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Active cooling of hot integrated circuits using a rotating cylinder and NEPCM-water mixture: Numerical analysis of the impact of phase change and Magnetohydrodynamics on double-diffusive mixed convection

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Abstract

Efficient cooling of integrated circuits is crucial for maintaining optimal performance and longevity of electronic devices. This study addresses this challenge by investigating the double-diffusive mixed convection around a hot integrated circuit (using) a nano-encapsulated phase change material-water mixture for enhanced heat absorption. The cooling process is carried out by a cylinder rotating at a constant speed inside a square cavity surrounded by the NEPCM-water mixture. Using the Galerkin finite element method, we numerically analyzed the influence of various parameters, including the Reynolds number ($10 \leq Re \leq 100$), Richardson number ($0.1 \leq Ri \leq 10$), Hartmann number ($0 \leq Ha \leq 80$), NEPCM volume fraction ($0.01 \leq \phi \leq 0.035$), Lewis number ($0.1 \leq Le \leq 10$), buoyancy ratio ($1 \leq Nz \leq 5$), fusion temperature ($0.1 \leq \theta_f \leq 0.9$), and Stefan number ($0.1 \leq Ste \leq 0.8$), on the average Nusselt number (Nu_{av}), average Sherwood number (Sh_{av}), total entropy generation (S_{total}), and Bejan number (Be). The results demonstrate that increasing Re and Ri enhances Nu_{av} and Sh_{av} by up to 175% and 162%, respectively, while applying a magnetic field (increasing Ha) suppresses heat and mass transfer rates by up to 58% and 50%, respectively. Increasing ϕ improves Nu_{av} by up to 34% with minimal impact on Sh_{av}. The Le and Nz govern the coupling between heat and mass transfer processes, with Le substantially influencing Sh_{av} and Nz affecting both Nu_{av} and Sh_{av}. The θ_f exhibits a non-monotonic effect on Nu_{av}, suggesting an optimal fusion temperature, while Ste shows an inverse relationship with Nu_{av}. The S_{total} is significantly influenced by Re, Ri, Ha, and ϕ, while Be is affected by Re, Ri, Ha, and ϕ to a lesser extent. These findings provide valuable insights into the complex interplay of forced and natural convection, magnetohydrodynamics, and NEPCMs in the active cooling of hot electrical elements. The results can be applied to optimize cooling system designs, potentially leading to more efficient and effective thermal management in electronic devices.

Graphical abstract