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Magnetohydrodynamic flow of a Casson fluid over an exponentially inclined permeable stretching surface with thermal radiation and chemical reaction

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Abstract This article investigates the theoretical study of the steady two-dimensional MHD convective boundary layer flow of a Casson fluid over an exponentially inclined permeable stretching surface in the presence of thermal radiation and chemical reaction. The stretching velocity, wall temperature and wall concentration are assumed to vary according to specific exponential form. Velocity slip, thermal slip, solutal slip, thermal radiation, chemical reaction and suction/blowing are taken into account. The proposed model considers both assisting and opposing buoyant flows. The non-linear partial differential equations of the governing flow are converted into a system of coupled non-linear ordinary differential equations by using the similarity transformations, which are then solved numerically by shooting method with fourth order Runge–Kutta scheme. The numerical solutions for pertinent parameters on the dimensionless velocity, temperature, concentration, skin friction coefficient, the heat transfer coefficient and the Sherwood number are illustrated in tabular form and are discussed graphically.

1. Introduction

The theory of non-Newtonian fluid flow over a stretching surface has become a field of active research for the last few decades due to its wide range of applications in technology and industry. Such applications include polymer extrusion from a dye, wire drawing, the boundary layer along a liquid film in condensation processes, glass blowing, paper production, artificial fibers, hot rolling, cooling of metallic sheets or electronic chips, food stuffs, slurries and many others. Many researchers and scientists [1–9] analyzed the boundary layer flow over a stretching surface on various non-Newtonian models. The various non-Newtonian fluids are power-law fluids, micropolar fluids, viscoelastic fluids, Jeffrey fluid, Rivlin-Ericksen fluids, Casson fluids, Walter's liquid B fluids etc. Although various types of non-Newtonian fluid models are

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Nomenclature

U	stretching velocity
U_0	reference velocity
T_0	reference temperature
C_0	reference concentration
L	reference length
B_0	constant
P_y	yield stress of the fluid
u	velocity component in the x direction (ms^{-1})
v	velocity component in the y direction (ms^{-1})
x, y	coordinates along and normal to the stretching surface (m)
p	fluid pressure
g	acceleration due to gravity
c_p	specific heat at constant pressure (J kg^{-1} k^{-1})
k	thermal conductivity (w m^{-1} k^{-1})
k'	dimensional permeability
T	temperature of the fluid (K)
T_w	surface temperature
C_w	surface concentration
T_∞	temperature far away from the stretching sheet
C	concentration of the fluid (kmol m^{-3})
C_∞	concentration of the ambient fluid
q_r	radiative heat flux
D	mass diffusion coefficient (m^2 s^{-1})
k^*	Rosseland mean absorption coefficient
H	magnetic parameter
K	permeability parameter
Gr	local Grashof number
Gc	local solutal Grashof number
R	radiation parameter
Pr	Prandtl number
Sc	Schmidt number
S	suction parameter
N	velocity slip factor
M	thermal slip factor
P	solutal slip factor
V	velocity at the wall
N_1	constant
M_1	constant
P_1	constant
S_v	non dimensional velocity slip
S_t	non dimensional thermal slip
S_c	non dimensional solutal slip
q_w	surface heat flux
J_w	mass flux
C_f	skin friction coefficient
Nu_x	local Nusselt number
Sh_x	local Sherwood number
Re_x	local Reynolds number

Greek symbols

μ_B	plastic dynamic viscosity of the non-Newtonian fluid
π	$(i,j)th$ component of the deformation rate
π_c	critical value of this product based on the non-Newtonian model
υ	kinematic viscosity
ρ	density of the fluid (kg m^{-3})
β	Casson parameter
σ	electrical conductivity
β_T	coefficient of thermal expansion (m^3/kmol)
β^*	coefficient of solutal expansion (K^{-1})
α	inclination angle from the vertical direction
σ^*	Stefan–Boltzmann constant
λ	buoyancy parameter
η	similarity variable
δ	solutal buoyancy parameter
θ	dimensionless temperature
ϕ	dimensionless concentration
Γ	chemical reaction rate (kmol m^{-3})
γ	chemical reaction parameter
τ_w	surface shear stress (N m^{-2})

Subscripts

w	conditions at the wall
∞	ambient condition

Superscript

$'$	differentiation with respect to η

proposed to explain the behavior, one of the most important types of non-Newtonian fluids is the Casson fluid. The Casson fluid is a plastic fluid, which yields shear stress in Constitutive equations. Some of the examples of Casson fluid model are jelly, soup, honey, tomato sauce, concentrated fruit juices, drilling operations, food processing, metallurgy, paints, coal in water, synthetic lubricants, manufacturing of pharmaceutical products, synovial fluids, sewage sludge and many others. Human blood is also considered as Casson fluid because of the presence of several substances like protein, fibrinogen and globin in aqueous base plasma in the blood. Human red cells from a chain like structure, known as aggregates or rouleaux. If the rouleaux behave like a plastic solid then there exists a field stress that can be identified with the constant stress in Casson fluid [10]. Majority of researchers [11–20] analyzed the Casson fluid flow over a stretching sheet. Recently, the steady stagnation point flow Casson nano fluid over a convective stretching surface is examined by Nadeem et al. [21].

Thermal radiation and chemical reaction effects on heat and mass transfer over a stretching surface play an important role in Physics and Engineering due to its wide range applications, such as Nuclear power plants, combustion of fossil fuels, liquid metal fluids, gas turbines, plasma wind tunnels, photo ionization, geophysics, and the various propulsion devices for missiles, aircraft, space vehicles, and satellites. The effects of thermal radiation over a stretching sheet under different flow conditions have been reported by several researchers [22–34]. Very recently, the numerical solutions for steady boundary layer flow and heat transfer for a Casson fluid over an exponentially permeable stretching surface in the presence of thermal radiation are analyzed by Pramanik [35].