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Heat Transfer Enhancement in Heated Microchannels: Role of Filament Characteristics and Flapping Dynamics

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ABSTRACT

This study investigates the physical characteristics of a single flow-induced filament on the fluid dynamics and heat transfer performance inside an unconfined heated microchannel through numerical simulations. The contributions of length (L_x), mass ratio (M) and reduced velocity (U_r), as controlling parameters for flexibility, heat transfer enhancement have been analyzed in a laminar flow regime. In this regard, the Lattice Boltzmann Model (LBM), a promising and computationally efficient method for micro-scale simulation, is used to solve the governing equations for fluid flow and thermal fields. The Lattice Spring Model (LSM) and Immersed Boundary Method (IBM) have engaged in tracking filament interaction with the fluid. Results indicate that filaments in the range of $3.5 < \frac{h}{L_x} < 6$ (h indicating channel width) revealed a higher heat transfer rate. This is due to its soaring flapping frequency and the vortex pattern shaped from their flapping modes. Compared with a bare channel, the maximum heat transfer enhancement of 67.62% is achieved for the shortest filament with M =1.5. It is found that higher flexibility caused a reduction in flapping frequency and heat transfer rate owing to a lessening in elasticity forces stored in the filament. Increasing L_x ($\frac{h}{L_x} < 3$) and decreasing M ($M < 1$) resulted in more stable and predictable performance due to comfortability in coupling with the flow frequency. As a result of increasing inertia forces with length, filaments resist the forces imposed by fluid, which restrains from sudden changes in the behavior.