



Experimental and numerical studies on melting phase change heat transfer in open-cell metallic foams filled with paraffin

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ABSTRACT

In the current study, the melting phase change heat transfer in paraffin-saturated in open-celled metallic foams was experimentally and numerically studied. The experiments were conducted with seven high-porosity copper metal foam samples ($\epsilon \geq 90\%$), and paraffin was applied as the phase-change material (PCM). The wall and inner temperature distribution inside the foam were measured during the melting process. The effects of foam morphology parameters, including porosity and pore density, on the wall temperature and the temperature uniformity inside the foam were investigated. The melting heat transfer is enhanced by the high thermal conductivity foam matrix, although its existence suppresses the local natural convection. A numerical model considering the non-Darcy effect, local natural convection, and thermal non-equilibrium was proposed. The velocity, temperature field, and evolution of the solid–liquid interface location at various times were predicted. The numerically predicted results are in good agreement with the experimental findings. The model as well as the feasibility and necessity of the applied two-equation model were further validated.

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1. Introduction

Phase-change materials (PCMs) have been widely used in many applications, such as passive cooling for electronic devices, protection systems in aircrafts, food processing, and energy conservation in buildings, because of their high latent heat, chemical stability, suitable phase-change temperature, and reasonable price. Experimental and analytical/numerical studies in published literatures have focused on moving boundary problems [1–4]. Agyenim et al. [5] summarized the various applications of PCMs with different melting temperatures in suitable thermal energy storage systems. The size and the shape of the PCM container were also taken into consideration to ensure the long-term stable thermal performance of the system. Dutil et al. [6] presented main four types of numerical solutions dealing with the thermal behaviors of PCM in solid/liquid systems and showed the predicted results of different configurations.

Although some organic PCMs, such as paraffin, are very popular in energy storage applications and electronic cooling systems because of the aforementioned advantages and their low density compared with other kinds of heat storage materials (e.g., metal PCMs and hydrated salts). However, organic PCMs suffer from low conductivity ($\approx 0.1 \text{ W m}^{-1} \text{ K}^{-1}$), which is likely to cause failure in

electronic devices. For example, in some electronic cooling systems, the chip experiences a transient or periodic heat generation, which requires a highly efficient coolant system to dissipate the heat in case of chip exposure to extreme-temperature environments. However, the poor conductivity of organic PCMs reduces the rate of heat storage, thereby increasing the junction temperature of the devices beyond the allowable range.

In order to address this unacceptable problem, thermal conductivity enhancement techniques that increase heat transfer rates have been developed. These enhancement techniques are summarized in the following three methods: (1) Dispersing high-conductivity particles in PCMs; Wang et al. [7] experimentally proved that the thermal conductivity of composite PCMs is enhanced by incorporating a β -aluminum nitride additive. (2) Utilizing high-conductivity matrices, such as a metal or a graphite compound, as heat delivery promoters; Kim and Drazal [8] improved the effective thermal conductivity of paraffin by stirring exfoliated graphite nanoplatelets (xGnP) in liquid paraffin. The authors found that the thermal conductivity of paraffin/xGnP composite PCMs increases as the xGnP loading content increases without reducing the latent heat of the paraffin wax. (3) Filling extensive surfaces such as fins into the body of PCM; Shatikian et al. [9] numerically investigated the effect of internal fins on melting rate, melting front profiles, and heat transfer. (4) Varying the shape of the heat storage-heat transfer system; Banaszek et al. [10].

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