

Enhancement of heat transfer in phase change material using graphite-paraffin composites

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Abstract. Phase change materials (PCMs) are energy storage materials which can be used for maintaining a controlled thermal environment for various applications in earth and space. PCMs are used in advanced technologies in aerospace cooling applications like heat exchangers and heat pipes for re-entry vehicles and spacecraft. Paraffin is a phase change material (PCM) commonly used for energy storage-related applications. Paraffin wax exhibits slow thermal response due to low thermal conductivity value (~0.2 W/m K for most paraffin waxes). In the present work, an attempt is made to fabricate a composite PCM using graphite powder. Such a composite material has enhanced thermal conductivity along with reduced melting period which are desirable properties of a PCM during solid to liquid phase change process. The reduction in melting period is indicated by the difference in change in temperature measured by the thermocouples during a specified time. The temperature variation and solid-liquid interface formation during the melting process are experimentally studied. The results showed that composite graphite powder with paraffin can improve the total phase transition time.

1 Introduction

The key concern in today's world is reducing the disparity of supply and energy demand by storing it. To reduce the greenhouse emissions, there was a paradigm shift to utilize renewable sources of energy. One of the potential sources of renewable energy is the sun rays. Thermal Energy Storage (TES) is a technique used for releasing and storing of renewable energy in the form of sensible and latent heat.

Latent heat thermal energy storage is a better method as it provides a relatively high energy storage density as detailed by Agyenim et al. [1]. Latent heat storage can store the latent heat of fusion in an isothermal process which corresponds to phase transition temperature of the phase change material (PCM). A PCM initiating the melt and solidification process will release more heat during liquid to solid and absorb more heat during solid to liquid phase change because of lower thermal resistance.

The solid-liquid phase change involves relatively less volume change when compared to a solid-gas or liquid-gas phase process with less latent heat transfer. Sharma et al. [2] and Kenisarin and Mahkamov [3] detailed the desirable physical, thermal, kinetic and chemical properties of a PCM. An ideal PCM should have high specific heat and thermal conductivity in both solid and liquid state, low vapour pressure, less volume variation during solidification and should be chemically stable. The organic ones are normally preferred then inorganic type of PCMs used in Latent heat Energy Storage system.

This is because when compared to Inorganic PCMs like salt hydrates, organic PCMs have better chemical stability, biodegradability, non-toxic and are non-corrosive in nature. Thirugnanam and Marimuthu [4] detailed that Paraffin could be used in various applications as it had excellent thermal storage, high heat of fusion, inertness, compatibility with all metal containers and ability to be incorporated easily into thermal storage systems. Lin et al. [5], developed a heat exchanger based on PCM for NASA future space missions. The heat exchanger was used to store thermal energy in excess during high heat load periods by melting paraffin wax. The excess thermal energy was later rejected by the space craft's radiator, freezing the PCM which was utilized for next heating cycle. Moreover, experiments indicated that the paraffin would freeze without supercooling. Nihal and Emel [6] observed that lower thermal conductivity of paraffin reduced the heat transfer performance of charging and discharging cycle during the phase change. Many recent attempts have been made for thermal conductivity enhancement of PCM. This could be achieved by different metal foams addition resulting in increased heat discharging and charging rates in thermal energy storage as observed by [7-11]. Wang et al. [7] increased the thermal storage performance of paraffin by adding copper foam. Zhang et al. [8] investigated numerically the heat transfer characteristics during the melting process of a composite PCM. A copper foam was used to increase the thermal conductivity of the paraffin. Mills et al. [9] fabricated a composite PCM using expanded graphite (EG) and paraffin wax. The thermal

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conductivity value was found to be 20–130 times larger than that of pure paraffin because of addition. Mattawee and Assassa [10] observed that the adding dispersed aluminium powder inside paraffin wax increased thermal conductivity. The charging time was decreased by 60% and with enhanced heat transfer characteristics. Jackson and Fisher [11] in their study, compared paraffin heat transfer characteristics with different metal foams like copper, aluminium and graphite having different pore sizes. It was concluded that the graphite foam combination gave better result due to its higher thermal conductivity than other metal foams.

From the above-mentioned works, it can be understood that thermal conductivity and heat transfer rate can be enhanced by using different metal foams. The manufacturing of metal foams involves a complex process and the metal foams are expensive. In the present study, graphite powder is used with paraffin wax to improve the thermal performance and heat transfer rate. The total phase transition period from solid to liquid state is improved for a Graphite/paraffin composite when compared to pure paraffin wax. This is indicated by difference in thermocouple readings for a specific period of time

2 Experimental Setup

Fig.1 shows the experimental setup. The heat transfer characteristics of pure paraffin and paraffin/graphite composite PCM is studied using a cubical glass container, constant heat flux system (mica plate heater), AC power supply and a data acquisition system. The cubical glass container has a size of 5.6 cm x 5.6 cm x 6 cm with each side having a thickness of 4 mm. Paraffin wax is filled up to a height of 5.6 cm. The top portion of the container is open to the atmosphere so that the wax can contract and expand during the phase change process. The bottom side of the glass enclosure is attached to a mica plate heater which is used to melt the paraffin.

Four K-type thermocouples placed consecutively on a small wooden piece are kept inside the glass enclosure containing wax and is evenly spaced 1cm apart to each other. The temperature difference is measured at a gap of 1 cm by these thermocouples. The thermocouples are connected to a standard NI9213 module with NI cDAQ-9174 chassis. The thermocouple temperatures are stored in a computer for further processing. The typical constant heat flux is supplied for both the cases (Paraffin and Composite PCM).

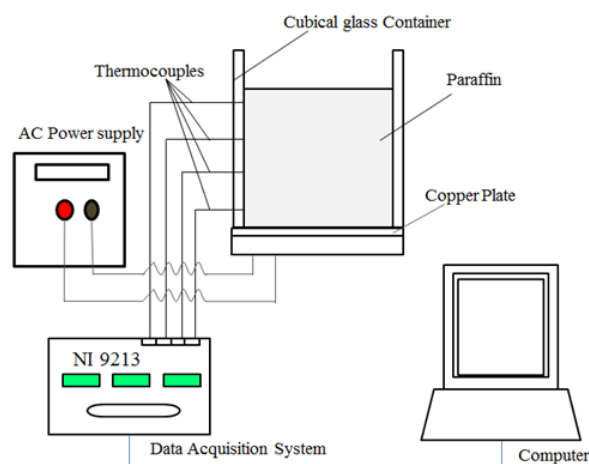


Fig. 1. Schematic illustration of the experimental setup

3 Results and discussions

The experimental data recorded by all the four thermocouples for plain wax without graphite are detailed in Fig. 2. Similarly, the temperature curve of pure paraffin with graphite powder during melting is shown in Fig. 3.

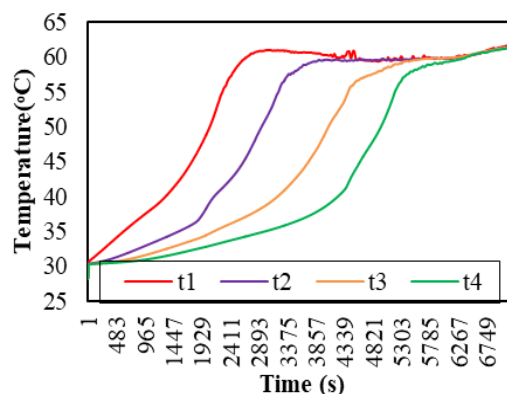


Fig. 2. Temperature curve for melting paraffin wax

During the initial study, the characterization of phase change from solid to liquid is observed for pure paraffin wax. In this case, 140g paraffin wax is filled up to a height of 5.6 cm in the glass enclosure. In the second study, the solid-liquid phase change behaviour is observed for paraffin wax with 10 % of graphite powder. In this second case of study, 14 g of graphite powder is mixed with 126 g of paraffin wax and the mixture is filled up to 5.6 cm in the glass enclosure. The phase change of solid to liquid at different stages and their characteristics are recognized from the temperature-time graph from four thermocouple temperature measurements. The temperature curve starts to rise from room temperature (28 °C) for both the cases. The melting point of paraffin wax is 58 °C.

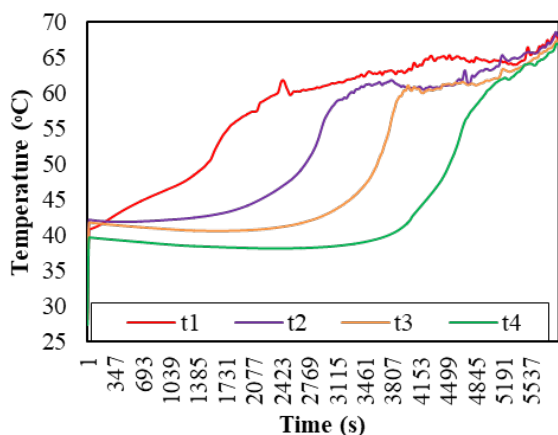


Fig. 3. Temperature curve for melting paraffin wax with graphite powder

A gradual increase in temperature is observed for all thermocouple locations but at different temperature range. Meanwhile, for the composite PCM, increase in temperature occurs at a rapid rate as the graphite powder has higher thermal conductivity (300 to 550 W/mK). For both the cases, the first thermocouple (t1) region is closer to the heating surface. Hence, the paraffin wax in both the cases at bottom side melts sooner than the top layers inside the glass container. It is observed visually that the melting process occurred layer by layer. While the melting happens at the lower layers and the paraffin at that region entirely transferred to the liquid phase, the unchanged paraffin remains solid at the top and appear to be floating over the liquid paraffin as shown in Fig. 4.

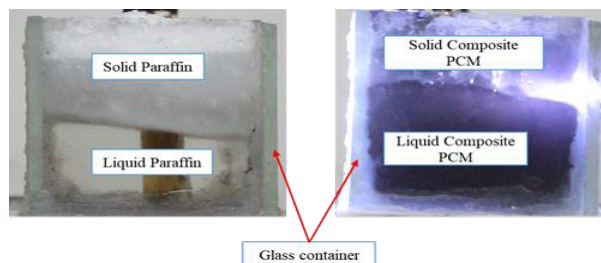


Fig. 4. Melting process of paraffin and composite paraffin

As the temperature rises above 58 °C (melting point), the paraffin wax is completely converted from solid to liquid which is observed in the recorded video. In the first case, the first thermocouple (t1) reached 58 °C at a period of 2468 s. In the second case (with graphite powder), the first thermocouple (t1) reached the melting point at 2132 s. For the other thermocouples, the melting point is reached faster in the second case when compared to the first case. From the Temperature-Time graphs, it is also observed all the thermocouples reached a common temperature of 62 °C in 7228 s, (pure paraffin) which indicates that the total volume of paraffin wax has melted completely to liquid. After this phase change process, the temperature indicated by all the thermocouples increased homogeneously. In the second case (paraffin/graphite composite), all the thermocouples reach 67 °C in 5879 s indicating that the composite PCM is in a liquid state. From the results above, it is understood that, by using graphite powder as a composite material for PCM, the heat transfer

characteristics of paraffin is enhanced. The melting process is rapid and is 500 s to 1000 s slower when compared to a pure paraffin wax under similar heat load conditions. Hence, the total phase transition time is improved in composite PCM case. The composite paraffin starts to melt at lower layers initially and the recirculation of graphite powder is observed within the liquid paraffin which in turn improved the heat transfer performance. This phenomenon proves that the heat transfer is dominated by heat diffusion.

4 Conclusion

In the present work, the solid-liquid phase change process of a paraffin wax and a composite paraffin wax (graphite powder) is studied experimentally. The composite material has enhanced heat transfer characteristics with desired thermal storage. The enhancement is measured as delay in time during phase change process indicated by the temperature change of the thermocouples. The limitation of higher thermal resistance of paraffin wax is overcome by adding graphite powder. Compared to the pure paraffin, paraffin/graphite powder composite showed a better heat transfer performance because of the high thermal conductivity of Graphite Powder.

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