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A Particle-Resolved Computational Study for Thermal Performance of Nanofluids

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ABSTRACT

Nanofluids, the fluid suspensions of metal oxide nanoparticles, have gained increasing interest in the past decades for their potential to enhance the thermal performance in various heat transfer applications. Extensive analytical and experimental studies have been conducted to explore correlations between the effective thermophysical parameters of nanofluids and the nanoparticle and base fluid properties, and numerous models and formulas have been proposed for this purpose. However, controversial findings exist in the literature, and our knowledge and understanding of nanofluid thermal performances are still limited, considering the complicated microscopic mechanisms involved in nanofluids.

Generally, one-phase or two-phase methods are adopted for nanofluid simulations, and these simulations rely on empirical correlations of effective viscosity and thermal conductivity. In this work, we investigate the thermal performance of nanofluids using a particle-resolved numerical model where the nanofluid is considered explicitly as a suspension of spherical particles dispersed in a fluid. Governing equations for the fluid flow, heat transfer, flow-particle interaction, and particle dynamics are solved simultaneously by integrating the lattice Boltzmann method (LBM) and the smoothed profile method (SPM). Therefore, an exact representation of the three-dimensional (3D) geometry of the nanoparticle is considered and the fluid and particle thermophysical properties are applied directly with no empirical relations involved.

Simulations have been conducted for nanofluids of different particle volume fractions and under different thermal and flow conditions. The individual effects of the particle volume fraction and flow and thermal conditions on the conductive and convective heat transfer are carefully examined. Our results show that adding solid particles to the base fluid can improve the conductive heat transfer, benefiting from the high conductivity of the nanoparticle materials. However, the presence of nanoparticles increases the effective nanofluid viscosity, hence, the convection contribution on heat transfer is reduced; and the overall thermal performance could be negatively affected. This apparently counter-intuitive observation suggests that adding nanoparticles to a base fluid may not necessarily enhance the thermal performance of heat transfer systems, especially for those where the convection plays a dominant role. Our results and analysis imply that nanofluids might be more suitable for heat transfer enhancement in microchannels or porous materials where the flow velocity is small. The model used in this study can also be extended to include other factors for future nanofluid studies.

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