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Numerical study of mixed convection in an inclined two sided lid driven cavity filled with nanofluid using two-phase mixture model ☆

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ABSTRACT

Mixed convection of a nanofluid consisting of water and SiO2 in an inclined enclosure cavity has been studied numerically. The left and right walls are maintained at different constant temperatures while upper and bottom insulated walls are moving lids. Two-phase mixture model has been used to investigate the thermal behaviors of the nanofluid for various inclination angles of enclosure ranging from $\theta = -60°$ to $\theta = 60°$, volume fraction from 0% to 8%, Richardson numbers varying from 0.01 to 100 and constant Grashof number 10^4. The governing equations are solved numerically using the finite-volume approach. Results are presented in the form of streamlines, isotherms, distribution of nanoparticles and average Nusselt number. In addition, effects of solid volume fraction of nanofluids on the hydrodynamic and thermal characteristics have been investigated. The results reveal that addition of nanoparticles enhances heat transfer in the cavity remarkably and causes significant changes in the flow pattern. Besides, effect of inclination angle is more pronounced at higher Richardson numbers.

1. Introduction

Convective heat transfer is very important for many industrial heating or cooling equipments. The heat convection can passively be enhanced by changing flow geometry, boundary conditions or by enhancing fluid thermophysical properties. One way is by adding small solid particles in the fluid. The main idea backs Maxwell's study [1]. He showed the possibility of increasing thermal conductivity of a fluid–solid mixture by more volume fraction of solid particles. The particles with micrometer or even millimeter dimensions were used. Those particles caused several problems such as abrasion, clogging and pressure dropping. By improving the technology to make particles in nanometer dimensions, a new generation of solid–liquid mixtures that is called nanofluid, was appeared. The nanofluids are a new kind of heat transfer fluid containing small quantity of nano-sized particles (usually less than 100 nm) that are uniformly and stably suspended in a liquid. The dispersion of a small amount of solid nanoparticles in conventional fluids changes their thermal conductivity remarkably. Choi [2] quantitatively analyzed some potential benefits of nanofluids for augmenting heat transfer and reducing size, weight and cost of thermal apparatuses, while incurring little or no penalty in the pressure drop. Xuan and Roetzel [3] have identified two causes of improved heat transfer by nanofluids: the increased thermal dispersion due to the chaotic movement of nanoparticles that accelerates energy exchanges in the fluid and the enhanced thermal conductivity of nanofluids. On the other hand Kelbinski et al. [4] have studied four possible mechanisms that contribute to the increase in nanofluid heat transfer: Brownian motion of the particles, molecular-level layering of the liquid/particle interface, heat transport in the nanoparticles and nanoparticles clustering. Wen and Ding [5] focused on the entry region under laminar flow condition using nanofluids containing γ-Al2O3 nanoparticles of various concentrations. It is shown that the enhancement increases with the Reynolds number as well as the volume concentration of nanoparticle. In a comparison between particle sizes it was observed that nanofluid with smaller particles shows higher heat transfer coefficient than that with larger particles [6]. Incorporating a dispersion model similar to that for the flow through porous media, Khanafer et al. [7] presented a two-dimensional numerical simulation of natural convection of nanofluids in a vertical rectangular enclosure. Ghasemi et al. [8] studied the natural convection heat transfer in an inclined enclosure filled with a water-cuo nanofluid. They indicated that the inclination angle has a significant impact on the flow and temperature fields and the heat transfer performance at high Rayleigh numbers. Ho et al. [9] studied natural convection of nanofluid in a square enclosure numerically to identify the effects due to uncertainties in effective dynamic viscosity and thermal conductivity. Zhang et al. [10] studied effects of Brownian and thermophoretic diffusions of nanoparticles on nonequilibrium heat conduction in a nanofluid layer with periodic heat flux. They showed that the Brownian and thermophoretic diffusions only affect the nanoparticle temperature, but their effect on the heat transfer enhancement is negligible. Talebi et al. [11] investigated the mixed convection flows in a square lid-driven cavity utilizing nanofluid which

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