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Research Paper

Effect of magnetic field on slip flow of nanofluid induced by a non-linear permeable stretching surface

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HIGHLIGHTS

- Nanofluid flow over a non-linear permeable stretching sheet is study.
- Thermophoresis effect and Brownian motion with slip effects are considered.
- Lewis number decreases the nanoparticle concentration across the boundary layer region.
- Thermophoresis in the flow field raises both the temperature and nanoparticle concentration.

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ABSTRACT

In this effort the influence of magnetic field on boundary layer nanofluid flow induced by a non-linear permeable stretching sheet has been explored. The flow is happening due to stretching surface along with slip conditions in boundary layer. The governing equations are solved numerically by means of a robust programming MAPLE-17 which includes RK-4 method accompanied by shooting criteria. The impact of appropriate factors on flow are deliberated and physical characteristics of the flow are exhibited through graphs and tables and discussed from the reasonable judgment. Our analysis conveys that the reduced Nusselt number amplifies as the thermophoresis parameter and Brownian motion parameter enhances. On the other hand, it is perceived that thermal boundary layer thickness moderates with the growth of thermal slip parameter. Moreover, it is thought-provoking to find that the concentration distribution declines as the Lewis number escalates. To sum up, the verdict of the current study is that the proficiency of a thermal system can be enriched by scheming the strength of applied magnetic field as well as by electing the applicable values of the physical parameters.

1. Introduction

The study of MHD flow for an electrically conducting fluid passing through transverse applied magnetic field has quite a lot of practical applications in many engineering problems such as plasma studies, in the field of petroleum industries, MHD power generators, emergency cooling of nuclear reactors, the boundary layer control in aerospace engineering and crystal growth. The influence of magnetic field in electrically conducting nanofluid flow is reasonably significant due to the presence of nanoparticle in the base fluid and is useful to many applications in medical science, engineering, applied physics, etc. Also the theory of applied magnetic field plays an important role in heat transfer in boundary layer flow of different kind of conducting fluids induced by stretching surface. That's why many researchers inspected the boundary layer flow in existence of magnetic field under various flow patterns [1,2]. The question of natural convection in a triangular enclosure filled with MHD nanofluid was considered by Mahmoudi et al. [3]. Malvandi and Ganji [4] scrutinized the nanoparticles movement and heat transfer of water based nanofluid in a channel in presence of magnetic field. Using KKL model Sheikholeslami et al. [5] studied heat transfer characteristics of nanofluid flow. Sheikholeslami et al. [6] discussed the effect of Lorentz forces on CuO–water nanofluid flow and convective heat transfer. Using the concept of Lie symmetry group analysis, the effect of magnetic field on nanofluid flow over a stretching sheet

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Nomenclature

u, v	velocities of the flow along x and y axis	κ	thermal conductivity
X_w	property of the flow at the wall where $X = u, T, C$	P_r	Prandtl number
v_w	suction/injection velocity	R	radiation parameter
B_o	initial magnetic flux applied to the flow	ξ	temperature slip parameter
T_r	relative temperature ratio parameter	C_f	skin friction coefficient
q_r	radiative heat flux of the surface	C_fr	reduced skin friction coefficient
$(\rho C_p)_f$	effective heat capacity fluid	T	is the temperature of the flow
$(\rho C_p)_p$	effective heat capacity of nanoparticle	X_∞	property of the flow far away from the sheet where $X = u, T, C$
α	thermal diffusivity	n	velocity power index
M	magnetic parameter	ν	kinematic viscosity of the nanofluid
N_t	thermophoresis parameter	D_T	thermophoresis diffusion parameter
ς	velocity slip parameter	B	flux of transverse magnetic field
Re_x	local Reynold's Number	τ	ratio of effective heat capacities of nanoparticle and base fluid
Nur	reduced Nusselt number	f	stream function
C	nanoparticle concentration in the base fluid	θ	dimensionless temperature
X_s	flow property due to slip effect in the flow where $X = u, T$	ϕ	dimensionless nanoparticle volume fraction
f_w	suction/injection parameter	N_b	Brownian motion parameter
r	prescribed surface temperature parameter	Le	Lewis number
$D_\mathbf{B}$	Brownian diffusion parameter	Nu	local Nusselt number
σ	electrical conductivity of the fluid	η	similarity variable
ρ	density of the fluid and		
C_p	specific heat at constant pressure		

is presented numerically by Vishnu Ganesh et al. [7]. Malvandi [8] inspected anisotropic characteristic of magnetic nanofluids in a vertical plate in presence of multi directional magnetic field. Dhanai et al. [9] studied MHD boundary layer flow over a stretching/shrinking permeable sheet. Govindaraju et al. [10] discussed the entropy generation of MHD nanofluid flow analytically. Heat and mass transfer of MHD nanofluid flow inside a porous microchannel was investigated by Moshizi [11]. Mabood et al. [12] showed MHD flow characteristics of nanofluid over a nonlinear stretching sheet. Malvandi et al. [13] deliberated a study related to film boiling of magnetic nanofluids over a vertical plate in presence of a uniform variable-directional magnetic field. Recently, Ziaei-Rad et al. [14] investigated MHD dissipative nanofluid flow on a permeable stretching surface using artificial neural network.

Due to enormous industrial, transportation, electronics, biomedical applications, such as in automobiles, fuel cells, drug delivery and biological sensors, the convective heat transfer in nanofluid has become a very motivating topic. Raptis et al. [15] studied the effect of radiation on two-dimensional steady MHD optically thin gray gas flow into account the induced magnetic field. Pop et al. [16] theoretically studied the steady two-dimensional stagnation-point flow of an incompressible fluid over a stretching sheet. Mohamed et al. [17] considered the thermal radiation and MHD effects on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation and chemical reaction. Abdul-Kahar et al. [18] studied the chemically reacting nanofluid flow past a porous vertical stretching surface. The effects of magnetic field along with the thermal radiation effects in stretching sheet are investigated by many researchers [19,20]. Vishnu Ganesh et al. [21] discussed both analytically and numerically the effect of thermal radiation on MHD flow of water based metal Nano fluids over a stretching sheet. Rashidi et al. [22] studied the buoyancy effect on MHD flow of water based nanofluid over a stretching sheet in presence of thermal radiation. Hedayati et al. [23] examined asymmetric heating of totally developed forced convection of Al_2O_3–water nanofluid in a micro channel. Radiative nanofluid flow over a non-linear permeable sheet was investigated by Dhanai et al. [24]. Later, Malvandi et al. [25] depicts the effect of nanoparticle migration and asymmetric heating of alumina water nanofluid in a micro channel. Recently, Das et al. [26] elaborates the situation where convective heating of nanofluid happens in a heat source/sink.

In several fluid flow situations like foam and polymer solution, emulsions, we can't ignore the slip effect between the nanofluid and the solid boundaries (Yoshimura and Prudhomme [27]). On the other hand, when fluid flows in micro electro mechanical system (MEMS, no-slip condition is not applicable at the solid–fluid interface. The fluid slippage phenomenon at the solid boundaries appears in many applications such as in micro-channels or nano-channels and in applications where a thin film of light oil is attached to the moving plates or when the surface is coated with special coating like thick monolayer of hydrophobic octadecyltricholorosilane. Yazdi et al. [28] studied MHD flow and heat transfer over non-linear permeable stretching surface with boundary slip. Das [29] considered slip boundary condition in his study of nanofluid flow over a stretching sheet. Malvandi et al. [30] solved analytically the problem of boundary layer flow over an expanding surface. The partial slip effect on MHD flow of a Newtonian fluid over a porous stretching sheet has discussed in Abdul Hakeem et al. [31]. Malvandi and Ganji [32] studied the effect of Brownian motion and thermophoresis on the slip flow of nanofluid inside a circular micro channel in the presence of a magnetic field. They [33] also investigated nanoparticle migration effect on forced convection in a cool parallel plate channel. Later, Das [34] studied partial slip flow over a nonlinear expanding sheet. Malvandi et al. [35] examined boundary layer flow induced by permeable stretching sheet. Das et al. [36] considered the effect of chemical reaction on nanofluid flow over a nonlinear stretching sheet. MHD mixed convection nanofluid flow over an inclined cylinder due to velocity and thermal slip was investigated by Dhanai et al. [37]. Hedayati et al. [38] discussed forced convection on TiO_2 water nanofluid and studied the effect of nanoparticle migration on the flow in a micro channel. Lately, Hasiao [39] studied stagnation MHD nanofluid flow in presence of external electrical field.