Study on MHD Free Convection flow of a Casson Fluid Flow Past a Vertical Porous Plate With Uniform Boundaries

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Abstract

The current work focuses on the analysis of unsteady heat and mass transfer rates through porous media in the presence of a uniform transverse magnetic field, as well as radiation/absorption, heat generation/absorption, and homogeneous chemical reaction effects. Perturbation method is used to solve the coupled non-linear partial equations. Various parameters effects on flow characteristics are investigated. The results are presented in the form of graphs that show the effect of various parameters on fluid flow. The Casson parameter has an effect on fluid velocity. The flow within the boundary layer is reduced by the heavier species with low conductivity. Because of the importance of non-Newtonian fluids in real-time applications in chemical industries and petroleum refineries, the Casson parameter is used.

Subject Classification:[2020]76S05,35Q35,35Q40,80A21,80A30.
Keywords: Casson fluid, thermal radiation, Grashof Number, Porous Medium, MHD.

1 Introduction

The present investigation has been focused on how the influence of such foreign mater on the heat and mass transfer characteristics of the chemical fluid flows.The present essential need for various chemical industries and manufacturing firms is how to reduce or completely eliminate the adverse effects or hazards happened in different chemical reactions takes place during the processing of products. The main cause of this is due to presence of any foreign elements or unexpected agents in the processing. Faruk Abdullahi et al. [1] have investigated the Casson fluid effects on magneto-hydrodynamics (MHD) unsteady heat and mass transfer free convective past an infinite vertical plate. Haroon ur Rasheed et al. [2-3] have done the computer analysis to investigate the effect of mathematical abstractions on velocity, energy, concentration and the influence of skin-friction and Nusselt number. Also the effects of Joule heating and viscous dissipation on magnetohydrodynamic boundary Layer Flow of Jeffrey nano fluid. Zeeshan et al. [4] have examined the impact of embedded parameters such asvariable thickness, unsteadiness, Prandtl number, Schmidt number, Brownian-motion, and thermophoretic) on thin film nano fluids. Saeed Islam et al. [5] have examined the impact of variable thickness and thermal conductivity characteristics in view of melting heat flow on Williamson nanofluid flow. Zeeshan Khan [6] have investigated the effect on physical appearance of material parameters on the flow field, temperature, concentration, drag force, and Nusselt number on convective heat transfer flow of Casson fluid. Haroon Ur Rasheed et al. [7-8] have investigated the Joule heating and variable viscosity effect on reactive Casson fluids and also performed the numerical analysis with chemical reaction and Hall current on unsteady MHD flow of Casson fluid. Hayat et al. [9] presented several aspects by investigating oscillatory rotating flows of a fractional Jeffrey fluid filling a porous space. Abu zeid et al. [10] have contributed their efforts to investigate the various effects of parameters in the MHD flow of Casson fluid flows. Later Veera Krishna et al. [11, 12, 13, 14] examined Hall and ion slip effects on MHD rotating boundary layer flow of nanofluid past an infinite vertical plate under a variety of geometries. Chamka [15] discussed MHD-free convection from a vertical plate embedded in a thermally stratified porous medium with Hall effects. Veera Krishna [16] analyzed MHD-free convection from a vertical plate embedded in a thermally stratified porous medium with Hall effects. Magyari [17] found analytical solution on heat generation or absorption and first-order chemical reaction on micropolar fluid flows over a uniformly stretched permeable surface. Takhar [18] examined MHD flow over a moving plate in a rotating fluid with magnetic field, Hall currents and free stream velocity. Chamka [19, 20, 21, 22] established Soret and Dufour effects on MHD mixed convection flow under rotation. Veera Krishna [23] considered Hall and ion slip effects on MHD rotating boundary layer flow of nanofluid past an infinite vertical plate embedded in a porous medium. Chamka [24, 25] discussed analytically thermal radiation and buoyancy effects on hydromagnetic flow over an accelerating permeable surface with heat source or sink. Khedr [26] analyzed MHD flow of a micropolar fluid past a stretched permeable surface with heat generation or absorption. Takhara et al. [27] discussed unsteady flow and heat transfer on a semi-infinite flat plate with an aligned magnetic field. Ganesh Kumar et al. [28] analyzed Cattaneo-Christov heat diffusion phenomenon in Reiner-Philippoff fluid through a transverse magnetic field. HadiSeyedi et al. [29] considered heat and mass transfer investigation of MHD Eyring-Powell flow in a stretching channel with chemical reactions. Chamka et al. [30] examined Unsteady MHD natural convection from a heated vertical porous plate in a micropolar fluid with Joule heating, chemical reaction and radiation effects. Sudarsana Reddy and Chamka [31, 32] analyzed Soret and Dufour effects on MHD convective flow of Al2O3–water and TiO2–water nanofluids past a stretching sheet in porous media with heat generation/absorption. In the present investigation, the presence of radiation absorption and a transverse magnetic field is considered in an unsteady free convective flow of Casson fluid past an infinite vertical porous plate in a porous medium with time dependent oscillatory suction along with the permeability. This kind of environment is mostly present in various industries such as food processing firms, dairy industries, distilleries and beverage industries, polymer fabrication firms, glass manufacturing industries, pharmaceutical industries etc. The literature seen does not consider radiation absorption and chemical reaction and so we considered it in this analysis. The novelty of the present study is to analyse the effect of time defendant fluctuate suction and permeability of the medium on a Casson fluid flow in the presence of radiation, heat absorption, radiation absorption and chemical reaction. The Casson parameter is taken due to the significance of non-Newtonian fluids in real time applications in chemical industries and petroleum refineries.

2 Formulation

Let a vertical plate is considered in a fluid flow direction such that assume the $-x^*$- axis is along the plate and the-y^*- axis is normal to it.The physical model of the present investigation has shown in Fig.A.

Let us consider the magnetic Reynolds number is much less than unity so that induced magnetic field is neglected in comparison with the applied transverse magnetic field. The basic flow in the medium is, therefore, entirely due to the buoyancy force caused by the temperature difference between the wall and the medium. It is assumed that initially, at $t^* < 0$, the plate as well as fluids are at the same temperature and also concentration of the species is very low so that the Soret and Dofour effects are neglected. Whent^*, the temperature of the plate is instantaneously raised to

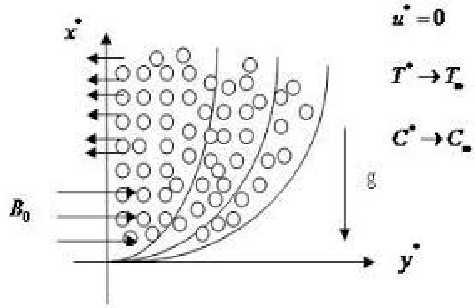

Fig.A

$T_W{}^*$and the concentration of the species is to $C_W{}^*$. Let the permeability of the porous medium and the suction velocity be considered in the following forms respectively.

$K^*(t^*) = K_p{}^*(1 + \varepsilon e^{n^*t^*}), v^*(t^*) = -v_0(1 + \varepsilon e^{n^*t^*})$ (1)

Where $v_0 > 0$ and $\varepsilon \leq 1$ are positive constants. Under the above assumptions and with usual Boussinesq's approximation, the governing equations and boundary conditions are given by

$\frac{\partial u^*}{\partial t^*} = (1 + \frac{1}{\beta})\nu\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T_\infty{}^*) + g\beta^*(C^* - C_\infty{}^*) - \sigma B_0{}^2\frac{u^*}{\rho} - (\frac{1}{1+\beta})\nu\frac{u^*}{k^*}$ (2)

$\frac{\partial T^*}{\partial t^*}\rho c_p = K\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q^*}{\partial y^*} - Q^*(T^* - T_\infty{}^*) + Q_l{}^*(C^* - C_\infty{}^*)$ (3)

$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - K_r(C^* - C_\infty{}^*)$ (4)

$$u = f(t) = 1, T^* = T_\infty + \varepsilon(T_W - T_\infty)e^{n^*t^*}, C^* = C_\infty + \varepsilon(C_W - C_\infty)e^{n^*t^*} \text{at } y = 0\backslash n$$

Introducing the non-dimensional quantities,

$$y = \frac{v_0 t^*}{\nu}, t = \frac{v_0{}^2 t^*}{4\nu}, w = \frac{4\vartheta w^*}{v_0{}^2}, u = \frac{u^*}{v_0}, T = \frac{T^* - T_\infty{}^*}{T_W - T_\infty}, C = \frac{C^* - C_\infty{}^*}{C_W - C_\infty},$$

$S = \frac{\vartheta S^*}{v_0{}^2}, K_p = \frac{v_0^2 K_p^2}{\nu^2}, M^2 = \sigma\frac{B_0^2\nu}{v_0^2\rho}, P_r = \frac{\nu}{K}, S_c = \frac{V}{D}, R_c = \frac{v_0^2 K_0}{\nu^2\rho},$

$G_c = \frac{\nu g\beta(C_W - C_\infty)}{v_0^3}, G_r = \frac{\nu g\beta(T_W - T_\infty)}{v_0^3}, F = \frac{4I_1\nu}{v_0^2\rho C_p}, s = \frac{Q\nu}{v_0^2\rho C_p},$

$R = \frac{Q_1\nu(C_W^* - C_\infty)}{v_0^2\rho(T_W^* - T_\infty)}, K_c = \frac{k_r\nu}{v_0^2}, H = F + S$ (6)

The equations (2)-(5) reduce to following non-dimensional form

$\frac{1}{4}\frac{\partial u}{\partial t} = (1 + \frac{1}{\beta})\frac{\partial^2 u}{\partial y^2} + G_r T + G_c C - (M^2 + \frac{1}{K_p})u$ (7)

$\frac{1}{4}\frac{\partial T}{\partial t} = \frac{1}{P_r}\frac{\partial^2 T}{\partial y^2} - HT + RC$ (8)

$\frac{1}{4}\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K_c C$ (9)

$$u = f(t) = 1, T = 1 + \varepsilon e^{\text{nt}}, C = 1 + \varepsilon e^{\text{nt}} \quad \text{y} = 0\backslash n$$

3 Solution

In view of periodic suction, temperature and concentration at the plate let us assume the velocity, temperature, concentration the neighborhood of the plate be

$u(y, t) = u_0(y) + \varepsilon e^{\text{nt}}u_1(y), T(y, t) = T_0(y) + \varepsilon e^{\text{nt}}T_1(y), andC(y, t) = C_0(y) + \varepsilon e^{\text{nt}}C_1(y)$ (11)

Substituting equations (11) into (7-9) and comparing the no harmonic & harmonic terms we get

$(1 + \frac{1}{1\beta})u_0{}^{11} - (M^2 + \frac{1}{K_p})u_0 = -G_r T_0 - G_c C_0$ (12)

$(1 + \frac{1}{1\beta})u_1{}^{11} - (M^2 + \frac{1}{K_p} + \frac{n}{4})u_1 = -G_c C_1 - G_r T_1$ (13)

$T_0{}^{11} - P_r H T_0 = -R P_r C_0$ (14)

$T_1{}^{11} - (H + \frac{n}{4}) P_r T_1 = -R P_r C_1$ (15)

$C_0{}^{11} - K_c S_c C_0 = 0$ (16)

$C_1{}^{11} - (K_c + \frac{n}{4}) S_c C_1 = 0$ (17)

The boundary conditions now reduce to

$$u_0 = 1, u_1 = 0, T_0 = T_1 = 1, C_0 = C_1 = 1, \quad \text{at } y = 0\backslash n$$

Solving these differential equations (12)-(18) with the help of boundary conditions we get $u(y,t) = (1 - b_3 - b_4)e^{-\sqrt{a_5}y} + b_3 e^{-\sqrt{a_3}y} + b_4 e^{-\sqrt{a_1}y}$

$+\varepsilon e^{nt}\left\{(-b_5 - b_6)e^{-\sqrt{a_8}y} + b_5 e^{-\sqrt{a_4}y} + b_6 e^{-\sqrt{a_2}y}\right\}$ (19)

$T(y,t) = (1 - b_1)e^{-\sqrt{a_3}y} + b_1 e^{-\sqrt{a_1}y} + \varepsilon e^{nt}\left\{(1 - b_2)e^{-\sqrt{a_4}y} + b_2 e^{-\sqrt{a_2}y}\right\}$ (20)

$C(y,t) = e^{-\sqrt{a_1}y} + \varepsilon e^{nt}\left\{e^{-\sqrt{a_2}y}\right\}$ (21)

The skin friction at the plate in terms of amplitude and phase angle is given by

$\tau = \frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_0}{\partial y}$, at y = 0

$\tau = \left[-(1 - b_3 - b_4)\sqrt{a_5} - b_3\sqrt{a_3} - b_4\sqrt{a_1}\right] + \varepsilon e^{nt}\left[(b_5 - b_6)\sqrt{a_8} - b_5\sqrt{a_4} - b_6\sqrt{a_2}\right]$ (22)

The rate of heat transfer. That is heat flux at the $N_u$in terms of amplitude and phase is given by $N_u = -\left[\frac{\partial T_0}{\partial y} + \varepsilon e^{nt}\frac{\partial T_1}{\partial y}\right]$ at y = 0

$N_u = \left[(1 - b_3)\sqrt{a_3} + b_1\sqrt{a_1}\right] + \varepsilon e^{nt}\left[(1 - b_2)\sqrt{a_4} + b_2\sqrt{a_2}\right]$ (23)

The mass transfer coefficient, that is the Sherwood numberS_h at the plate in terms of amplitude and phase is given by

$S_h = -\left[\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right]$ at y = 0

$S_h = \left[\sqrt{a_1}\right] + \varepsilon e^{nt}\left[\sqrt{a_2}\right]$ (24)

4 Results and Discussions:

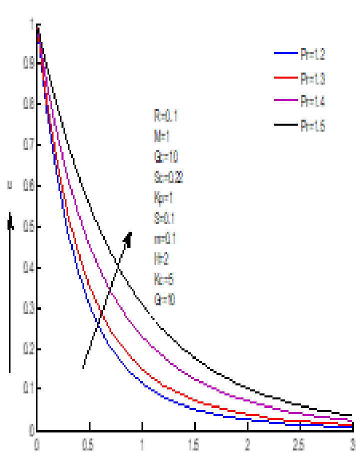

Fig. 2: Effect of Pr on Velocity

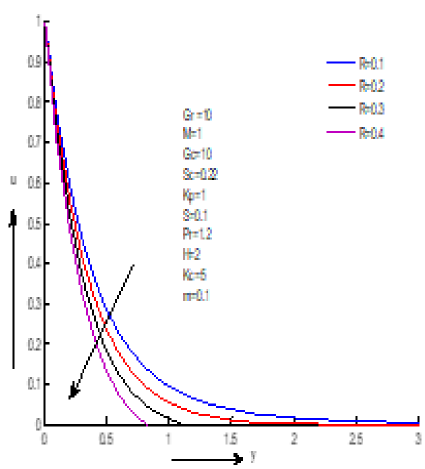

Fig. 3: Effect of R on Velocity

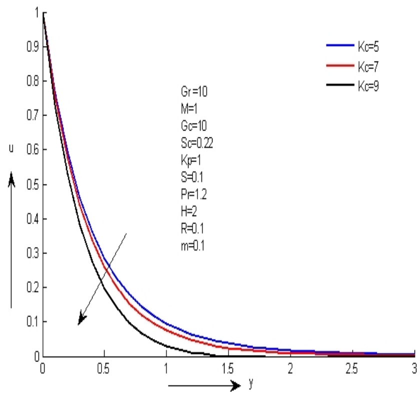

Fig. 4: Effect of Kc on Velocity

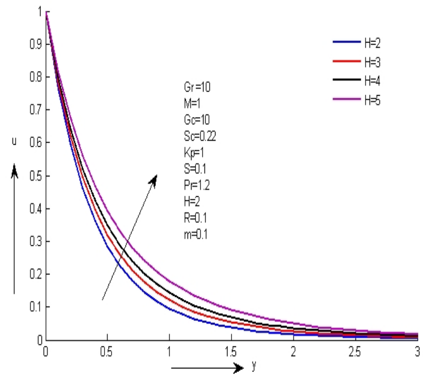

Fig. 5: Effect of H on Velocity

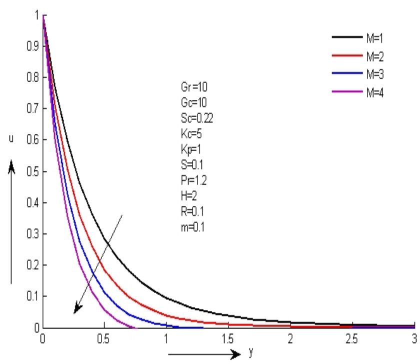

Fig. 6: Effect of M on Velocity

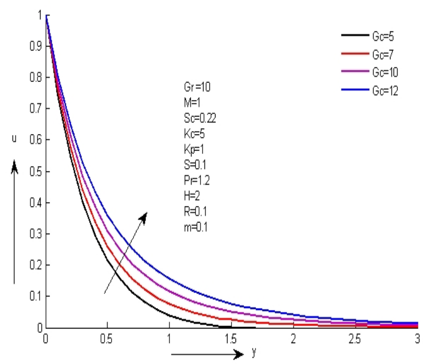

Fig. 7: Effect of Gc on Velocity

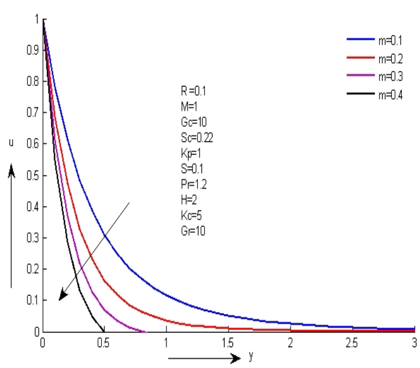

Fig. 8: Effect of β on Velocity

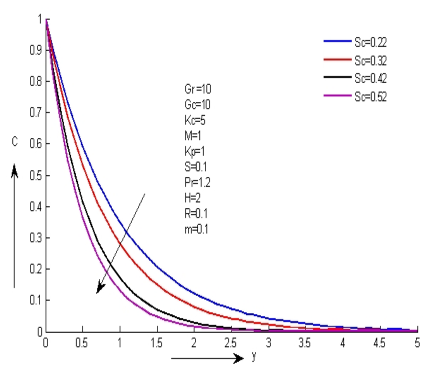

Fig. 9: Effect of Sc on Velocity

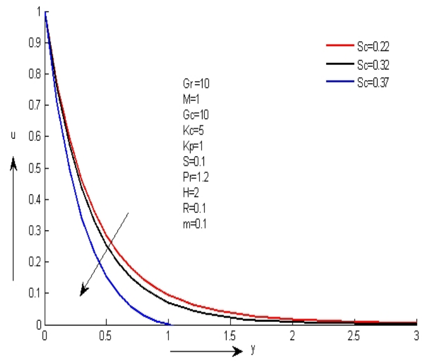

Fig. 10: Effect of Sc on Velocity

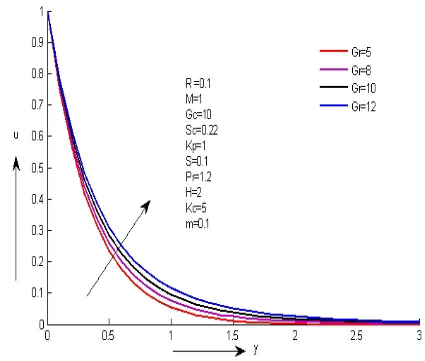

Fig. 11: Effect of Gr on Velocity

In order to assess the effects of the dimensionless thermo physical parameters on the regime calculations have been carried out on velocity field, temperature field and concentration field for varies physical parameters like magnetic parameter, Prandtl parameter, Grashof number, modified Grashof number, chemical reaction parameter etc. The results are represented through graphs in figures 1 to 10. From figure 1 shows that velocity increases for the increasing values of Pr number. From figure 2 it is observed that velocity decreases with the increasing values of R. From figure 3 shows that velocity decreases for increasing values of chemical reaction parameter. From figure 4 displays that velocity increases in chemical reaction. Figure 5, displays the velocity profiles for varies values of magnetic parameter M. It is observed that the velocity decreases with an increase in M. This is due to fact that the applied magnetic field which acts as retarding force that condenses the momentum boundary layer. From figure 6, it is displays that the velocity increases with an increases in Gc number. From figure 7 it is noticed that the velocity decreases with an increase in m. Effect of Schmidt number parameter on concentration is presented in figure 8, which witnesses that concentration decreases as the values of Sc increase. A similar effect is noticed from figure 9, in the presence of Schmidt number where velocity decreases. Figure 10, depicts the effects of Grashof number on velocity, from this figure it is observed that the velocity increases with an increase in Gr.

Tab. 14: Comparison of present results with previously published results.

Sc	**Results of Harron et al. [7]**	**Present results t**
0.22	2.1592	2.091357
0.60	1.9614	1.951142
0.78	1.9299	1.904455
0.96	1.9006	1.899954

5 Conclusions:

The present investigation excellently helps to improve the heat and mass transfer effects in unsteady MHD free convection flow of Casson fluid past on a porous plate. It is mainly observed from the investigation in the presence of the heavier species with low conductivity in fluid flow results the reduction the flow rate with in the boundary layer. It is also observed that an increment in the elasticity of the fluid results the decrease the velocity of fluid flow. It is finally concluded that the impact of Casson parameter leads to reduce the fluid velocity of flow.The velocity profile decreases with increasing the Casson parameter.The concentartion decreases as the values of schmidt number increases.

6 Appendix:

$a_1 = S_c K_c`$, $a_2 = (K_c + \frac{n}{4})S_c$ $a_3 = P_r H$, $a_4 = (H + \frac{n}{4})P_r$, $a_5 = (M^2 + \frac{1}{K_P})/(1 + \frac{1}{\beta})$,$a_6 = -Gr/(1 + \frac{1}{\beta})$,$a_7 = -Gc/(1 + \frac{1}{\beta})$,$a_8 = (M^2 + \frac{1}{K_P} + \frac{n}{4})/1 + (\beta)$, ,$b_1 = \frac{-RP_r}{a_1 - a_3}$, $b_2 = \frac{-RP_r}{a_2 - a_4}$ $b_3 = \frac{a_6(1-b_1)}{a_3 - a_5}$,$b_4 = \frac{a_6 b_1 - a_7}{a_3 - a_5}$, $b_5 = \frac{a_6(1-b_2)}{a_4 - a_8}$, $b_6 = \frac{a_6 b_2 + a_7}{a_2 - a_8}$

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