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Original Research Paper

Radiative flow of Casson fluid over a moving wedge filled with gyrotactic microorganisms

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ABSTRACT

The present study investigates the effects of thermophoresis and Brownian motion on two-dimensional magnetohydrodynamics (MHD) radiative Casson fluid past a moving wedge filled with gyrotactic microorganisms. Numerical results are presented graphically as well as in tabular form with the aid of Runge-Kutta and Newton's methods. Effects of pertinent parameters on velocity, temperature, concentration and density of motile organism distributions are presented and discussed for two flow cases namely suction and injection. The obtained results are validated by comparing with the available previous studies and found good agreement. The thermal and concentration boundary layer are significantly modulated with the rise of thermophoresis and Brownian motion parameters for both suction and injection flow cases. The increasing values of thermophoresis parameter boost up the temperature and concentration field while thermal boundary layer decreased for increasing the Brownian motion parameter. With the rise of Casson fluid parameter, the velocity increases but the temperature, concentration and density of motile organism is found to decrease in both suction and injection flow cases. The influence of the pertinent parameters on the local shear stress coefficient, local Nusselt and local Sherwood numbers are discussed with the assistance of the table for two flow cases separately (suction and injection). The thermal radiation parameter boost up the local Sherwood number, gyrotactic microorganisms mass transfer rate and depreciates the local Nusselt number for the suction and injection flow cases. An important finding of the present investigation is that the gyrotactic microorganisms can enhance the heat and mass transfer rate.

1. Introduction

The steady laminar flow over a fixed wedge was first investigated by Falkner and Skan [1] to demonstrate the application of Prandtl's boundary layer theory. In their study, the Prandtl's boundary layer theory was developed by transforming the governing partial differential equations (PDEs) to ordinary differential equation (ODEs) (which are known as Falkner-Skan equations) using similarity transformation. There are number of literature available on the solutions of Falkner-Skan equation such as Hartree [2], Stewartson [3], Chen and Libby [4], Kuo [5] and so many. In addition, the heat and mass transfer behaviors of the flow past a wedge was numerically and analytically studied by Goyal et al. [6] and Hady [7]. The flow past a wedge has numerous industrial applications such as plastic films, metal spinning, polymer extrusion and metallurgical processes. Due to the aforesaid applications, researchers [8–11] studied the characteristics of heat and mass transfer in magnetohydrodynamics (MHD) flows over a fixed or moving wedge considering the various effects, such as convection conditions, suction or injection effect and chemical reaction effects. Later, Yacob et al. [12] investigated the Falkner-Skan nanofluid flow past a moving wedge by considering the effect of prescribed surface flux and found that the nanoparticle volume fraction increases the thermal conductivity of the fluid. Further, Postelnicu and Pop [13] examined the Falkner-Skan flow over a stretching wedge. Rashidi et al. [14] presented the homotopy analysis method (HAM) to investigate the heat transfer characteristics of a non-Newtonian fluid over a non-isothermal wedge and reported that increasing the values of the Prandtl number enhanced the heat transfer rate. Recently, the Falkner-Skan nanofluid over a wedge with various properties, such as slip, suction or injection, heat

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Nomenclature

θ	dimensionless temperature
ϕ	dimensionless concentration
f	dimensionless velocity
Cf_x	skin friction coefficient
Nu_x	local Nusselt number
Sh_x	local Sherwood number
Re_x	local Reynolds number
Pr	Prandtl number
Le	Lewis number
M	magnetic field parameter
β	Casson fluid number
β_1	fluid number
n	power-law index parameter
R	thermal radiation parameter
Pe	Peclet number
θ_w	temperature parameter
Nt	thermophoresis parameter
Nb	Brownian motion parameter
λ	wedge angle parameter
u, v	velocity components in x and y directions respectively (m/s)
c_p, c_s	specific heat capacity at constant pressure (J/kg K)
x	distance along the surface (m)
y	distance normal to the surface (m)
T	temperature of the fluid (K)
C	concentration of the fluid (Moles/kg)
N	concentration density of the motile organism (Moles/kg)
g	acceleration due to gravity (m/s^2)
α_f	diffusion coefficient (m^2/s)
$(\rho c_p)_f$	heat capacity of the fluid (kg/m^3 K)
$(\rho c_p)_p$	effective heat capacity of the nanoparticle medium (kg/m^3 K)
τ	the ratio of effective heat capacity of the nanoparticle phase to fluid
γ	moving wedge parameter
B_0	magnetic induction parameter
Γ	time constant
k	thermal conductivity (W/m K)
η	similarity variable
σ	electrical conductivity (S/m)
σ^*	Stefan-Boltzmann constant (W/m^2 K^4)
k^*	mean absorption coefficient
h_f	heat transfer coefficient
m	stream wise pressure gradient or Falkner-Skan power law index
ρ	density of the fluid (kg/m^3)
v	kinematic viscosity (m^2/s)
μ	dynamic viscosity of the fluid (kg/ms)
μ_∞	viscosity of the ambient fluid
b	chemotaxis constant
W_c	maximum cell swimming speed
T_w, T_∞	temperatures near and far away from the surface
U_w, U_∞	velocities near and far away from the surface
C_w, C_∞	concentration near and far away from the surface
D_B, D_T	diffusion coefficient (m^2/s)
D_n	diffusion coefficient of the microorganism (m^2/s)

Subscripts

w	condition at the wall
∞	condition at the free stream

source/sink and chemical reaction were studied by many researchers [15–18].

In recent years, the study of the flow and transport processes in non-Newtonian fluids has gained much attention owing to its extensive application in industry, biological process, and chemical engineering. A few examples of such applications include the manufacture of optical fibers and plastic polymers, clay coating and cosmetic products. The famous Naiver-Stokes equations are not enough to describe the characteristics of non-Newtonian fluids, hence, some physical models such as Cross and Ellis model, the Casson model, and the Carreaue model are needed to fill up this gap. The usage of physical conditions of non-Newtonian fluid flow is largely challenging for the researchers due to its complex nature and lack of constitutive equation for presenting all flow properties of non-Newtonian fluid. Due to the wide diversity of non-Newtonian fluids, the important rheological characteristics of such flows cannot be addressed by a single constitutive relation between the shear stress and the shear rate. Significant contributions to the study of non-Newtonian fluid models with a variety of rheological properties have been made by Harris [19] and Bird et al. [20]. Later on, several authors [21–25] studied the non-Newtonian flow characteristics in the presence of various flow controlling parameter.

The study of the MHD flow of electrically conducting fluid past a heated surface has many researchers in view of its significant applications in numerous engineering problems such as plasma studies, petroleum industries, MHD power generators, cooling of nuclear reactors, the boundary layer control in aerodynamics and crystal growth. The problem of steady forced, free, and mixed convection on MHD with a combination of various boundary flow characteristics and geometries such as horizontal, vertical and inclined surfaces has been studied by different investigators [26–34] due to the considerable theoretical and practical interest. Bandaru and Vijaya [30] analyzed the variable conductivity on heat transfer flow characteristics over a vertical porous plate in a rotating system. The induced magnetic field and homogeneous-heterogeneous reactions on viscoelastic flow over a stretching surface with unequal diffusivities were illustrated by Animasaun et al. [35] and highlighted that the homogeneous-heterogeneous reactions help to control the mass transfer profiles. Raju and Sandeep [36] discussed the three-dimensional flow characteristics of Carreau-Casson fluids over stretching sheet in the presence of unsteadiness and concluded that unsteadiness has a tendency to control the flow. Recently, Srinivasacharya et al. [37] examined the effect of thermophoresis on convection flow over saturated permeable vertical wavy stretching sheet.

The bio-convection flow pattern mostly performs in bacteria's and it has higher density than water at the boundary of the fluid. This phenomenon is known as unstable situation and in this case bacterial boundary layer distributed into group of bio-convection cells. In general, these are of two types namely gyrotactic microorganism and oxytoctic microorganism. The fundamental bio-convection mechanism of both continuums modeling is invariant. Hence, the researchers investigated more on enhancing the mass transfer rate and concentration species owing to its industrial applications such as extrusion process, the characteristics of