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Hydromagnetic slip flow of water based nanofluids past a wedge with convective surface in the presence of heat generation (or) absorption

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ABSTRACT

Heat transfer characteristics of a two-dimensional steady hydromagnetic slip flow of water based nanofluids (TiO_2–water, Al_2O_3–water, and Cu–water) over a wedge with convective surface taking into account the effects of heat generation (or absorption) has been investigated numerically. The local similarity solutions are obtained by using very robust computer algebra software MATLAB and presented graphically as well as in a tabular form. The results show that nanofluid velocity is lower than the velocity of the base fluid and the existence of the nanofluid leads to the thinning of the hydrodynamic boundary layer. The rate of shear stress is significantly influenced by the surface convection parameter and the slip parameter. It is higher for nanofluids than the base fluid. The results also show that within the boundary layer the temperature of the nanofluid is higher than the temperature of the base fluid. The rate of heat transfer is found to increase with the increase of the surface convection and the slip parameters. Addition of nanoparticles to the base fluid induces the rate of heat transfer. The rate of heat transfer in the Cu–water nanofluid is found to be higher than the rate of heat transfer in the TiO_2–water and Al_2O_3–water nanofluids.

1. Introduction

A base fluid (water, engine oil, ethylene glycol etc) containing suspension of ultra fine metallic (for example Cu, Al, Fe, Hg, Ti etc) or a non-metallic (for example Al_2O_3, CuO, SiO_2, TiO_2) nanometer-sized (usually less than 100 nm) solid particles or fibers is termed nanofluid (Choi [1]). The main characteristics of this fluid are the significant enhancement of the thermal properties of the base fluid; minimal clogging in flow passage; long term stability and homogeneity compared to those fluids containing micro- or milli-sized particles (see Masuda et al. [2], Lee et al. [3], Xuan and Li [4], and Xuan and Roetzel [5]). Thus, nanofluids appear to be a very interesting alternative for advanced thermal applications, in particular micro-scale and nano-scale heat transfer. Due to the better performance of heat exchange, great potentials and features; nanofluids can be utilized in several industrial applications as in transportation, chemical production, production of microelectronics, automotives, power generation in a power plant, advanced nuclear systems (Buongiorno [6]), and nano-drug delivery (Kleinstreuer et al. [7]). Because of the wide range of applications of nanofluids in macro/micro devices significant research has been carried out in recent years to study heat transfer characteristics of these fluids. A recent review on this subject by Kakac and Pramuanjaroenkij [8] provide excellent information on convective heat transfer enhancement with nanofluids.

Recent advances in nanotechnology have allowed researchers to study the next-generation heat transfer nanofluids. The past decade has seen increasing research activities in heat intensification using nanofluids. Eastman et al. [9] noticed 40% increase in thermal conductivity using 0.3% of pure Cu nanoparticles of sized less than 10 nm dispersed in ethylene glycol. Murshed et al. [10] noticed 33% enhancement of thermal conductivity for 5% volume fraction of TiO_2 dispersed in pure water. Many researchers have studied and reported results on convective heat transfer in nanofluids considering various flow conditions in different geometries. See, e.g., Khanafer et al. [11], Maiga et al. [12], Jou and Tzeng [13], Hwang et al. [14], Tiwari and Das [15], Oztop and Abu-Nada [16], Abu-Nada and Oztop [17], Muthtamilselvan et al. [18]. Excellent reviews on nanofluids have been done by Das et al. [19], and Wang and Mujumdar [20–22]. Kuznetsov and Nield [23] studied the natural convection boundary layer flow of a nanofluid past a vertical plate while Nield and Kuznetsov [24] studied a double-diffusive natural convection boundary layer flow along a vertical plate embedded in a porous medium saturated by a nanofluid. In both studies they applied Buongiorno [6] nanofluid model which includes Brownian diffusion and thermophoresis and investigated

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Nomenclature

Greek symbols

a	constant appears in Eq. (1)
B_0	magnetic induction
Bi	Biot number
C_f	skin-friction coefficient
C_p	specific heat due to constant pressure
f	dimensionless stream function
Gr_{bf}	local thermal Grashof number
g	acceleration due to gravity
h	convective heat transfer coefficient
K	slip parameter
Kn_x	Knudsen number
$Kn_{x,L}$	Knudsen number based on mean free path
L	slip length
M	square of the Hartmann number
m	constant
Nu_x	local Nusselt number
P	pressure
Pr	Prandtl number
Q	nondimensional heat generation or absorption parameter
Q_0	dimensional heat generation or absorption coefficient
q_w	wall heat flux
Re_{bf}	local Reynolds number
T_∞	temperature of the nanofluid within the boundary layer
T_0	temperature of the fluid below the surface
T_w	temperature at the surface of the wedge
T_∞	temperature of the ambient nanofluid
U	free stream velocity of the nanofluid
u	velocity along the surface of the wedge
v	velocity normal to the surface of the wedge
(x,y)	Cartesian coordinates
α_{nf}	effective thermal diffusivity of the nanofluid
α_{bf}	effective thermal diffusivity of the base fluid
β	wedge angle parameter
β^*_{nf}	volumetric coefficient of thermal expansion of nanofluid
β^*_{bf}	volumetric coefficient of thermal expansion of base fluid
γ	thermal buoyancy parameter
ρ_{nf}	effective density of the nanofluid
ρ_{bf}	effective density of the base fluid
$(\rho c)_{nf}$	effective heat capacity of the nanofluid
$(\rho c)_{bf}$	effective heat capacity of the base fluid
μ_{nf}	effective dynamic viscosity of the nanofluid
μ_{bf}	effective dynamic viscosity of the base fluid
υ_{nf}	kinematic coefficient of viscosity of nanofluid
υ_{bf}	kinematic coefficient of viscosity of base fluid
κ_{nf}	thermal conductivity of the nanofluid
κ_{bf}	thermal conductivity of the base fluid
θ	dimensionless temperature
ϕ	solid volume fraction of the nanofluid
ψ	stream function
η	similarity variable
σ	magnetic permeability
σ^*	tangential momentum accommodation coefficient

Subscripts

w	surface conditions
nf	nanofluid
bf	base fluid
sp	solid particle
∞	conditions far away from the surface

Superscripts

’	differentiation with respect to η

the dependencies of solutions on the nanofluid parameters entered into the analysis. Bachok et al. [25] studied boundary layer flow of nanofluids over a moving surface in a flowing fluid. They noticed that dual solutions may exist when the plate and free stream flow move in opposite directions. Khan and Pop [26] studied forced convective boundary layer flow of a nanofluid past a stretching surface considering Buongiorno's [6] model. On the other hand Hamad and Pop [27] studied the boundary layer flow near a stagnation-point on a heated permeable stretching surface in a porous medium saturated with a nanofluid in the presence of heat generation and absorption considering the model of Tiwari and Das [15]. They have considered a single-phase model where both the base fluid and the solid particles are in thermal equilibrium state and flow with same local velocity. The effects of Brownian diffusion and thermophoresis were neglected and the fluid was treated as Newtonian. Ahmad and Pop [28] continued with the same model and investigated mixed convection boundary layer flow from a vertical flat plate embedded in a porous medium filled with nanofluids.

Heat transfer due to surface convection over various geometries has received considerable attention (see Aziz [29], Bataller [30], Makinde and Aziz [31], Ishak [32], Rahman [33], Yao et al. [34], Rahman [35]) because of its potential applications in several engineering and industrial processes like transpiration cooling process, material drying, etc. All of the afore-mentioned papers [29–35] considered convective heat transfer boundary condition for a Newtonian fluid model. The general conclusion of these studies is that temperature at the surface of the plate increases with the increase of the surface convection parameter. Inspired from this finding very recently Rahman and Ibrahim [36] studied radiative heat transfer in a hydromagnetic nanofluid past a nonlinear stretching surface with convective surface condition. They have noticed that the local rate of heat transfer for a nanofluid is strongly influenced by the surface convection parameter.

The principal aim of this paper is to investigate the dynamics of the natural convection boundary layer flow of water based nanofluids (TiO_2–water, Al_2O_3–water, and Cu–water) over a wedge in the presence of a transverse magnetic field with internal heat generation or absorption. The model of Tiwari and Das [15] is used due to the availability of most of the data relating to the thermal properties of the nanofluid. Instead of the commonly used conditions of constant surface temperature or constant heat flux, a convective surface condition is employed which makes this study unique and the results are more realistic and practically useful. The conventional ‘no-slip’ velocity boundary condition is also replaced by the ‘partial slip condition’ (see Yazdi et al. [37]). Thus, the main focus of the analysis is to investigate how the flow and temperature fields of a nanofluid within the boundary layer are influenced by the amount of slip, applied magnetic field, heat generation or absorption and convective surface condition. To the best of the authors' knowledge no research has been carried out considering the above-stated flow model for a nanofluid. The local similarity equations are derived and solved numerically with the widely used and robust computer algebra software MATLAB. Graphs and tables