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ORIGINAL ARTICLE

Effect of viscous dissipation and suction/injection on MHD nanofluid flow over a wedge with porous medium and slip

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KEYWORDS

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Suction/Injection

Abstract The purpose of present study is to identify the effects of viscous dissipation and suction/injection on MHD flow of a nanofluid past a wedge with convective surface in the appearance of slip flow and porous medium. The basic non-linear PDEs of flow and energy are altered into a set of non-linear ODEs using auxiliary similarity transformations. The system of equations together with coupled boundary conditions have been solved numerically by applying Runge-Kutta-Fehlberg procedure via shooting scheme. The influence of relevant parameters on non-dimensional velocity and temperature profiles are depicted graphically and investigated in detail. The results elucidate that as enhance in the Eckert number, the skin friction coefficient increases, while heat transfer rate decreases. The outcomes also specify that thermal boundary layer thickness declines with an increase in suction parameter. Moreover, it is accelerated with augment in injection parameter. The results are analogized with the study published earlier and it creates a fine concord.

1. Introduction

There is a significant role of heat transfer in several potential fields due to the heating and cooling process implicated. Escalating the efficiency of heat transfer in macro-and nano-size devices is desirable, because as enhancing efficiency, decreases process time of work and extended the existence of apparatus. On enhancing the thermal conductivity of working fluid heat transfer efficiency improved. The base fluids (such as water, engine oil and ethylene glycol) have low thermal conductivity relative to nano-solid particles (for instance Cu, Ag, Au, Al, Fe, Hg, CuO, SiC, Al_2O_3, TiO_2 Fe_2O_3, etc.). These nano-solid particles are used to enhance the thermal conductivity of base fluid and they have exclusive chemical and physical properties and have smaller thermal expansion coefficient and high thermal conductivity comparatively regular fluid. Buongiorno [1] evolved a nanofluid model in which Brownian diffusion and thermophoresis slip mechanism are used to augment the base fluids thermal property. There are two major approaches to examine the heat transfer enhancement by tiny

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Nomenclature

A	constant
a	constant
B	constant
$B(x)$	variable magnetic field
Bi	Biot number
B_0	magnetic field strength
C	constant
C_f	skin-friction coefficient
C_p	heat capacity (J/kg K)
D	constant
E	constant
Ec	Eckert number
f	non-dimensional stream function
Gr_f	local Grashof number
g	acceleration due to gravity (m/s^{-2})
h	heat transfer coefficient
K	velocity slip parameter
k	thermal conductivity (W/m^{-2} K)
l	slip length (m)
M	magnetic field parameter
m	Falkner-Skan parameter
Nr	buoyancy parameter
Nu_x	local Nusselt number
Pr	Prandtl number
Q_0	heat generation/absorption coefficient
Q	heat generation/absorption parameter
Re	Reynolds number
S	suction/injection parameter
T	temperature of the fluid (K)
T_w	temperature of the surface of wedge (K)
T_∞	temperature of fluid far from the wedge
U	uniform velocity of nanofluid (m/s)
u, v	velocity along x and y direction (m/s)
(x, y)	Cartesian coordinates (m)

Greek symbols

α_{nf}	thermal diffusivity of nanofluid (m^2/s)
β	wedge angle parameter
β^*_{bf}	thermal expansion coefficient of base fluid (K^{-1})
β^*_{nf}	thermal expansion coefficient of nanofluid (K^{-1})
β^*_{sp}	thermal expansion coefficient of solid particle (K^{-1})
ϕ	solid volume fraction (%)
λ	porosity parameter
ρ_{bf}	density of base fluid (kg/m^3)
ρ_{nf}	density of nanofluid (kg/m^3)
ρ_{sp}	density of solid particle (kg/m^3)
μ_{bf}	dynamic viscosity of base fluid (kg/ms)
μ_{nf}	dynamic viscosity of nanofluid fluid (kg/ms)
ν_{bf}	kinematic viscosity of base fluid (m^2/s)
θ	non-dimensional temperature
ψ	stream function
π	pi
η	similarity variable

Superscripts

$*$	asterisk
$\prime$	derivative with respect to η

Subscripts

bf	base fluid
nf	nanofluid
sp	solid particle fluid
∞	free stream condition

solid particles, which are suspended in a fluid. One of them is two-phase model, this nanofluid model is applied by Sheikholeslami and Abelman [2] for simulation of heat transfer and nanofluid flow. Recently, Sheikholeslami and Ganji [3] have preferred two phase model, in which slip velocity between solid particles and fluid cannot be zero, for the simulation nanofluid flow and heat transfer performance of nanofluid. The second approach is single-phase model, in which both solid particles and fluid are in thermal equilibrium and solid particles are move with fluid with equal velocity. Various factors may affect heat transfer enhancement, for example, Brownian diffusion, Brownian forces, sedimentation, gravity, diffusion and friction between solid particles and fluid. In the lack of any appropriate theoretical studies and experimental data in the literature to examine these aspects, the active macroscopic two-phase model is not relevant for analyzing nanofluids [4–6]. If the primary significance is focused on heat transfer process, single-phase model, accounting for some of the above issues, is more expedient than two-phase model. Hence, the single-phase model is simpler and expedient in computational steps. Furthermore, advanced characteristics of nanofluid permit it to perform similar to a fluid that the conventional solid-fluid mixtures. Several studies have developed the single phase model to find the numerical results of heat transfer and hydrodynamic properties of the flow [3,7–9]. Loganathan and Arasu [10] have introduced that heat and mass transfer flow on non-Darcy magnetohydrodynamic flow with suction/injection, thermophoresis and porous medium. They depicted that concentration boundary layer is thinner as increase in thermophoretic parameter. Yacob et al. [11] have discussed steady flow of nanofluid over a static or moving wedge by employing Tiwari and Das nanofluid model [6]. They found that skin friction coefficient with rate of heat transfer boosts as raise in volume fraction of nanoparticles and wedge angle. Moreover, Rahman et al. [12] have also implemented Tiwari and Das approach to describe the influence of heat generation/absorption on two dimensional steady flow over a wedge with convective surface for nanofluid. They found that Nusselt number enhances with raising the values of Biot number and slip parameter. The impact of mixed convection on boundary layer flow over an inclined plate in the presence of porous medium in nanofluid is intentional by Rana et al. [13]. Rashad et al. [14] inspected the parallel impact of mixed convection and porous medium on nanofluid boundary layer flow past a circular cylinder. They analyzed that both heat and mass transfer coefficients are escalating function of either parameter of mixed convection or Biot number. Kuznetsov and Nield [15] have considered the classical problem of natural