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Numerical study of flow and heat transfer characteristics of alumina-water nanofluids in a microchannel using the lattice Boltzmann method ☆

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ABSTRACT

In the present study, mathematical modeling is performed to simulate force d convection flow of Al_2O_3/water nanofluids in a microchannel using the lattice Boltzmann method (LBM). Simulations are conducted at low Reynolds numbers ($Re \leqq 16$). Results indicate that the average Nusselt number increases with the increase of Reynolds number and particle volume concentration. The fluid temperature distribution is more uniform with the use of nanofluid than that of pure water. Furthermore, great deviations of computed Nusselt numbers using different models associated with the physical properties of a nanofluid are revealed. The results of LBM agree well with the classical CFD method for predictions of flow and heat transfer in a single channel and a microchannel heat sink concerning the conjugate heat transfer problem, and consequently LBM is robust and promising for practical applications.

1. Introduction

Nanofluids have a distinctive characteristic, which is quite different from those of traditional solid–liquid mixtures in which milli-meter or micro-meter sized particles are involved. Thus, nanofluids are best for applications in which fluid flows through small passages because nanoparticles are small enough to behave similarly to liquid molecules. Experimental works [1–3] reported that with low nanoparticles concentrations (1–5 vol.%), the effective thermal conductivity of the suspensions can increase by more than 20% for various mixtures. Experiments were conducted to investigate the cooling performance of a microchannel with Al_2O_3/water nanofluid [4], and the results showed the nanofluid-cooled heat sink outperformed the water-cooled one by examining the heat transfer rate and the pressure drop. The thermal performance of a microchannel cooled with Cu/water nanofluids was numerically studied [5] and it was indicated that the heat transfer rate is significantly affected by the solid volume fraction and slip velocity coefficient at high Reynolds numbers. A dispersion model was used to study laminar-flow convective heat transfer of nanofluid in a circular tube [6]. Results clearly showed that the addition of nanoparticles to the base liquid produces considerable enhancement of heat transfer. Ghasemi and Aminossadati [7] numerically studied the problem of natural convection heat transfer in an inclined enclosure filled with a CuO/water nanofluid. For high Rayleigh numbers, there is an optimum value for the solid volume fraction which maximizes the heat transfer enhancement. Turbulent convective heat transfer performance and pressure drop of very dilute (less than 0.24% volume) CuO/water nanofluid flowing through a circular tube were investigated experimentally [8]. Measurements showed that the addition of small amounts of CuO particles to the base fluid increased heat transfer coefficients considerably.

Laminar forced convection flow of nanofluids over a 2D horizontal backward facing step was numerically investigated using a finite volume method [9]. It was noted that the static pressure and wall shear stress increase with the Reynolds number and vice versa for skin friction coefficient. Lotfi et al. [10] involved single-phase, two-phase mixture and two-phase Eulerian models to study the forced convective flow in horizontal tubes and discussed the effect of particles concentration on the thermal parameters. In the studies [11,12], results showed that, under a fixed pumping power, the nanofluid exhibits no higher heat transfer rate than water at lower values of heat flux. In the work of Mohammed et al. [13], the presence of nanoparticles could enhance the cooling of MCHS under the extreme heat flux conditions with the optimum value of nanoparticles, and a slight increase in the pressure drop across the MCHS was found compared with the pure water-cooled MCHS.

The relative effects of nanoparticle motion mechanisms of dilute suspensions, i.e., Brownian motion, thermophoresis and osmophoresis, including size dependence, on the thermal conductivity were theoretically investigated [14]. The Brownian motion effect was found to be more significant. Nguyen et al. [15] investigated the viscosity of Al_2O_3/water nanofluid, and it revealed that for higher particle fractions, viscosities of 47 nm particle-size are clearly higher than those of 36 nm size. Besides, the finding showed that the application of Einstein's formula and those derived from the linear

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