International Communications in Heat and Mass Transfer
Volume 161, February 2025, 108520

Numerical analysis of NE-phase change material and water mixture in a chamfered cavity with flexible fin

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https://doi.org/10.1016/j.icheatmasstransfer.2024.108520

Abstract

This study investigates the coupled effects of flexible fin dynamics and nano-encapsulated phase change material (NEPCM) behavior in a chamfered cavity, addressing critical challenges in compact thermal management systems. Our novel approach combines the mechanical response of an elastic fin with NEPCM-enhanced heat transfer, utilizing the Arbitrary Lagrangian-Eulerian (ALE) method to handle the complex fluid-structure interaction. The research examines the effects of various parameters on heat transfer performance, including Rayleigh number ($10^3 \leq Ra \leq 10^5$), Stefan number ($0.1 \leq Ste \leq 0.9$), fusion temperature ($0.1 \leq \theta_f \leq 0.9$), NEPCM concentration ($0.01 \leq \phi \leq 0.04$), oscillation amplitude ($0.05 \leq A \leq 0.15$), and Young's modulus ($10^9 \leq E \leq 10^{11}$). Our findings reveal that optimal heat transfer enhancement occurs through a specific combination of parameters: increasing Rayleigh number up to 10^5 doubles the heat transfer rate, while maintaining lower Stefan numbers and intermediate fusion temperatures maximizes thermal efficiency. A 25% improvement in heat transfer is achieved with increased NEPCM concentration, though benefits plateau at higher concentrations. Notably, smaller fin oscillation amplitudes prove more effective for heat transfer. These discoveries provide crucial design guidelines for developing more efficient cooling systems in electronic devices and compact heat exchangers where space optimization is critical.