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Natural convection flow of a nanofluid over a vertical plate with uniform surface heat flux

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ABSTRACT

Natural convective flow of a nanofluid over a vertical plate with a constant surface heat flux is investigated numerically, following a similarity analysis of the transport equations. The transport model employed includes the effect of Brownian motion and thermophoresis. The analysis shows that velocity, temperature and concentration profiles in the respective boundary layers depend, besides the Prandtl and Lewis numbers, on three additional dimensionless parameters, namely a Brownian motion parameter *Nb*, a thermophoresis parameter *Nt*, a buoyancy ratio parameter *Nr*. In addition to the study of these parameters on the boundary layer flow characteristics (velocity, temperature, nanoparticle concentration, skin friction, and heat transfer), correlations for the Nusselt and Sherwood numbers have been developed based on a regression analysis of the data. These correlations predict the numerical results with a maximum error of 5.5% for the reduced Nusselt number and 3.2% for the reduced Sherwood number.

1. Introduction

Convective heat transfer in nanofluids is a topic of major contemporary interest both in sciences and engineering. The word “nanofluid” coined by Choi [1] describes a liquid suspension containing ultra-fine particles (diameter less than 50 nm). The ultra-fine particles are usually made by a high-energy-pulsed process from a conductive material. With the rapid advances in nano manufacturing, many inexpensive combinations of liquid/particle are now available. These include particles of metals such aluminum, copper, gold, iron and titanium or their oxides. The base fluids used are usually water, ethylene glycol, toluene and oil. The choice of base fluid-particle combination depends on the application for which the nanofluid is intended. Experimental studies [e.g. 2–7] show that even with small volumetric fraction of nanoparticles (usually less than 5%), the thermal conductivity of the base liquid can be enhanced by 10–50%. The enhanced thermal conductivity of a nanofluid together with the thermal dispersion of particles and turbulence induced by their motion contributes to a remarkable improvement in the convective heat transfer coefficient which in turn makes the nanofluid a superior heat transfer medium for cooling applications such as in advanced nuclear systems [8] and cylindrical heat pipes [9]. The literature on the thermal conductivity and viscosity of nanofluids has been reviewed by Trisaksri and Wongwises [10],Wang and Mujumdar [11], Eastman et al. [12], and Kakac and Pramuanjaroenkij [13], among several others. These reviews discuss in detail the preparation of nanofluids, theoretical and experimental investigations of thermal conductivity and viscosity of nanofluids, and the work done on convective transport in nanofluids. A benchmark study of thermal conductivity of nanofluids has been published by Boungirno et al. [14]. This study analyzed the experimental thermalconductivity data gathered by 30 organizations worldwide and found most of them to be consistent within 10%. The study concludes that the thermal conductivity of a nanofluid increases with the particle concentration and aspect ratio in conformity with the classical Maxwell theory which predicts that the effective thermal ratio k/k_f is a function of particle volume fraction C and the thermal conductivity ratio k_p/k_f. This functional dependence is valid for $C << 1$ and $k_p/k_f < 10$.

The other base fluid property which is affected by the presence of nanoparticles is its viscosity. Earlier studies on nanofluids indicated that the benefit of enhanced thermal conductivity (increase in heat transfer) may be offset or even overshadowed by the accompanying increase in the viscosity of the fluid (increase in

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