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Heat Transfer Enhancement of Magnetic Microparticle Dynamics inside Confined Microchannels under an External Magnetic Field

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Microchannel heat exchangers based on ferrofluid particulate suspensions work as an effective approach for high heat-flux thermal management of microelectronic devices, in which the dynamic response of microparticles subjected to a magnetic field is the key mechanism underlying heat transfer enhancement. The system of interest involves complex multiphysical-field coupling effects, two-way fluid–structure interaction, and microparticle self-assembly behaviors, making it challenging to identify the leading factor dominating the heat transfer performance.

This work develops a direct numerical simulation (DNS) model based on the lattice Boltzmann method (LBM) with double distribution functions to fully resolve the evolution of the flow and thermal fields in microchannels. Meanwhile, the discrete element method (DEM) is employed to track the motion of microparticles immersed in ferrofluid, and the fluid–structure interaction between the carrier flow and the solid objects is captured by the bounce-back schemes. Further, a series of numerical simulations with various Reynolds numbers (*Re*), Rayleigh numbers (*Ra*), and Mason numbers (*Ma*) are conducted to explore the effects of flow, thermal, and magnetic fields on the microparticle dynamics in microchannels.

Additionally, varying particle sizes and volume fractions are considered to investigate the influence of microparticle dynamic behavior on heat transfer performance. The findings provide an in-depth understanding of heat transfer enhancement mechanisms in confined spaces and support the optimization of microchannel heat exchanger technology.

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