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MHD slip flow of a dissipative Casson fluid over a moving geometry with heat source/sink: A numerical study

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ABSTRACT

A Mathematical model is developed for investigating the heat and mass transfer of magnetohydrodynamic Casson fluid over a moving wedge with slip, nonlinear thermal radiation, uniform heat source/sink and chemical reaction. For regulating the momentum and concentration gradients we also considered the viscous dissipation and cross diffusion effects. Numerical solutions are carried out by employing Runge-Kutta and Newton's methods. The effects of the physical governing factors on the flow, temperature and concentration profiles are illustrated graphically for accelerating and decelerating flow cases. We also computed the local Nusselt and Sherwood numbers along with friction factor for the same cases. It is found that increasing the temperature jump parameter encourages the heat transfer rate. It is also concluded that the local Nusselt number is high in accelerating flow case when equated with the decelerating flow case.

1. Introduction

The Falkner-Skan equation plays a significant role in the growth of fluid dynamics. Initially, this equation was proposed for analyzing the stream wise pressure gradient boundary layer theory. The basic Falkner-Skan equation with the common conditions $f(0) = \delta, f'(0) = \gamma$ and $f'(\infty) = 1$ is of the form $f''' + ff'' + \lambda(1 - f'^2) = 0$, where δ is mass transfer at the wall and $\lambda = 2m/(m + 1)$ is a pressure gradient with stream wise. The special case of Falkner-Skan equation with $\beta = 0, \gamma = 0$ represents the fixed and impermeable wedge flow. A brief summary of Falkner-Skan equation is given by the researchers [1–3]. In continuation of this, the authors [4–6] presented the analytical as well as the numerical solutions of flow over a wedge with various flow properties. Later on, Mushtaq et al. [7] considered the numerical treatment of nanofluid flow due to nonlinear thermal radiation and provided the challenges of nonlinear thermal radiation. Recently, the flow of Falkner-Skan equation over a wedge in the presence of slip condition was numerically discussed by Turkyilmazoglu [8].

Most of the investigators have been paying attention on the concept of heat and mass transport distribution in numerous disciplines such as chemical industries, power controlling in generator systems and agriculture fields etc. Physically, if the heat and mass transfer takes place then the multiple performances was perceived in the correlation between the fluxes and the flux can be generated by the concentration and temperature gradients systems. These are of two types. One is the flux induced by the concentration gradient is referred as Dufour effect. Similarly the flux influenced by the temperature is referred as Soret effect. These properties may be unnoticed as they are of a smaller order of magnitude while equated with the properties encouraged by the law of Fick's and Fourier's. Conversely, in particular they have particular significance in the numerous fields such as chemical transport phenomena, geo-technology, petroleum and aerospace industries. Because of this importance initially Tewfik et al. [9] recognized the significance of Dufour and Soret impact on flow behavior and discussed the importance of these effects on heat transport distribution over a cylinder by choosing helium injection. They perceived that injection process does not affect the velocity gradient and pressure circulation till the laminar separation point. Later on some progressive work contributed for Soret and Dufour effects by considering the different channels by the researchers [10–17].

The fluid flow slips at the wall have numerous benefits in the process of micro and nano heat and mass transport controlling processes such as micro valves, pumping and nozzle systems and hard disk drives etc. Keeping view into partial slip on flow over stretching sheet with convection conditions was principally investigated by Yoshimura and Prudhomme [18]. Further, the closed form solution for magnetohydrodynamic flow due to stretching sheet was investigated by Anderson [19]. Later on, enormous authors have incorporated a partial slip at the wall whenever they need. Inspired by the stated applications and challenges the researchers [20–25] described the slip effect with various types of flow geometries as well as boundary

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Nomenclature

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
Sc	Schmidt number
δ	temperature jump parameter
ε	slip parameter
Q_H	heat source/sink parameter
M	Magneticfield parameter
β	Casson fluid parameter
Ec	Eckert number
R	thermal radiation parameter
θ_w	The ratio of temperatures
Kr	chemical reaction parameter
Sr	Soret number
Du	Dufour number
λ	Wedge angle parameter
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)
f	Dimensionless velocities (m/s)
T	Temperature of the fluid (K)
C	Concentration of the fluid (Moles/Kg)
g	Acceleration due to gravity (m^2/s)
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 nano particle medium (Kg/m^3 K)
γ	moving wedge parameter
B_0	Magnetic induction parameter
Γ	Time constant
k	Thermal conductivity (W/mK)
η	Similarity variable
σ	Electrical conductivity (S/m)
σ^*	Stefan-Boltzmann constant ($W/m^2 K^4$)
k^*	Mean absorption coefficient
ρ	Density of the fluid (Kg/m^3)
ν	Kinematic viscosity (m^2/s)
k_0	Chemical reaction rate
Q_0	Heat source/sink
μ	Dynamic viscosity of the nanofluid (Kg/ms)
μ_∞	Viscosity of the ambient fluid
T_w, T_∞	Temperatures of the near and far away from the surface
U_w, U_∞	Temperatures of the near and far away from the surface
C_w, C_∞	Concentration of the near and far away from the surface
D_B	Diffusion coefficient (m^2/s)
D_m	Diffusion coefficient (m^2/s)

Subscripts:

f	Fluid
w	Condition at the wall
∞	Condition at the free stream

conditions. With this they concluded that slip have tendency to controls the rate of heat and mass transfer. Ashwini and Eswara [29] magnetohydrodynamic Falkner-Skan flow due stretching surface with heat absorption or generation and highlighted that heat generation or absorption parameter decreases the temperature field. The buoyancy forces on viscoelastic fluid due to wedge were investigated analytically by Rostami et al. [30]. Rashidi et al. [31] studied the mixed convection on magnetohydrodynamic viscoelastic fluid past a permeable wedge in the presence of thermal radiation. Shi et al. [32] flow over a blunt wedge with free stream pulse disturbances at Mach level. Optimal asymptotic homotopy analysis of Falkner-Skan flow over a wedge was investigated by Madaki et al. [33]. Recently, Raju and Sandeep [34] presented the cross diffusion on Falkner-Skan magnetohydrodynamic Carreau fluid over a wedge and concluded that cross diffusion effects are controls the mass distribution phenomena. Very recently, the researchers [35–39] analyzed the heat transfer behavior of magnetic flows through various geometries.

Motivated by the above mentioned studies and challenges, still no studies have been described up to the author's knowledge on nonlinear thermal radiation and heat source or sink effect on magnetohydrodynamic slip flow of Falkner-Skan Casson fluid over a wedge in the presence of chemical reaction and cross diffusion effects. The thermal and velocity slips at the boundary also taken into account. The transformed ordinary differential equations are solved numerically. Comparisons of some exceptional cases are made with the previous results and found a good agreement.

2. Mathematical formulation

The cross diffusion and nonlinear thermal radiation on magnetohydrodynamic flow of a Casson fluid over a wedge is considered. The velocities at the wedge and at free stream are $u_w(x) = U_w x^m$ and $u_e(x) = U_\infty x^m$ respectively. The heat source/sink and chemical reactions are taken as $Q(x) = Q_0 x^{(m-1)/2}$, $k(x) = k_0 x^{(m-1)/2}$ respectively. $\lambda = 2m/(m+1)$ is the stream wise pressure gradient or wedge angle parameter. The total angle of the wedge is $\Omega = \lambda\pi$. Similarly, the temperature and concentration of the boundary and free stream are indicated by T_w, T_∞ and C_w, C_∞ respectively. A uniform magnetic field $B(x) = B_0 x^{(m-1)/2}$ is applied to the flow direction as displayed in Fig. 1. The rheological model for Casson fluid is Mabood and Mastroberardino [23] given as follows:

$$\tau^{1/q} = \tau_0^{1/q} + \mu\dot{\gamma}^{1/q} \tag{1}$$

$$\tau_{i,j} = \begin{cases} 2(\mu_B + p_y/\sqrt{2\pi})e_{ij}, \ \pi > \pi_c \\ 2(\mu_B + p_y/\sqrt{2\pi})e_{ij}, \ \pi < \pi_c \end{cases} \tag{2}$$

In the above equation $\pi = e_{ij}e_{ij}$ and e_{ij} is the (i, j) th component of the deformation rate, π be the product deformation rate, π_c is a critical value of this product based on the non-Newtonian model, p_y is the yield

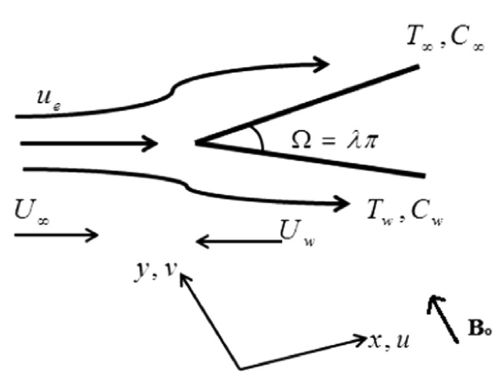

Fig. 1. Physical configuration of the flow model.