



A direct comparison of three different material enhancement methods on the transient thermal response of paraffin phase change material exposed to high heat fluxes

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ABSTRACT

The thermal performance and energy storage capabilities of a 54 °C organic paraffin wax is tested and directly compared using three common different thermal conductivity enhancement methods (TCE). These include the use of graphite foam with infiltrated PCM, aluminum foam with infiltrated PCM, and PCM with 10 wt% graphite nanofibers. The applied heat flux varies from 1.93 W/cm² to 19.3 W/cm². This allows the study of higher heat flux conditions than any previously studied and the first direct comparison of the effectiveness of these three different methods on the control of the heated base temperature. The performance of the PCM in both the solid and liquid phase as well as the motion of the melt front between the two phases is examined for each TCE configuration.

It is found that the selection of enhancement method has a significant effect on the thermal response of the system. The base paraffin consistently shows the development of a superheated liquid layer at the base and Rayleigh-Benard convection currents in the melt region. With the addition of 11 wt% GNF the convection currents at the base are suppressed and the PCM is coupled more closely to the module. The GNF/PCM was more effective at controlling the base temperature than the base paraffin at low power loads, but this effect decreased with increased power loading. The GNF/PCM mixture was less effective at base temperature control when compared to the aluminum or graphite foams. However, the foams are found to improve the heat sink abilities of the system without exhibiting any significant delay to steady-state through effective use of the PCM mass. The results provide much needed valuable insight into the comparative effectiveness of different TCE designs for high power configurations.

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1. Introduction

As a material changes state from solid to liquid it absorbs energy while maintaining a constant temperature. The amount of energy absorbed during this transition is a function of the particular material and is quantified by the latent heat of fusion (energy absorbed per unit mass). Materials with high latent heat of fusion can be used to absorb large amounts of energy without an increase in temperature, which can be beneficial in many transient applications including solar energy systems and thermal management of portable electronics. Materials such as these are classified as Phase Change Materials (PCMs) and commonly include paraffin and hydrated salts.

While PCMs can be easily utilized in small mass systems, the low thermal conductivity of most high latent heat materials typically leads to isolation of the melt front at the heat source when used in large mass, high power systems [1]. This can lead to situations in melting where a liquid layer near the heat source overheats while the solid PCM layer farther away is isolated. The overheat of the liquid layer reduces the temperature difference at the heated surface, reducing the heat transfer further. Conversely in solidification, the heat to be shed must pass directly through the solid PCM layer to reach the heat sink. The resistance to heat flow then increases as the solidification front progresses away from the sink. This aspect of PCM behavior is referred to as self-insulating [2]. Thus, in both melting and solidification the low thermal conductivity of the PCM can lead to degradation in performance.

Various techniques have been used to increase the thermal response of PCMs. These have included the use of pin and plate fin heat sinks embedded in the PCM system [2–5]. Embedded heat

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