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Free convection heat transfer of non Newtonian nanofluids under constant heat flux condition ☆

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ABSTRACT

Two different kinds of non-Newtonian nanofluids were prepared by dispersion of Al_2O_3 and TiO_2 nanoparticles in a 0.5 wt.% aqueous solution of carboxymethyl cellulose (CMC). Natural convection heat transfer of non-Newtonian nanofluids in a vertical cylinder uniformly heated from below and cooled from top was investigated experimentally. Results show that the heat transfer performance of nanofluids is significantly enhanced at low particle concentrations. Increasing nanoparticle concentration has a contrary effect on the heat transfer of nanofluids, so at concentrations greater than 1 vol.% of nanoparticles the heat transfer coefficient of nanofluids is less than that of the base fluid. Indeed it seems that for both nanofluids there exists an optimum nanoparticle concentration that heat transfer coefficient passes through a maximum. The optimum concentrations of Al_2O_3 and TiO_2 nanofluids are about 0.2 and 0.1 vol.%, respectively. It is also observed that the heat transfer enhancement of TiO_2 nanofluids is higher than that of the Al_2O_3 nanofluids. The effect of enclosure aspect ratio was also investigated. As expected, the heat transfer coefficient of nanofluids as well as the base fluid increases by increasing the aspect ratio.

1. Introduction

The word nanofluid, first used by a research group in Argonne National Laboratory in the USA [1], describes suspensions of nanoparticles (<100 nm) in a base fluid. Since thermal conductivity of solid particles is much higher than that of the conventional heat transfer fluids, it is expected that dispersion of nanoparticles in fluids improves their thermal behavior. Nanofluids have novel properties that make them potentially useful in many applications. They exhibit higher thermal conductivity and the convective heat transfer coefficient compared to those of their base fluids. This enhanced thermal conductivity of nanofluids has been widely confirmed [1–10]. For instance, Eastman et al. [11] reported an increase in thermal conductivity of about 40% for a nanofluid with a 0.3% (by volume) dispersion of 10-nm in diameter metallic nanoparticles in water. Based on the available literature data, using nanofluids under forced convection [12–15] as well as mixed convection [16–21], could produce a significant enhancement of the heat transfer coefficient.

A few investigations have been experimentally studied on natural convection heat transfer of nanofluids. Putra et al. [22] have studied free convection heat transfer of Al_2O_3–water and Cu–water nanofluids inside a horizontal cylinder heated from one end and cooled from the other. Their results show that unlike forced convection a definite deterioration in natural convective heat transfer occurs. The deterioration is function of particle density, concentration, and the aspect ratio of the cylinder. Natural convection of a layer of TiO_2–water nanofluids between two disks which was heated from bottom and cooled from top was experimentally investigated by Wen and Ding [23]. Their results also confirm that the Nusselt number of nanofluids decrease by increase in nanoparticle concentration. They have discussed about the possible mechanisms of the observed behavior.

Numerical simulations related to natural convection heat transfer were conducted by different investigators [24,25]. Khanafer et al. [26] have studied heat transfer enhancement of Cu–water nanofluids in a two dimensional enclosure numerically. They developed a model to analyze heat transfer performance of nanofluids and compared their results with previous published investigations. They have shown that the nanofluid heat transfer rate increases with increase in the nanoparticles volume fraction. Kim et al. [27] have investigated the convective instability and the heat transfer characteristics of nanofluids. They introduced a new parameter which measures the ratio of the Rayleigh number of a nanofluid to that of a base fluid. Their result indicated that heat transfer coefficient increased by increasing the nanoparticle concentration. They have also pointed that rod-like particles are more effective than a spherical one. Heat transfer enhancement utilizing nanofluids in a two-dimensional enclosure was investigated for various parameters by Jou et al. [28]. They used the Khanafer's model to analyze the heat transfer performance of nanofluids and numerically solved transport equations by finite difference approach. Their results show that increase in the buoyancy parameter and volume fraction of nanofluids causes an increase in the average

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