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Experimental study of mixed convection with water–Al_2O_3 nanofluid in inclined tube with uniform wall heat flux

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A B S T R A C T

An experimental investigation was carried out to study mixed convection of Al_2O_3–water nanofluid inside an inclined copper tube submitted to a uniform wall heat flux at its outer surface. The effects of nanoparticles concentration and power supply on the development of the thermal field are studied and discussed under laminar flow condition. Results show that the experimental heat transfer coefficient decreases slightly with an increase of particle volume concentration from 0 to 4%. Two new correlations are proposed to calculate the Nusselt number in the fully developed region for horizontal and vertical tubes, for Rayleigh number from 5×10^5 to 9.6×10^5, Reynolds number from 350 to 900 and particle volume concentrations up to 4%.

1. Introduction

Modern nanotechnology has permitted the fabrication of materials with average size below 50 nm. Fluids formed of saturated liquid and suspended nanoparticles are called nanofluids, a term first used by Choi [1]. Relevant experimental data [1–3] has shown that nanofluids possess superior heat transfer properties compared to those of ordinary fluids. Such studies also indicate that these suspensions are relatively stable because of the very small particle size. Thus, nanofluids can constitute a promising alternative for advanced thermal applications, in particular for micro/nano-heat transfer applications where the current tendency towards smaller and lighter heat exchanger systems is considerable [3–5].

In order to explain the enhancement of nanofluid thermal conductivity, researchers have proposed different mechanisms. Keblinski et al. [6] and Eastman et al. [7] have attributed it to several factors such as the Brownian motion of nanoparticles, the molecular level layering of the liquid at the liquid/particle interface, the phonon heat transport inside nanoparticles and the effects due to particle clustering. On the other hand, Xuan & Li [8] and Xuan & Roetzel [9] stipulated that the improvement of the effective thermal conductivity of nanofluids is due to the increase of the contact surface between the particles and the fluid as well as to the interaction and collision between particles. These authors have also introduced the concept of thermal dispersion due to nanoparticles. It is worth mentioning that Khaled & Vafai [10] have studied the effect due to thermal dispersion on the heat transfer characteristics of nanofluids. Their numerical results have shown that the presence of dispersive elements resulted in a 21% augmentation of the Nusselt number for a uniform heated tube.

However, there are no general models which may satisfactorily explain the strong heat transfer enhancement due to nanofluids as well as to accurately determine their properties. Most of the first experimental and theoretical studies were conducted to determine the nanofluid effective thermal conductivity [1–3,7,8,11–13]. Some studies also provide data for the nanofluid effective viscosity [2,11,12,14]. Wang & Mujumdar [15] presented a review of recent research works on the heat transfer characteristics of nanofluids.

Several numerical and experimental works have been carried out to study the hydrodynamic and thermal behaviour of nanofluids in confined flows. For forced convective heat transfer, Pak & Cho [11] studied the heat transfer behaviour in heated tubes and observed that, for a given Reynolds number, the convective heat transfer

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