85kJ/kg.k   |
| Specific heat capacity (liquid)| 2.384kJ/kg.k  |
| Thermal conductivity         | 0.4W/mk       |
| Density (solid)              | 856kg/m³      |
| Density (liquid)             | 775kg/m³      |
| Melting point                | 60°C          |

**Table 1. Thermo-physical properties of paraffin wax**

| PROPERTY                      | VALUE         |
|-------------------------------|---------------|
| Atomic mass                  | 12 amu        |
| Melting point                | 4000 K        |
| Density                      | 2.266g/cm³    |
| Thermal conductivity         | 80 W/mk       |

**Table 2. Thermo-physical properties of Graphite powder**
2. Applications:

Applications of phase change materials include, but are not limited to[3]:

- Storing thermal energy
- Cooking using solar energy
- Keeping temperature constant in buildings.
- Cooling heat engines
- Used in medical industry
- Textiles
- Wasteheat management

3 Processing:

Figure 1. Flow chart of all the processes conducted in the experimented
This involves the melting of paraffin wax and adding Graphite particles to it. Before melting the weight of different samples are measured. Now paraffin wax is taken into a glass beaker. The heating mantle is turned on. From the study it is known that paraffin wax melting point is around 60°C. So the temperature of the heating mantle is adjusted to 60 degrees. Now the beaker is kept on the heating mantle. Due to the heat generation, the paraffin wax is melted. The time for melting is noted down. The Graphite powder is poured slowly into the liquid paraffin wax and it is slowly stirred. This allows the mixing of paraffin wax and Graphite particles. Now the mixture is taken into mould and it is allowed to cool down. In this way the composite is obtained.

4 Analytical calculations:

The thermal conductivity is determined analytically using Nielsen equation[1]. The equation is

\[ K = K_p \frac{(1 + A.B. \phi)}{(1 - B. \varphi. \phi)} \]

\[ B = \frac{k_f}{k_p} \]

\[ \varphi = 1 + \frac{(1 + \phi_m)\phi}{\phi_m} \]

Where

\( K \) = Thermal conductivity of composite in W/mk

\( K_p \) = Thermal conductivity of paraffin wax in W/mk
K_f = thermal conductivity of filler particles in W/mk

Ø = Volume fraction of filler particles

φ = a constant calculated based on the volume fraction of filler particles

A = a constant determining the shape of the filler particles

B = a constant calculated based on the thermal conductivities of filler particles and matrix.

Sample calculation for 10% filler particles:

For Graphite

A = 1.3, Ø = 0.1[4]

\[
B = \frac{k_f - 1}{k_p + A}
\]

\[
B = \frac{80 - 1}{0.4 + 1.3}
\]

= 0.988

\[
\phi = 1 + \frac{(1 + \phi_m)\phi}{\phi_m^2}
\]

\[
\phi = 1 + \frac{(1 + 0.52) 0.1}{0.52^2}
\]

= 1.37

\[
K = K_p \frac{(1 + A.B.\phi)}{(1 - B.\phi.\phi)}
\]

\[
K = 0.4 \frac{(1 + 1.3 \times 0.988 \times 0.1)}{(1 - 0.988 \times 1.56 \times 0.1)}
\]

= 0.534 W/mk
5. SEM analysis:

The microstructure of all the composites were observed using scanning electron microscope. The interaction between the paraffin wax and the Graphite powder is observed.

![Figure 6. 90% wax](image6)
![Figure 7. 80% wax](image7)

![Figure 8. 70% wax](image8)
![Figure 9. 60% wax](image9)
![Figure 10. 50% wax](image10)

6. Tabulation and graphs:

Various results were obtained for the melting time and solidification time of the composite. The values of thermal conductivity were measured using Neilsen’s equation. The graphs were plotted between the solidification time vs volume fraction, melting time vs volume fraction, thermal conductivity vs volume fraction. The slope of the curves in the graphs between melting point vs volume fraction, solidification time vs volume fraction is almost constant. If we observe the graph between thermal conductivity vs volume fraction, there is a rapid increase in thermal conductivity from 70% to 60% paraffin wax concentration. Further by adding filler particles, the thermal conductivity of paraffin wax is increased. The
highest thermal conductivity is obtained for the paraffin wax with 60% composition and the value is found to be 7.1 w/mk

Table 3. Melting and solidification time

| Volume fraction     | Heating time in seconds | Solidification time in seconds |
|---------------------|-------------------------|-------------------------------|
| 100% paraffin wax   | 913                     | 1773                          |
| 90% paraffin wax    | 829                     | 1320                          |
| 80% paraffin wax    | 775                     | 1170                          |
| 70% paraffin wax    | 676                     | 963                           |
| 60% paraffin wax    | 630                     | 890                           |
| 50% paraffin wax    | 542                     | 724                           |

Table 4. Thermal conductivity values

| Volume fraction     | Thermal Conductivity W/mk |
|---------------------|---------------------------|
| 100% paraffin wax   | 0.4                       |
| 90% paraffin wax    | 0.534                     |
| 80% paraffin wax    | 1.19                      |
| 70% paraffin wax    | 2.77                      |
| 60% paraffin wax    | -2.1                      |
Figure 11. Solidification time vs volume fraction

Figure 12. Melting time vs volume fraction
7. Results and discussion:

In SEM analysis, we observe that for 90% paraffin wax, the volume concentration is very less. But if we observe for 50% paraffin wax, the filler particle concentration is more. There is an increasing trend in the volume concentration when filler particles concentration is increasing. The slope of the curves in the graphs between melting point vs volume fraction, solidification time vs volume fraction is almost constant. If we observe the graph between thermal conductivity vs volume fraction, there is a rapid increase in thermal conductivity from 80% to 70% paraffin wax concentration. Further by adding filler particles, the thermal conductivity of paraffin wax is increased. This results showed that using high thermal conductive fillers are effective for enhancing the thermal conductivity of PCM. The highest thermal conductivity is obtained for the paraffin wax with 70% composition and the value is found to be 2.77 W/mK.
8. References

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