International Journal of Thermal Sciences 50 (2011) 1326–1332

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition

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ARTICLE INFO

Article history:
Received 14 October 2010
Received in revised form
17 February 2011
Accepted 20 February 2011
Available online 26 March 2011

Keywords:
Nanofluid
Boundary layer flow
Stretching sheet
Convective boundary condition

ABSTRACT

The boundary layer flow induced in a nanofluid due to a linearly stretching sheet is studied numerically. The transport equations include the effects of Brownian motion and thermophoresis. Unlike the commonly employed thermal conditions of constant temperature or constant heat flux, the present study uses a convective heating boundary condition. The solutions for the temperature and nanoparticle concentration distributions depend on five parameters, Prandtl number *Pr*, Lewis number *Le*, the Brownian motion parameter *Nb*, the thermophoresis parameter *Nt*, and convection Biot number *Bi*. Numerical results are presented both in tabular and graphical forms illustrating the effects of these parameters on thermal and concentration boundary layers. The thermal boundary layer thickens with a rise in the local temperature as the Brownian motion, thermophoresis, and convective heating each intensify. The effect of Lewis number on the temperature distribution is minimal. With the other parameters fixed, the local concentration of nanoparticles increases as the convection Biot number increases but decreases as the Lewis number increases. For fixed *Pr*, *Le*, and *Bi*, the reduced Nusselt number decreases but the reduced Sherwood number increases as the Brownian motion and thermophoresis effects become stronger.

1. Introduction

The fluid flow over a stretching surface is important in applications such as extrusion, wire drawing, metal spinning, hot rolling, etc [1–3]. It is crucial to understand the heat and flow characteristics of the process so that the finished product meets the desired quality specifications. A wide variety of problems dealing with heat and fluid flow over a stretching sheet have been studied with both Newtonian and non-Newtonian fluids and with the inclusion of imposed electric and magnetic fields, different thermal boundary conditions, and power law variation of the stretching velocity. Both similarity as well as direct numerical solutions of the convective transport equations have been reported. A representative sample of the recent literature on the topic is provided by references [4–12].

In the past few years, convective heat transfer in nanofluids has become a topic of major contemporary interest. The word “nanofluid” coined by Choi [13] describes a liquid suspension containing ultra-fine particles (diameter less than 50 nm). Experimental studies (e.g. [14–19]) show that even with small volumetric fraction of nanoparticles (usually less than 5%), the thermal conductivity of the base liquid is enhanced by 10–50% with a remarkable improvement in the convective heat transfer coefficient. The literature on nanofluids has been reviewed by Trisaksri and Wongwises [20], Wang and Mujumdar [21], Eastman et al. [22], and Kakac and Pramuanjaroenkij [23], among several others. These reviews discuss in detail the work done on convective transport in nanofluids. In a recent paper, Boungiorno [24] evaluated the different theories explaining the enhanced heat transfer characteristics of nanofluids. He showed that the high heat transfer coefficients in nanofluids cannot be explained satisfactorily by thermal dispersion phenomenon or increase in turbulence intensity promoted by the presence of nanoparticles or nanoparticle rotation as suggested in the literature. He developed an analytical model for convective transport in nanofluids which takes into account the Brownian diffusion and thermophoresis. The Boungiorno [24] model has recently been used by Kuznetsov and Nield [25] to study the natural convective flow of a nanofluid over a vertical plate. Their similarity analysis identified four parameters governing the transport process, namely a Lewis number *Le*, a buoyancy-ratio number *Nr*, a Brownian motion number *Nb*, and a thermophoresis number *Nt*. The same authors later extended the work to a nanofluid saturated porous medium [26]. In a recent paper Khan and Pop [27] used the model of

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1290-0729/$ – see front matter
doi:10.1016/j.ijthermalsci.2011.02.019