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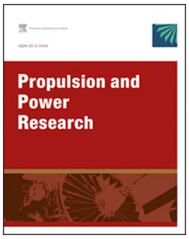

ORIGINAL ARTICLE

Double diffusive magnetohydrodynamic heat and mass transfer of nanofluids over a nonlinear stretching/shrinking sheet with viscous-Ohmic dissipation and thermal radiation

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Abstract The study of magnetohydrodynamic (MHD) convective heat and mass transfer near a stagnation-point flow over stretching/shrinking sheet of nanofluids is presented in this paper by considering thermal radiation, Ohmic heating, viscous dissipation and sink parameter/sink effects. Non-similarity method is adopted for the governing basic equation before they are solved numerically using Runge-Kutta-Fehlberg method using shooting technique. The numerical results are validated by comparing the present results with previously published results. The focus of this paper is to study the effects of some selected governing parameters such as Richardson number, radiation parameter, Schimdt number, Eckert number and magnetic parameter on velocity, temperature and concentration profiles as well as on skin-friction coefficient, local Nusselt number and Sherwood number.

1. Introduction

Mixed convective heat and mass transfer phenomena arise in industrial and technological applications in the presence of magnetic field. Thus the study of mixed convection boundary layer flow of an electrically conducting nanofluid has been

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Nomenclature

C	concentration of the fluid (unit: kg/m^3)
C^*	dimensionless concentration of the fluid
C_f	skin friction coefficient
C_p	specific heat at constant pressure (unit: J/(kg $\cdot$ K))
C_∞	free stream concentration (unit: kg/m^3)
C_w	concentration at the wall (unit: kg/m^3)
B_0	strength of magnetic field (unit: T)
D_m	specific diffusivity (unit: J/(kg $\cdot$ K))
Ec	Eckert number
Gr	local Grashof number
K^*	Rosseland mean spectral absorption coefficient (unit: m^{-1})
M	power-law stretching/shrinking parameter (unit: J/(mol $\cdot$ K))
m_w	wall mass flux (unit: kg $\cdot$ s^{-1} $\cdot$ m^{-2})
Nr	thermal radiation parameter (unit: W/m^2)
Nu_x	local Nusselt number
Pr	Prandtl number
q_r	thermal radiative heat flux (unit: J/m^3)
q_w	wall heat flux (unit: W/m^2)
Q_0	dimensional heat generation/absorption coefficient (unit: W/(m^2 $\cdot$ K))
Re_x	local Reynolds number
Ri	Richardson number
S	suction/injection parameter
Sc	Schimdt number
T	temperature of the fluid (unit: K)
T_∞	free stream temperature (unit: K)
T_w	temperature at the wall (unit: K)
u	velocity component in x-direction (unit: m/s)
u_w	stretching/shrinking sheet velocity (unit: m/s)
U	free stream velocity of the nanofluid (unit: m/s)
v	velocity component in y-direction (unit: m/s)
x, y	direction along and perpendicular to the plate, respectively (unit: m)

Greek letters

ζ	buoyancy ratio
λ	heat generation/absorption parameter
μ_{nf}	effective dynamic viscosity of the nanofluid
μ_f	dynamic viscosity of the fluid (unit: N $\cdot$ s/m^2)
ν_f	kinematic viscosity of the fluid (unit: Pa $\cdot$ s)
ρ_{nf}	effective density of the nanofluid (unit: kg/m^3)
σ	electrical conductivity of the fluid (unit: S/m)
σ^*	Stefan-Boltzmann constant (unit: W $\cdot$ m^{-2} $\cdot$ K^{-4})
κ_f	thermal conductivity of the fluid (unit: W/(m $\cdot$ K))
θ	dimensionless temperature of the fluid
ψ	stream function
κ_{nf}	effective thermal conductivity of the nanofluid
α_{nf}	effective thermal diffusivity of the nanofluid
α_f	fluid thermal diffusivity
β_T	coefficient of thermal expansion
β_C	coefficient of thermal expansion of concentration
β_{Tnf}	thermal expansion of nanofluid
B_{Cnf}	concentration expansion of nanofluid
β_f	thermal expansion coefficient of the fluid
β_s	thermal expansion coefficient of the nanoparticle
φ, φ_1, φ_2	solid volume fraction of the nanoparticles
η	similarity variable
ξ	magnetic parameter
σ	electrical conductivity of fluid
τ_w	wall skin friction

Subscripts

nf	nanofluid
f	liquid
s	solid

considered in this paper. Nanofluid is a suspension of solid nanoparticles or fibers of diameter 1–100 nm in basic fluids such as water, engine oil, ethylene glycol etc. Nanoparticles which are present in base fluids made from various materials (Choi et al. [1]). Recent research on nanofluid has revealed that nanoparticles (diameter less than 50 nm) may change characteristics of the fluid since thermal conductivity of nanoparticles particles was higher than convectional fluids such as water, ethylene glycol, and engine oil which are widely used as heat transfer fluids in thermal system. Nanofluids contains solid nanoparticles dispersion in a base fluid (such as water, oil, and ethylene glycol). The common nanoparticles those are in use are aluminum, copper, iron and titanium or their oxides. Experimental studies have shown that the thermal conductivity of the base liquid can be enhanced by 5%–15% with the small volumetric fraction of nanoparticles less than 5%. The enhanced thermal conductivity of nanofluid contributes to a remarkable improvement in the convective heat transfer coefficient. This feature of nanofluids has attracted researchers to use it in application such as advanced nuclear system since convective heat transfer mechanisms is a kind of heat exchanger.

Chio et al. [2] found that these nanofluids have better conductivity and convective heat transfer coefficient compared with the base fluid. Due to better performance of heat exchange, great potential and features, nanofluids can be used in several industrial applications such as in chemical production, transportation, car cooling systems, cooling of heat sinks, cooling of electronic chips, power generation in power plant and in nuclear system to obtain high rates of heat extraction from reactors. Many researchers, Das et al. [3], and Kakač and Pramuanjaroenkij [4] have made a comprehensive literature review in their books and review papers by discussing the heat transfer characteristics in nanofluids besides identifying future research in convective heat transfer of nanofluids. Bahiraei and Hangi [5] presented a review of flow and heat transfer characteristics of magnetic nanofluids.

The study of magnetohydrodynamics (MHD) boundary layer flow of a nanofluid over a stretching surface has become the basis of several industrial, scientific and engineering applications.

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