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Numerical investigation of laminar nanofluid developing flow and heat transfer in a circular channel

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ABSTRACT

This study presents numerical investigations of developing laminar forced convection flow of alumina–water nanofluid in a circular tube subjected to a uniform wall heat flux. The effects of particle diameter, Reynolds number and volume fraction of the particles are investigated on the average heat transfer coefficient. The present study uses discrete phase modeling (DPM) that is a Euler–Lagrangian approach. The fluid is treated as a continuous media and the flow field is solved based on Navier–Stokes equations. The nanoparticles are individually tracked in a Lagrangian reference frame and their trajectories are determined using particle force balance. Using this approach, a good match was obtained between our numerical model and the experimental results reported in literature. The validated numerical model is used for formulating a three-factorial design matrix with each of the three independent variables considered at three different levels. The matrix considers the particles size (of 50 nm, 75 nm and 100 nm), the Reynolds number (250, 750 and 1250), and the particle volume fraction (1, 2.5 and 4 percent). The results from 27 simulation runs (for three-level three-factorial design) were then used in multiple regression analysis to develop a prediction equation that illustrates the effects of the independent variables on the average heat transfer coefficient. Based on statistical analysis, it was seen that almost all of the variation in the heat transfer coefficient can be explained due to changes in the three independent variables. The Reynolds number is the most significant variable impacting the heat transfer coefficient, while volume fraction is the least significant. The heat transfer coefficient linearly increases with both Reynolds number and volume fraction, but shows non-linear parabolic decrease with increase in particle size. Also, the three variables are only weakly interacting with each other in terms of their impact on the average heat transfer coefficient.

1. Background and introduction

Advances in micro-fabrication processes have enabled manufacturers to down-scale the size of microprocessors. As the amount of heat dissipated per unit area increases with this downsizing, the traditional cooling methods reach their limitations. Thermal management issues are limiting barriers to the future growth of the electronics industry. The removal of heat from the electronic components can be enhanced using nanofluids (liquid solutions with dispersed nanometer-sized particles) due to their enhanced convective heat transfer effects reported in literature. Due to their small size, nanoparticle suspensions are much more stable than millimeter and micrometer size colloids with respect to particle deposition. Several numerical and experimental studies on the heat transfer characteristics of nanofluids recently reported in literature are mentioned below.

Moraveji et al. [1] investigated convective heat transfer in developing laminar alumina-water nanofluid flow with constant heat flux by assuming nanoparticles and water behave as a single-phase with average properties. They proposed a correlation for Nusselt number that was in good agreement with other existing correlations in literature. Lofti et al. [2] numerically investigated laminar and turbulent forced convection of alumina–water nanofluid using both single–phase and two–phase models. They concluded that the mixture model is more precise based on comparisons with experimental data. Heris et al. [3] numerically investigated laminar flow-forced convective heat transfer of alumina-water nanofluid in a triangular duct under constant wall temperature condition. They found that the low heat transfer in triangular shaped ducts can be enhanced by using nanoparticles while still maintaining the advantage of low pressure drops in such ducts. Their results indicated that the

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