Tailoring the Thermal Conductivity of Paraffin and Low-cost Device for Measuring thermal conductivity of Phase Change Material

Mohit Bhandwal, Amritanshu Verma, Basant Singh Sikarwar*
Department of Mechanical Engineering, Amity University, Uttar Pradesh, Noida-201313
*bssikarwar@amity.edu

Abstract. In this work, experiment is carried out for melting process of paraffin wax dispersed with high conductive nano-fillers such as Carbon Nanotube (CNT) and ZnO. In addition, a simple, economically viable, easy operating experimental setup is proposed to measure the thermal conductivity of altered PCMs. In this setup, the sample is placed in an insulated transparent cavity and its one end maintained at constant temperature. However, other ends are adiabatic. Temperature at four specific location of melting paraffin in the cavity are measured by T-type thermocouples. The digital camera is used to capture the instantaneous images of the moving thermal front of melting at various time steps. ImageJ® is used to know velocity of the melting front of PCMs from captured images. Based on energy balance, a mathematical expression for estimating the conductivity of the altered PCMs is derived. The measurement of proposed device is compared with commercial thermal conductivity measuring device and data available in the literature. The obtained results have 95% confidence level against the commercial device results and literature results. Post-calibration, experimental study of pure paraffin and altered paraffin wax are carried to know insights of Spatio-temporal energy storing in form of latent heat. This research is useful for design the heat sink for thermal energy management of pulsating heating generating device.

Key words: Melting, Solidification, Latent heat Energy, altered Paraffin wax, Carbon nanotubes (CNT).

1. Introduction
Energy storage is essential to utilize renewable energy sources effectively and efficiently [1]. Solar-thermal energy is stored in the form of latent, thermo-chemical and sensible heat. Among these methods, Latent heat storage is more effective for its high energy per volume capacity at isothermal nature and this method uses Phase Change Materials (PCMs) as storage medium which exchange the energy in form of latent heat by melting and solidification [2-4]. Any storage medium which have suitable thermo-physical properties reduce the cost of the system and make it more efficient [5]. In this context, several organic, inorganic and eutectic PCMs and their thermo-physical properties have been critically reviewed in literature for optimizing thermophysical properties of PCMs [6]. Among several PCMs, Paraffin wax has been widely employed, as it is chemically stable, readily available, safe and non-reactive, non-corrosive and economical. It is also available in a wide range of melting temperatures, which makes it a desirable thermal storage medium. These properties make paraffin wax
suitable PCM for domestic hot water systems, building cooling, heat exchangers etc. However, low thermal conductivity of it has caused an incessant challenge in its large-scale implementation. To enhance the thermal conductivity of paraffin wax, scientists and researchers ([7-14]) have reported various methods such as addition of nano-fillers, metal-powder, metal matrix, carbon-fibers/graphite. On the other hand, addition of conducting fins and altering surface morphology methods have also been explored for enhancing the performance of latent heat storage.

Several experimental studies [15-18] have been performed on tailoring the thermal conductivity of paraffin wax using various nano-additives. CNT and ZnO are the nano-fillers high intrinsic thermal conductivity for enhancing thermal conductivity of paraffin wax. However, the effect of CNT and ZnO dispersion in paraffin remains unexplored in the literature. In this work, CNT and ZnO are used as nanofiller to enhance thermal conductivity of paraffin wax. In addition, an experimental setup is fabricated to measure thermal conductivity of altered paraffin wax. The thermal conductivity measurement of proposed device is compared with commercial thermal conductivity measuring device and data available in the literature. The prosed device results have 95% confidence level against the commercial device results and literature results. Post-calibration, insights of Spatio-temporal energy storing in form of latent heat of altered paraffin were explored. It is found that convection is main mode of heat transfer in melting zone of altered paraffin wax because large buoyancy force. This research is useful for design the thermal energy management for uneven availability of energy [19].

2. Materials and Experiment

Pure paraffin wax which has melting temperature of 62±1 °C was bought from Chandri Wax Specialities Private Limited India. Various weight percentage of CNT and ZnO are used to alter thermal conductivity of paraffin wax. CNT is multi-walled carbon nanotubes grown by chemical vapor deposition (CVD) method using camphor as the carbon source. It is clear hollow tubular structures of outer diameter 5–20 nm, maximum abundance of diameter ~10 nm, length ~ 1–10 µm and specific surface area ~ 100 m²/g. However, powder form ZnO are bought from local vendor (Shakti chemical Delhi, India). These nano-filler is added into Paraffin wax when its temperature of wax is10 °C more than the its melting temperature. It is stirred for 45 minutes at 1500 rpm after pouring. Finally, the liquid form altered wax is ultra-sonicated for 60 minutes. It is noted that the temperature from stirring to sonicating process remains constant (=70 °C). Eventually, the altered paraffin is placed at room temperature for cooling. After cooling, it is placed in the refrigerator at 20 °C for two days.

Figure 1 shows an experimental setup for measuring the thermal conductivity of altered wax. Figure 1 (a) shows the schematic diagram and the photograph of experimental setup is given in Figure 1(b). The setup has rectangular 10 mm thick acrylic material cavity (Dimension: 3 cm × 3 cm × 6 cm) in which paraffin wax is filled up. The four faces of the cavity are insulated Nitrile PVC tape. However, right side face of cavity has aluminum block (3 cm ×6 cm) to maintain constant wall temperature for charging and discharging the energy to wax. The left face of the cavity maintains room temperature using heat sink with fins and fan. Constant temperature bath is used to flow water in the block, as shown in Figure 1. Front side of cavity has glass window for visualizing the melting and solidification process wax. Double glass window is used to minimize the loss through the visualization window. At top face of cavity, a port is provided to fill up and drain out the paraffin wax from cavity. T-type thermocouples with a bead size of 0.1 mm and measurement accuracy of ±0.05 C are located at different positions in the chamber. The location of Thermocouples is given in table 1.

| Thermocouple | X (cm) | Y (cm) | Z (cm) |
|--------------|-------|-------|-------|
| T₁           | 0.00  | 1.5   | 4     |
| T₂           | 1.00  | 1.5   | 4     |
| T₃           | 2.00  | 1.5   | 4     |
| T₄           | 3.00  | 1.5   | 4     |
To minimize the convection effect of atmospheric air, the complete setup is placed in another acrylic chamber. Before carrying out experiment, probes and devices are calibrated, and water is heated in constant temperature bath. To ensure that there no temperature gradient inside the Al block, water flow rate is set up at 40 L/min. The Phantom camera and Nikon (D-3300) camera with macro-lenses are used to capture the melting and solidification process of altered paraffin wax. NI DAQ (9174) with a frequency of five second is used to collect temperature data of various location automatically in a computer. In this way, the temperature variation with respect to time at four locations and spatio-temporal images of melting paraffin wax are recorded.

**Procedure for measuring the thermal conductivity:** The thermal conductivity of wax is estimated by knowing spatio-temporal position melting front and temperature distribution in wax. Figure 2(a) shows the pictorial view melting at various time step. After image processing, a clear image of solid-liquid interface is extracted, Figure 2(b). The mathematical expression is derived by applying energy balance at the solid-liquid interface. Its expression is as:

\[
\frac{\alpha \rho H_s \delta L_2}{\Delta t [L_2(T_1-T_2)-L_1(T_3-T_4)]}
\]

(1)

Here, \(L_1\) and \(L_2\) are distances between the thermocouples \(T_1\), \(T_2\), and \(T_3\), \(T_4\) respectively. The temperatures were measured at two different points of liquid region \((T_1\) and \(T_2)\) and two different point of solid region \((T_3\) and \(T_4)\). The experimental results show that there is negligible convection after third by fourth depth from the top of the surface. For minimizing the convection effect, thermocouples were imbedded at \(\frac{3}{4}\) depth from the top surface. The \(\delta = (\delta_1 - \delta_2)\) is estimated by superimposed images captured at \(\Delta t = (t_1-t_2)\) time step, as shown in Figure 2. By knowing the measured values from experimental studies, the thermal conductivity was measured using Equation 1.

![Experimental setup](image1)

**Fig. 1:** Experimental setup (a) Schematic diagram and (b) photograph

![Photograph of paraffin wax at two-time step](image2)

**Fig. 2:** (a) Photograph of paraffin wax at two-time step (b) Photographs after images process. \(\delta_1\) an \(\delta_2\) are position of solid-liquid interface at time \(t_1\) and \(t_2\). However, \(L_1\) and \(L_2\) are distance between thermocouples in liquid phase and sold phase of melted wax.
3. Results and Discussion
The device is calibrated before measuring the thermal conductivity of altered paraffin wax. Figure 3 shows the comparison of present device measurement with value of $k$ given by manufacturer and value of $k$ measured by commercial device (KD2-PRO). The device measurement is very close to measurement by commercial device and value reported by the literature. Post-calibration, the thermal conductivity of altered paraffin is measurement. Table 2 shows the thermal conductivity of altered paraffin wax.

Table 2: Thermal conductivity (W/m-K) of altered PCM

| PCM+Nano-fillers | 0.15% | 0.5%  | 0.75% | 1%   |
|------------------|-------|-------|-------|------|
| Paraffin + ZnO   | 0.3659| 0.4971| 0.5685| 0.9362|
| Paraffin +CNT    | 0.38  | 0.50  | 0.51  | 0.52  |

Figure 5 shows that solid-liquid interface displacement during melting process is faster than the other. At same percentage weight mixing of ZnO has high thermal conductivity as compared to CNT based altered paraffin wax.

Fig. 4: Temperature variation at location $T_2$ with respect to time of melting process of wax.
Figure 5 shows displacement of liquid-solid interface captured during melting experiment. Initially, the dominant mode of heat transfer in solid paraffin is conduction but as the wax starts melting, a rapid increment in temperature of wax is observed at top because of convection. Experimental results show that the transient response of altered paraffin wax is faster as compared to pure wax as the thermal conductivity of altered paraffin wax increases with increasing the percentage of CNT and ZnO. 1% CNT in paraffin wax enhance 12% speed to heat diffusion in tailored paraffin wax. However, 1% ZnO in wax enhances 10% speed of heat diffusion. Hence, the ZNO is more effective than CNT mixed paraffin wax.

4. Summary and Conclusion
An experimental study was conducted to analyze the thermal performance of paraffin wax when it is altered by adding CNT and Zno fillers. The transient response of thermal properties of wax was recorded during the melting process. The comparison of results from both proposed device and commercial device exhibited good agreement. In order to make an effective heat storage device using paraffin wax, it is essential to tailor the thermal properties of material so that the potential of energy storage device is fully utilized. This study provides a framework for designing the effective heat exchanger storing the solar energy in form of latent heat of wax. This research also gives a method to calculate the thermal conductivity of PCM by simple and low-cost device. the ZNO is more effective nanofiller as compared to the CNT.

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