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ORIGINAL ARTICLE

Nonlinear radiative magnetohydrodynamic Falkner-Skan flow of Casson fluid over a wedge

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Abstract This communication addresses the thermophoresis and Brownian motion effects on magnetohydrodynamic radiative Falkner-Skan flow of Casson fluid over a wedge with convective condition. In most of the existing studies thermal radiation is linear. Due to the noticeable significance of the numerous industrial as well as engineering applications, in this study we measured the thermal radiation is nonlinear. Numerical results are presented graphically as well as in tabular form with aid of Runge-Kutta and Newton's methods. Effects of pertinent parameters on velocity, temperature and concentration distributions are presented and discussed for three wedge positions (i.e. static wedge, forward and backward movements of wedge). For engineering interest we also computed friction factor, heat and mass transfer rates. It is observed that thermal, concentration and momentum boundary layers are not uniform at different wedge positions. It is also observed that the heat and mass transfer rate is high when the wedge is moving in forward direction.

1. Introduction

The famous Falkner-Skan equation played a significant role in the growth of fluid dynamics. This equation was first proposed for boundary layer flow driven by a stream wise pressure gradient. The equation $f''' + ff'' + \lambda(1 - f'^2) = 0$, with the common boundary conditions $f(0) = \beta$, $f'(0) = \gamma$ and $f'(\infty) = 1$ where β is the strength of the mass transfer at the wall, $\lambda = 2m/m + 1$ is a stream wise pressure gradient. The original Falkner-Skan equation involved $\beta = 0$, $\gamma = 0$ for a fixed and impermeable wedge flow. For developing the Ludwig Prandtl boundary layer theory, the governing partial differential equations are transformed into ordinary differential equations with aid of similarity transformation; currently it is well known as Falkner-Skan flow equation. The overview of flow over a wedge was given by [1–4]. The wedge is triangular shaped, which can be used in the process of separating the two objects, hold an object in a plane and lifting up an object. A wedge converts the lateral force into a transverse splitting force. Owing view into this the authors [5–7] presented the analytical as well as numerical solutions of flow past a wedge with various flow properties. With continuation of this Alizadeh et al. [8] analyzed the Falkner-Skan flow over a wedge by using a domain decomposition method (ADI). Analytical solution of Falkner-Skan equation over a stretching sheet in the presence of suction or injection was illustrated by Afzal [9] and highlighted that suction parameter plays no role in the estimation of friction factor coefficient, but it plays stabilizer character to the stream function. Fang et al. [10] studied the algebraic

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Nomenclature

u, v	velocity components in x and y directions respectively (m/s)
x	distance along the surface (m)
y	distance normal to the surface (m)
c_p, c_s	specific heat capacity at constant pressure (J/Kg K)
T	temperature of the fluid (K)
C	concentration of the fluid (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)
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
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
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_m	diffusion coefficient (m^2/s)

Dimensional less parameters

Cf_x	Skin friction coefficient
Nu_x	local Nusselt number
Sh_x	local Sherwood number
θ	dimensionless temperature
ϕ	dimensionless concentration
f	dimensionless velocity
Re_x	local Reynolds number
Pr	Prandtl number
Le	Lewis number
M	magneticfield parameter
β	Casson fluid number
n	power-law index parameter
R	thermal radiation parameter
Bi	Biot number
θ_w	temperature parameter
Nt	thermophoresis parameter
Nb	Brownian motion parameter
λ	wedge angle parameter

Subscripts

w	condition at the wall
∞	condition at the free stream

decaying velocity influence on Falkner-Skan flow in the presence of prescribed power-law wall temperature properties. With this they decided that the flow is controlled by the wall motion.

For demonstrating the non-Newtonian flow performance, Navier-Stokes equation is not sufficient. Therefore must essential some physical models to fill up this gap such as Casson, power-law fluids, Carreau model, Maxwell, Oldroyd-B fluid, and Cross and Ellis model it has demanded applications in various fields such as drawing of plastic films, conveyor belt, insulating materials, aerodynamics, aeronautical, metal spinning processes and paper production. The physical behaviors of non-Newtonian fluid flows are currently exciting to the engineers, scientist as well as mathematicians. The main drawbacks of these are complex in nature, but there is no single constitutive equation for demonstrating all non-Newtonian fluid flow properties. Inspired by this theory the authors [11–21] described the solutions of Newtonian as well as non-Newtonian fluid flows with various flow characteristics. Brownian motion and thermophoresis are the heat and mass transfer mechanism of movement of small particles in the way of diminishing thermal as well as concentration gradients. It affects the small particles associated with the bleak surfaces. It has challenging applications in different fields such as aerospace, hydrodynamics, nuclear safety processes, environmental, aerosol technology and atmosphere pollution. Initially, the dynamic theory of Brownian motion was given by Nelson [22]. Furthermore, many researchers focused on the thermophoresis and Brownian motion effects along with some other flow properties on MHD flow by choosing the various nano and Ferro particles with different flow geometries [23–28]. These researchers concluded that the ferro and nanoparticles help to improve the thermal conductivity of the suspended fluid.

Recently, Khan et al. [29] discussed the third grade fluid flow over a heated stretching surface filled with nanoparticles in the presence of convective condition. Three-dimensional flow characteristics of Oldroyd-B nanofluid past a stretching surface with thermal radiation were numerically investigated by Shehzad et al. [30] and found that thermal radiation improves the temperature profiles of the flow. Jasmine Benazir et al. [31] analyzed the non-uniform heat generation/absorption effect on unsteady MHD Casson fluid flow past a flat plate and a cone. In this study they highlighted that the non-uniform heat source/sink parameter encourages the temperature profiles. A magnetic field effect on three-dimensional Sisko nanofluid flow over a stretching surface filled with nanoparticles was studied by Hayat et al. [32]. Khan et al. [33] illustrated stagnation point flow of nanofluid through a radiative stretching surface in the presence of variable viscosity and non-aligned magnetic field. Abbasi et al. [34] analyzed the mixed convection on Maxwell nanofluid over a stretching surface in the presence of heat source/sink and highlighted that the heat generation/absorption coefficients improve the

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