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Comparative analysis of single and two-phase models for CFD studies of nanofluid heat transfer

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ABSTRACT

CFD predictions of laminar mixed convection of Al_2O_3–water nanofluids by single-phase and three different two-phase models (volume of fluid, mixture, Eulerian) are compared. The elliptical, coupled, steady-state, three-dimensional governing partial differential equations for laminar mixed convection in a horizontal tube with uniform heat flux are solved numerically using the finite volume approach. It is found that single-phase and two-phase models predict almost identical hydrodynamic fields but very different thermal ones. The predictions by the three two-phase models are essentially the same. For the problem under consideration the two-phase models give closer predictions of the convective heat transfer coefficient to the experimental data than the single-phase model; nevertheless, the two-phase models over-predict the enhancement of the convective heat transfer coefficient resulting from the increase of the alumina volume fraction. The results are calculated for two Reynolds numbers (1050 and 1600) and three nanoparticle volume concentrations (<2%). Although single-phase and two-phase models have been used before to analyze mixed convection of nanofluids, this is the first systematic comparison of their predictions for a laminar mixed convection flow which includes the hydrodynamic characteristics and the effect of temperature dependent properties.

1. Introduction

The low conductivity of liquids such as water, ethylene glycol, and engine oil which are used as heat transfer fluids in many industrial and residential applications constitutes an important drawback which limits the performance of engineering equipments such as heat exchangers and electronic devices. There has been a serious effort to overcome this problem since Maxwell [1] investigated the possibility of increasing the thermal performance of ordinary fluids by adding solid particles. Maxwell's study showed that the conductivity of liquid–solid mixtures improves with increasing particle volume fraction. This was the first step of an innovative approach aiming to improve the conductivity of liquids by adding small particles into the fluids. At first, millimetre or micrometer size particles were used which have a high risk of sedimentation and can cause erosion as well as high pressure loss. Later, technological progress led to the fabrication of nanosized particles which mix homogeneously with the base fluid, remain in suspension for long periods, and have a high thermal conductivity even for very small particle volume fractions. Compared with other techniques for heat transfer enhancement, these nanofluids (a name first proposed by Choi [2]) show considerable potential as replacements of conventional heat transfer fluids.

For heat transfer in ducts, buoyancy forces have a significant effect on the hydrodynamic and thermal fields, particularly for laminar flow in horizontal ducts. They generate secondary flows which lead to Nusselt numbers and friction coefficients very different from those corresponding to forced convection. In the case of conventional heat transfer fluids, these phenomena have been studied extensively [3–8]. In the case of nanofluids, some numerical studies of laminar mixed convection inside horizontal and inclined tubes considered the nanofluids as single-phase homogeneous mixtures [9,10], while others have used the two-phase approach [11,12]. However, none of them includes a systematic comparison of two phase and single phase mixed convection predictions.

Lotfi et al. [13] have compared the single-phase with the Mixture and Eulerian two-phase models for the forced convection flow of Al_2O_3–Water nanofluid with temperature independent properties. Specifically, they have compared the Nusselt number predictions for a 1% value concentration of nanoparticles with several correlations and one set of experimental values. They have also considered the effect of volume concentration on the wall

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