RADIATION, RADIATION ABSORPTION, CHEMICAL REACTION AND HALL EFFECTS ON UNSTEADY FLOW PAST AN ISOTHERMAL VERTICAL PLATE IN A ROTATING FLUID WITH VARIABLE MASS DIFFUSION WITH HEAT SOURCE

D. Chenna Kesavaiah[1], P. Govinda Chowdary[2], G. Rami Reddy[3], Dr. Nookala Venu[4]

[1, 2]Department of Basic Sciences & Humanities, Vignan Institute of Technology and Science, Deshmukhi (V), Pochampally (M), Yadadri-Bhuvanagiri (Dist), TS-508284, India
Email: chennakesavaiah@gmail.com & Email: chowdary.ratp@gmail.com

[3]Department of Mathematics, Malla Reddy Engineering College (Autonomous), Dulapally (V), Kompally (M), Medchal Malkajgiri (Dist), TS-500100, India

[4]Department of Electronics and Communication Engineering,
Balaji Institute of Technology and Science (Autonomous), Narsampet, Warangal, TS -506331, India
Email: venunookala@gmail.com

Abstract

The main objective of this paper is the unsteady MHD free convection heat and mass transfer for a heat generation/absorption with radiation absorption in the presence of a reacting species over an isothermal vertical plate has received little attention. Hence the main objective of this paper is to investigate the effects of thermal radiation, chemical reaction, heat source of an electrically conducting fluid past an isothermal vertical porous plate subjected to variable suction. The mathematical model, derived from the Navier-Strokes equation was reduced to a system of coupled partial differential equation for velocity, temperature and concentration using Boussinesq's approximation. The dimensionless governing equations are tackled using the usual perturbation technique. Also, the effects of velocity, temperature and concentration fields were intercepted for various physical parameters with the help of graphs.

Keywords: Radiation, Chemical reaction, Radiation absorption, Isothermal plate, Heat and Mass transfer

DOI Number: 10.14704/nq.2022.20.11.NQ66077 **NeuroQuantology 2022; 20(11): 800-815**

INTRODUCTION

Convection flows in porous media has gained significant attention in recent years because of their importance in engineering applications such as geothermal systems, solid matrix heat exchangers, thermal insulations, oil extraction and store of nuclear waste materials. These can also be applied to underground coal gasification, ground water hydrology, wall cooled catalytic reactors, energy efficient drying processes and natural convection in earth's crust. In view of the above (Pop and Watanabe, 1994) explained in detailed hall effects on magnetohydrodynamic free convection about a semi infinite vertical flat plate, (Chenna Kesavaiah et. al, 2021) expressed Radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (Vajravelu and Hadjinicolaou, 1997) illustrated the convective heat transfer in an electrically conducting fluid at a stretching surface with uniform free stream, (Rami Reddy et. al, 2021): Hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, (Chenna Kesavaiah and Venkateswarlu, 2020) has been considered chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al, 2019) studied the radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) motivated study on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Abel et. al, 2001): Convective heat and mass transfer in a viscoelastic fluid flow through a porous medium over a stretching sheet. (Mallikarjuna Reddy et. al, 2018) observed that the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (Salem and Abd El-Aziz, 2008) the effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption, (Chenna Kesavaiah and Sudhakaraiah, 2014) studied the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption,

Convective flows with simultaneous heat and mass transfer under the influence of a magnetic field and chemical reaction arise in many transport processes both naturally and artificially in many branches of science and engineering applications. This phenomenon plays an important role in the chemical industry, power and cooling industry for drying, chemical vapour deposition on surfaces, cooling of nuclear reactors and petroleum industries. Natural convection flow occurs frequently in nature. It occurs due to temperature differences, as well as due to concentration differences or the combination of these two, for example in atmospheric flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference. Some of the authors considered (Rajaiah et. al, 2015) has been studied chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium, (Chamkha and Khaled, 2000) extended the work on similarity solutions for hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through a porous medium, (Chenna Kesavaiah et. al, 2013) viewed the natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Chenna Kesavaiah and Satyanarayana, 2013) explained on MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (Nield and Bejan, 1999) given detailed information on convection in porous media, (Chenna Kesavaiah et. al, 2013) illustrated the radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, (Ibrahim et. al, 2008) the study on effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction, (Karunakar Reddy et. al, 2013) abstracted on MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, (Stanford Shateyi and Sandile Motsa, 2011) expressed the detailed information on the effect of unsteady magnetohydrodynamic convective heat and mass transfer past an infinite vertical plate in a porous medium with thermal radiation, heat generation/absorption and chemical reaction, (Ch Kesavaiah et. al, 2013) effectively studied the effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium,

When technological processes take place at higher temperatures thermal radiation heat transfer has become very important and its effects cannot be neglected. The effect of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes a very important for the design of the pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors, and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. (Rajaiah and Sudhakaraiah, 2015) expressed on unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, (Ch Kesavaiah et. al, 2012) illustrated on the radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, (Ibrahim et. al, 2008) motivated study on the effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction, (Satyanarayana et. al, 2011): Viscous dissipation and thermal radiation effects on an unsteady MHD convection flow past a semi-infinite vertical permeable moving porous plate, (Mohamed, 2009) has been considered Double-Diffusive convection radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects, (Ch Kesavaiah et. al, 2011) expressed the effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, (Haranth and Sudhakaraiah, 2015) motivated study on viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, (Chenna Kesavaiah, 2021) has been considered the MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, (Ali, 2007): The effect of lateral mass flux on the natural convection boundary layers induced by a heated vertical plate embedded in a saturated porous medium with internal heat generation, (Cussler, 1988): Diffusion mass transfer in fluid systems, (Das et. al, 1994) illustrated the effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction, (Anjalidevi and Kandasamy, 1999) the effects of chemical reaction, heat and mass transfer on laminar flow along a semi infinite horizontal plate, (Seddeek, 2007) motivated study on the effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation,

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Heat generation effects may alter the temperature distribution and this in turn can affect the particle deposition rate in nuclear reactors, electronic chips and semi conductor wafers. Although exact modelling of internal heat generation or absorption is quite difficult, some simple mathematical models can be used to express its general behaviour for most physical situations. Heat generation or absorption can be assumed to be constant, space-dependent or temperature-dependent. (Cortell, 2008) observed the effects of viscous dissipation and

radiation on the thermal boundary layer over a nonlinearly stretching sheet,

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In spite of all the previous studies, the unsteady MHD free convection heat and mass transfer for a heat generation/absorption with radiation absorption in the presence of a reacting species over an infinite permeable plate has received little attention. Hence the main objective of this paper is to investigate the effects of thermal radiation, chemical reaction, heat source of an electrically conducting fluid past an infinite vertical porous plate subjected to variable suction. The mathematical model, derived from the Navier-Strokes equation was reduced to a system of coupled partial differential equation for velocity, temperature and concentration using Boussinesq's approximation. The dimensionless governing equations are tackled using the usual perturbation technique. Also, the effect of velocity, temperature and concentration fields were intercepted for various physical parameters like Hall parameter, Hartmann number, thermal Grashof number, mass Grashof number, Schmidt number, chemical reaction parameter and rotation parameter.

MATHEMATICAL FORMULATION

An unsteady hydromagnetic flow of fluid past an infinite isothermal vertical plate with varying mass diffusion exists. The fluid and the plate rotate in unison with a uniform angular velocity Ω' about the $z'-$ axis normal to the plate. Initially the fluid is assumed to be at rest and surrounds an infinite vertical plate with temperature T'_∞ and concentration C'_∞. A magnetic field of uniform strength B_0 is transversely applied to the plate. The $x'-$axis is taken along the plate in the vertically upward direction and the $z'-$axis is taken normal to the plate. The physical model of the problem shown in fig. (1). At time $t'>0$, the plate and the fluid are at the same temperature T'_∞ in the stationary condition with concentration level C'_∞ at all the points. At time $t'>0$, the plate is subjected to a uniform velocity $u=u_0$ in its own plane against the gravitational force. The plate temperature and concentration level near the plate are raised uniformly and are maintained constantly thereafter. All the physical properties of the fluid are considered to be constant except the influence of the body force term. Then under the usual Boussinesq's approximation the unsteady flow equations are momentum equation, energy equation, and mass equation respectively.

Equation of Momentum:

$$\frac{\partial u'}{\partial t'} - 2\Omega' v = \nu \frac{\partial^2 u}{\partial z^2} - \frac{1}{\rho}\frac{\partial \rho}{\partial x} + g + \frac{B_0}{\rho} j_y \quad (1)$$

$$\frac{\partial v}{\partial t} - 2\,\Omega'\, u = \nu\,\frac{\partial^2 v}{\partial z^2} - \frac{B_0}{\rho} j_x \quad (2)$$

Equation of Energy

$$\rho c_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial z^2} - \frac{\partial q}{\partial z} - Q_0\left(T' - T'_\infty\right) + Q_l'\left(C' - C'_\infty\right) \quad (3)$$

Equation of diffusion

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C}{\partial z^2} - Kr'\left(C' - C'_\infty\right) \quad (4)$$

As, no large velocity gradient here, the viscous term in equation (1) vanishes for small and hence for the outer flow, beside there is no magnetic field along $x-$direction gradient, so this results in,

$$0 = D\frac{\partial \rho}{\partial x} - p_\infty g \quad (5)$$

By eliminating the pressure term from equation (1) and (5), we obtain

$$\frac{\partial u'}{\partial t'} - 2\Omega' v = \nu \frac{\partial^2 u}{\partial z^2} - \frac{1}{\rho}\frac{\partial \rho}{\partial x} + \left(\rho_\infty - \rho\right) g + \frac{B_0}{\rho} j_y \quad (6)$$

The Boussinesq approximation gives

$$\rho_\infty - \rho = \rho_\infty \beta\left(T' - T'_\infty\right) + \rho_\infty \beta\left(C' - C'_\infty\right) \quad (7)$$

On using (7) in the equation (6) and noting that ρ_∞ is approximately equal to 1, the momentum equation reduces to

$$\frac{\partial u'}{\partial t'} - 2\Omega' v = \nu \frac{\partial^2 u}{\partial z^2} + \frac{B_0}{\rho} j_y + g\;\beta\left(T' - T'_\infty\right) + g\;\beta^*\left(C' - C'_\infty\right) \quad (8)$$

The generalized Ohm's law with Hall currents is taken into account and ion – slip and thermo-electric

$$j+\frac{\omega \mathrm{T}_e}{B_0}(j\times B)=\sigma\left[E+q\times B\right] \qquad (9)$$

The equation (9) gives

$$j_x - mj_y = \sigma v B_0 \qquad (10)$$

$$j_y - mj_x = \sigma u B_0 \qquad (11)$$

where $m=\omega_e \mathrm{T}_e$ is Hall parameter;

Solving (10) and (11) for j_x and j_y, we have

$$j_x=\frac{\sigma B_0}{\left(1+m^2\right)}(v-mu) \qquad (12)$$

$$j_y=\frac{\sigma B_0}{\left(1+m^2\right)}(u-mv) \qquad (13)$$

where B_0 – Imposed magnetic field, m – Hall parameter, v – Kinematic viscosity, Ω_z – Component of angular viscosity, Ω – Non-dimensional angular velocity, J_z – component of current density j, ρ – Fluid density, σ – Electrical conductivity, t' – Time, μ – Coefficient of viscosity, T – Temperature of the fluid near the plate, T_w – Temperature of the plate, θ – Dimensionless temperature, T_∞ – Temperature of the fluid far away from the plate, C – Dimensionless concentration, κ – Thermal conductivity, β – Volumetric coefficient of thermal expansion, β^* – Volumetric coefficient of expansion with concentration, C' – Species concentration in the fluid, C_w – Wall concentration, C_∞ – Concentration for away from the plate, t – Non-dimensional time (u,v,w) – Components of velocity field F, (U,V,W) – Non dimensional velocity components, (x,y,z) – Cartesian co-ordinates.

On the use of (12) and (13), the momentum equations (8) and (2) become

$$\frac{\partial u'}{\partial t'}=v\frac{\partial^2 u}{\partial z^2}+2\Omega' v - \frac{\sigma\mu_e^2 H_0^2}{\rho\left(1+m^2\right)}(u+mv) + g\ \beta\left(T'-T'_\infty\right)+g\ \beta^*\left(C'-C'_\infty\right) \qquad (14)$$

$$\frac{\partial v}{\partial t'}=v\frac{\partial^2 u}{\partial z^2}+2\Omega v-\frac{\sigma\mu_e^2 H_0^2}{\rho\left(1+m^2\right)}(v-mu) \qquad (15)$$

$$\rho c_p\frac{\partial T'}{\partial t'}=k\frac{\partial^2 T'}{\partial z^2}-\frac{\partial q}{\partial z}-Q_0\left(T'-T'_\infty\right) + Q_l'\left(C'-C'_\infty\right) \qquad (16)$$

$$\frac{\partial C'}{\partial t'}=D\frac{\partial^2 C'}{\partial z^2}-Kr'\left(C-C'_\infty\right) \qquad (17)$$

Due to small Coriolis force, the second term on the right side of the equation (14) and (15) comes into existence.

The boundary conditions are given by:

$$u=0,\quad T=T^*_\infty,\ \ C=C^*_\infty,\ \ \forall\ \ y,t'\le 0$$

$$t'>0:\ \left.\begin{array}{l} u=u_0, T\to T_w, \\ C'=C'_\infty+\left(C'_w-C'_\infty\right)\end{array}\right\}\quad at\quad y=0$$

$$u\to 0, T\to T_\infty, C'\to C'_\infty \quad at\ \ y\to\infty$$

$$\left.\begin{array}{l} u=0,\quad T=T \\ C=C_\infty,\ v=0\end{array}\right\}\ \ \forall\ \ y,t'\le 0 \qquad (18)$$

$$\left.\begin{array}{l} u\to u, T\to T_w \\ C'=C'_w v=0\quad at\quad z=0\end{array}\right\}\ \forall\ t'\le 0 \qquad (19)$$

The dimensionless quantities are introduced as follows:

$$U=\frac{u}{u_0},\ V=\frac{v}{u_0},\ \ t=\frac{t'u_0^2}{v},\ \ \ Z=\frac{zu_0^2}{v^2}$$

$$Gr=\frac{g\beta v\left(T_\omega-T_\infty\right)}{u_0^{\ 3}},M^2=\frac{\sigma\mu_e^2H_0^{\ 2}v}{2\rho u_0^{\ 2}}$$

$$Gc=\frac{g\beta^* v\left(C'_\omega-C'_\infty\right)}{u_0^{\ 3}},\qquad \Omega=\Omega\frac{v}{u_0^2}\quad (20)$$

$$\Pr=\frac{\mu c_p}{\kappa},\ Kr=\frac{Kr'v}{u_0^2},\ Q=\frac{Q_0 v}{\rho C_p u_0^{\ 2}}$$

$$Q_l=\frac{Q_l' v}{\rho C_p u_0^{\ 2}},\qquad R=\frac{16a^*\sigma v^2T_\infty^3}{k\,u_0^2}$$

where $Sc-$ Schmidt number, $Gr-$Thermal Grashof number, $Gc-$Mass Grashof number, $\Pr-$Prandtl number, $M-$Hartman number, $Kr-$Chemical reaction parameter, $R-$Radiation parameter, Q_l-Radiation absorption parameter, $Q-$heat source parameter.

Together with the equation (1), (2), (3) and (4), boundary conditions (18), (19), using (20), we have

$$\frac{\partial U}{\partial t}=\frac{\partial^2 U}{\partial Z^2}+2V\left(\Omega-\frac{2m^2}{1+m^2}\right)+\frac{2m^2}{1+m^2}U+Gr\ \theta+Gc\ C \qquad (21)$$

$$\frac{\partial V}{\partial t}=\frac{\partial^2 V}{\partial Z^2}-2U\left(\Omega+\frac{2m^2}{1+m^2}\right)+\frac{2m^2}{1+m^2}V \qquad (22)$$

with the boundary conditions

$$\left.\begin{array}{ll}U=0, & \theta=0\\ C=0, & v=0\end{array}\right\}\quad \forall\ \ Z,t\le 0$$

$$\left.\begin{array}{ll}U\to 1, & \theta\to 1\\ C\to t, & v\to 0\end{array}\right\}\quad \forall\quad t>0 \qquad (23)$$

$$\left.\begin{array}{ll}U\to 0, & \theta\to 0,\\ C\to 0, & V\to 0\end{array}\right\}\quad \forall\quad t>0 \qquad (24)$$

Now equations (21), (22) and the boundary conditions (23), (24) can be combined to give:

$$\frac{\partial F}{\partial t}=\frac{\partial^2 F}{\partial Z^2}-F\ a+Gr\ \ \theta+Gc\ C \qquad (25)$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial Z^2}-\frac{1}{\Pr}\left(R+Q\right)\ \theta-\frac{1}{\Pr}Q_l\ C \qquad (26)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial Z^2}-Kr\ C \qquad (27)$$

where $F=U+iV$ and

$$a=2\left[\frac{M^2}{\left(1+m^2\right)}+i\left(\Omega-\frac{M^2m}{\left(1+m^2\right)}\right)\right]$$

In this study the value of (rotation parameter) is taken to be $\Omega-\frac{M^2m}{\left(1+m^2\right)}$, as a result of this the transverse velocity vanishes

with the boundary conditions

$$\begin{array}{l}F=0,\ \ \theta=0,\ \ C=0\ \ \forall\ \ Z,t\le 0\\ F\to 1,\ \ \theta\to 1,\\ \left.\begin{array}{l}C\to t,\ \ at\ Z=0\quad \forall\qquad t>0\\ F\to 0,\ \ \theta\to 0\end{array}\right\}\\ C\to 0,\quad at\ Z\to\infty\quad \forall\qquad t>0\end{array} \qquad (28)$$

Method of Solution

Equation (25) – (27) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (28). However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{array}{l}F\left(z,t\right)=F_0\left(z\right)e^{i\omega t}\\ \theta\left(z,t\right)=\theta_0\left(z\right)e^{i\omega t}\\ C\left(z,t\right)=C_0\left(z\right)e^{i\omega t}\end{array} \qquad (29)$$

Substituting (29) in Equation (25) – (27) and equating the harmonic and non – harmonic terms, we obtain

$$F_0''-\beta_3^2F_0=-Gr\,\theta_0-GmC_0 \qquad (30)$$

$$\theta_0''-\beta_2^2\theta_0=0 \qquad (31)$$

$$C_0'' - \beta_1^2 Sc\, C_0 = 0 \qquad (32)$$

The corresponding boundary conditions can be written as

$$\begin{aligned} &F_0 = 1,\ \theta_0 = 1,\ \ C_0 = t, \qquad at\ Z = 0 \\ &F_0 = 0,\ \theta_0 = 0, C_0 = 0, \qquad as\ Z \to \infty \end{aligned} \qquad (33)$$

Solving the equations (30) – (32) under the boundary condition (33), we get the solution for fluid velocity; temperature; concentration is expressed below using perturbation method:

$$F_0 = Z_1 e^{-\beta_2 y} + Z_2 e^{-\beta_1 y} + Z_3 e^{-\beta_3 y}$$

$$\theta_0 = B_2 e^{-\beta_2 y}$$

$$C_0 = t\ e^{-\beta_1 y}$$

In view of the above equation (29) becomes

$$F(z,t) = \left\{ Z_1 e^{-\beta_2 y} + Z_2 e^{-\beta_1 y} + Z_3 e^{-\beta_3 y} \right\} e^{i\omega t}$$

$$\theta(z,t) = \left\{ B_2 e^{-\beta_2 y} \right\} e^{i\omega t}$$

$$C(z,t) = \left\{ t\ e^{-\beta_1 y} \right\} e^{i\omega t}$$

Coefficient of Skin-Friction

The coefficient of skin-friction at the vertical porous surface is given by

$$C_f = \left(\frac{\partial F}{\partial Z} \right)_{z=0} = -\left(Z_1 \beta_2 + Z_2 \beta_1 + Z_3 \beta_3 \right)$$

Coefficient of Heat Transfer

The rate of heat transfer in terms of Nusselt number at the vertical porous surface is given by

$$Nu = \left(\frac{\partial T}{\partial Z} \right)_{z=0} = -B_2 \beta_2$$

Sherwood number

$$Sh = \left(\frac{\partial C}{\partial Z} \right)_{Z=0} = t\ \beta_1$$

RESULTS AND DISSCUSSIONS

Final results are shown graphically for various parameters like thermal Grashof number(Gr), rotation parameter(Ω), modified Grashof number(Gc), Prandtl number$(\Pr)$, Schmidt number(Sc), Chemical reaction parameter (Kr), Hartman number (M), Radiation parameter (R), Radiation absorption parameter (Q_l), heat source parameter (Q) on the velocity, temperature and concentration profiles can be analyzed from Fig. (2) – (17). The influence of thermal buoyancy force parameter (Gr) on the axial velocity shows in Fig. (2). As can be seen from this figure, the axial velocity profile increases with increases in the values of the thermal buoyancy. We actually observe that the axial velocity overshoot in the boundary layer region. Buoyancy force acts like a favourable pressure gradient which accelerates the fluid within the boundary layer therefore the solutal buoyancy force parameter (Gc) has the same effect on the velocity as Gr. From this figure we observe that the effect of magnetic field is to decrease the value of velocity profile throughout the boundary layer which results in the thinning of the boundary layer thickness. The influences of the Schmidt number (Sc) on the axial velocity profiles are plotted in Fig. (3) respectively. It is noticed from this figure that, the axial velocity decrease on increasing Sc. The Schmidt number embodies the ratio of the momentum to the mass diffusivity. The Schmidt number therefore quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic (velocity) boundary layer. Fig. (4) display the effect of magnetic field parameter or Hartmann number (M) on axial velocity. It is seen from these figures that the axial velocity increases when M increases. That is the axial velocity fluid motion is retarded due to application of transverse magnetic field. This phenomenon clearly agrees with the fact that Lorentz force that appears due to interaction of the magnetic field and fluid axial velocity resists the fluid motion. The influence of the hall parameter (m) on axial velocity profiles is as shown in Figs. (5) respectively. It is observed from these figures that the axial velocity profiles increase with an increase in the hall parameter m. This is because, in general, the Hall currents reduce the resistance offered by the Lorentz force. This means that Hall currents have a tendency to increase the fluid velocity components. Fig. (6) illustrates the influence of rotation parameter (Ω) on the velocity. Physically, the presence of rotation parameter effect has the tendency in resulting in a net reduction in the flow velocity. This behaviour is seen from this figure in which the velocity decreases as Ω increases. Fig. (7) illustrates the behaviour of axial velocity profiles for different values of the chemical reaction parameter (Kr). It is pertinent to mention that $(Kr > 0)$ corresponds to a destructive chemical reaction. It can be seen from the profiles that the axial velocity increases in the degenerating chemical reaction in the boundary layer. This is due to the fact that the increase in the rate of chemical reaction rate leads to thinning of a momentum in a boundary layer in degenerating chemical reaction. It can be seen from the profiles that the cross flow axial velocity reduces in the degenerating chemical reaction. It is evident from Fig. (8) that, the thermal radiation parameter (R) leads to increases in the axial velocity with increasing values of thermal radiation parameter. Thus, the Fig. (8) are in excellent agreement with the laws of Physics. Thus as R increases, the axial velocity increases. Now, from this figure, it may be inferred that radiation has a more significant effect on temperature than on velocity. Thus, the thermal radiation does not have a significant effect on the velocities but produces a comparatively more pronounced effect on the temperature of the mixture. It is noticed form Fig. (9) that the effects of rotation on the axial respectively. It is evident from this figure that, axial velocity increases on increasing in reaction parameter (K). This implies that rotation retards fluid flow in the axial velocity flow direction and accelerates fluid flow in the axial velocity flow direction in the boundary layer region. The hydrodynamic boundary layer decreases as the heat source (Q) effects increase. The effects of on the velocity field are shown in Fig (10). It is clearly seen from this figure that the velocity profiles decrease monotonically with the increase of suction parameter indicating the usual fact that suction stabilizes the boundary layer growth. The effect of increasing the value of the radiation absorption parameter (Q_l) on the velocity is shown in Fig. (11). we observe in this figure that increasing the value of the radiation absorption parameter the axial velocity decreases. The influence of Prandtl number, radiation parameter, heat source parameter and radiation absorption on the temperature distribution is respectively, shown on Figs. (12) - (15).

Fig. (12) Shows the temperature profile for different values of Prandtl number $(\Pr)$. It is observed that temperature increases with decrease in values of Prandtl number and also heat transfer is predominant in air when compared to water. Fig. (13) indicates that effect of radiation parameter (R) on the temperature profiles. It is deduced that temperature profiles decrease of the fluid near the plate decrease when radiation parameter are increased. Physically, thermal radiation causes a fall in temperature of the fluid medium and thereby causes a fall in kinetic energy of the fluid particles. This results in a corresponding decrease in fluid velocities. The effect of heat source parameter (Q) on the temperature profile is shown on Fig (14). It is seen from this figure that the effect of heat source parameter (Q) is to decrease temperature in the boundary layer as the radiated heat is absorbed by the fluid which in turn increases the temperature of the fluid very close to the porous boundary layer and its effect diminishes far away from the boundary layer. From Fig. (15) We observe that the effect of radiation absorption is to enhance heat transfer as thermal boundary layer thickness decreases with increase in the radiation absorption parameter. Figs. (l6) and (17) depict the influence of the non-dimensional chemical reaction parameter *γ* and the Schmidt number (Sc) on concentration profiles, respectively. From Fig. (16). the effect of chemical reaction parameter is very important in the concentration field. Chemical reaction increases the rate of interfacial mass transfer. Reaction reduces the local concentration, thus increases its concentration gradient and its flux. In Fig. (17) We see that the concentration profiles decrease with increasing values of the Schmidt number.

Conclusions:

The following main conclusions can be drawn from the present paper:

- Wall suction stabilizes the velocity, thermal as well as concentration boundary layer growth.
- Boundary layer flow attains minimum velocity values for large Hartmann numbers.
- Buoyancy parameter is to increase the velocity distribution in the momentum boundary layer.
- The presence of heat source effects cause reductions in the fluid temperature which resulted in decreases in the fluid velocity.
- The concentration decreases with increasing the chemical reaction parameter.
- Both the velocity and temperature profiles decrease with increasing values of radiation absorption parameter.
- These results might find wide applications in engineering, such as geothermal system, heat exchangers, and nuclear waste depositors.

APPENDIX

$$\beta_1^2 = \left(i\omega + Kr\right)Sc, \beta_2^2 = \left(i\omega \Pr + R + Q\right)$$

$$\beta_3^2 = \left(i\omega + Q\right), B_1 = -\frac{t Q_l}{\beta_1^2 - \beta_2^2}$$

$$B_2 = \left(1 - B_1\right), Z_1 = -\frac{B_2 Gr}{\beta_1^2 - \beta_3^2}$$

$$Z_2 = -\frac{t\ Gc}{\beta_1^2 - \beta_3^2}, Z_3 = \left(1 - Z_1 - Z_2\right)$$

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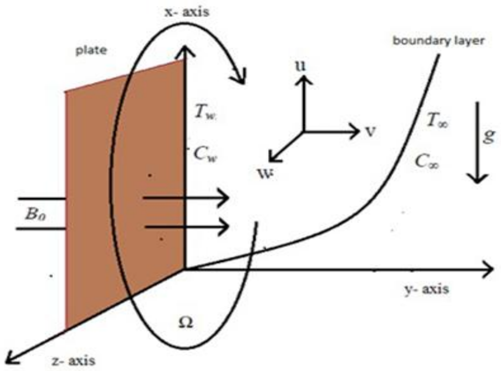


Fig. (1): The geometrical model of the problem

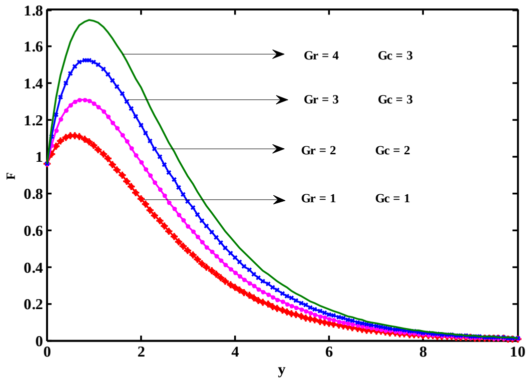


Fig. (2): Axial velocity profiles for different values of Gr, Gc

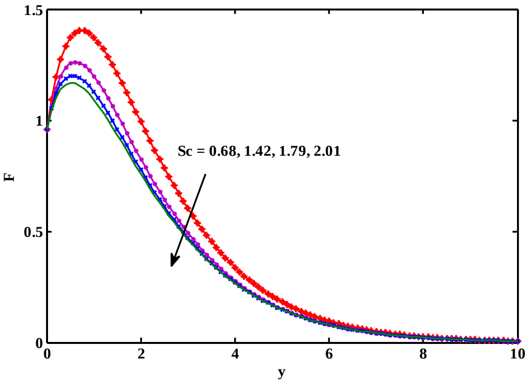


Fig. (3): Axial velocity profiles for different values of Sc

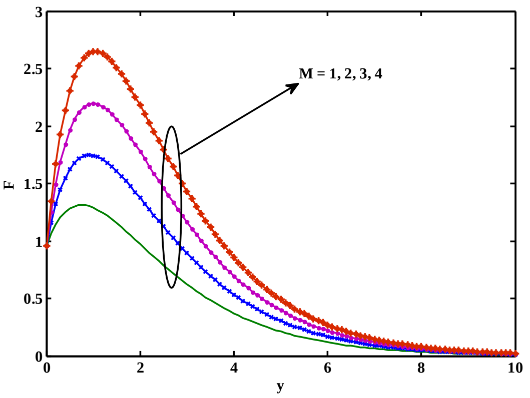


Fig. (4): Axial velocity profiles for M

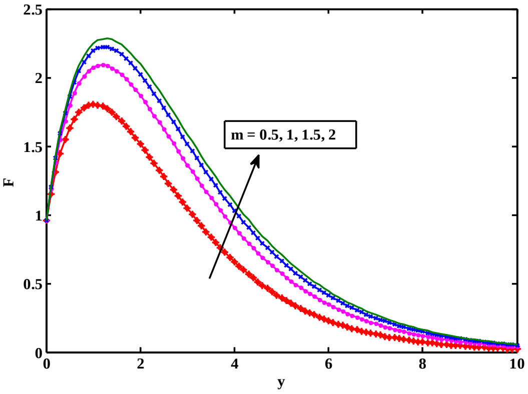


Fig. (5): Axial velocity profiles for m

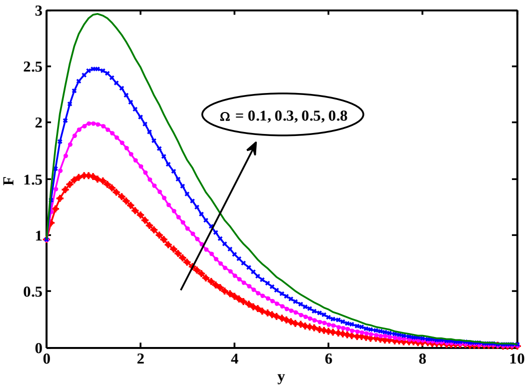


Fig. (6): Axial velocity profiles for Ω

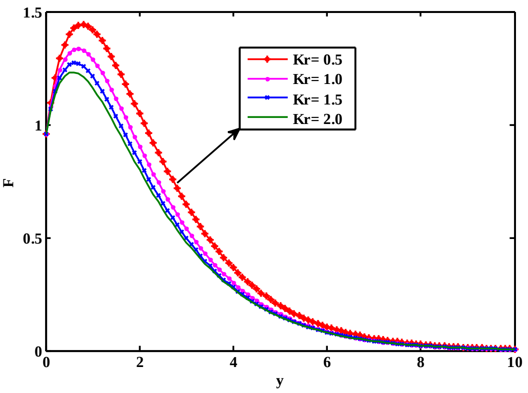


Fig. (7): Axial velocity profiles for Kr

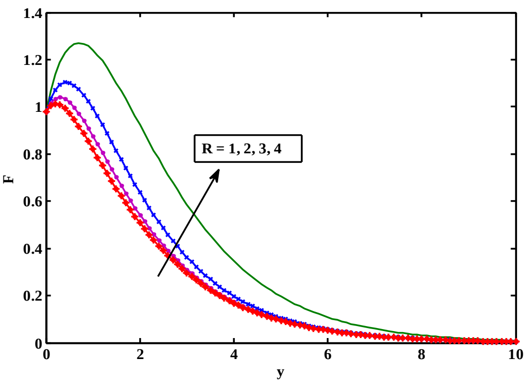


Fig. (8): Axial velocity profiles for R

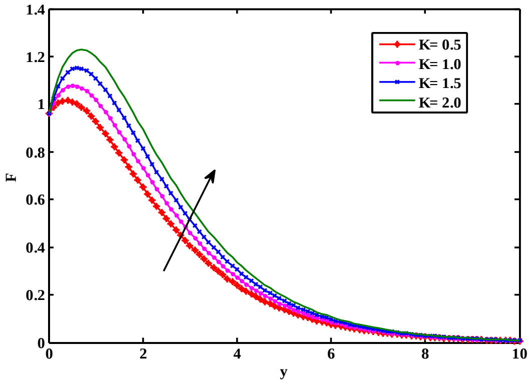


Fig. (9): Axial velocity profiles for K

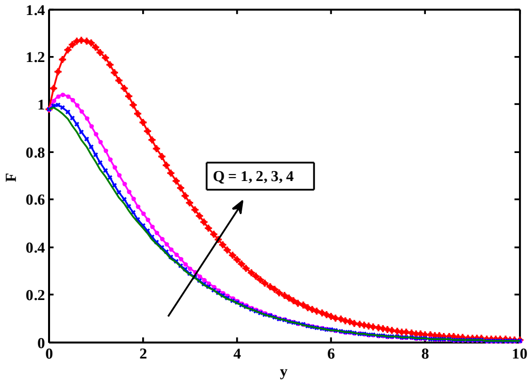


Fig. (10): Axial velocity profiles for Q

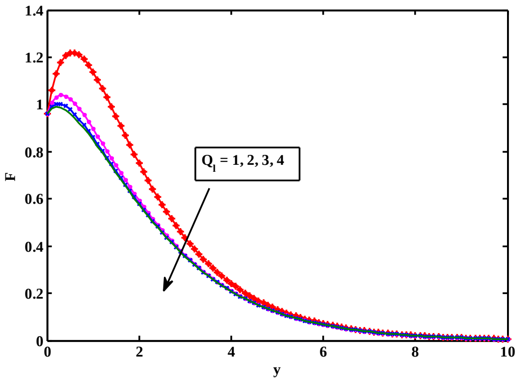


Fig. (11): Axial velocity profiles for Q_l

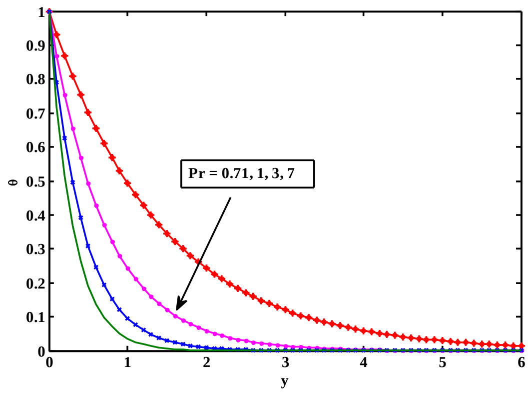


Fig. (12): Temperature profiles for Pr

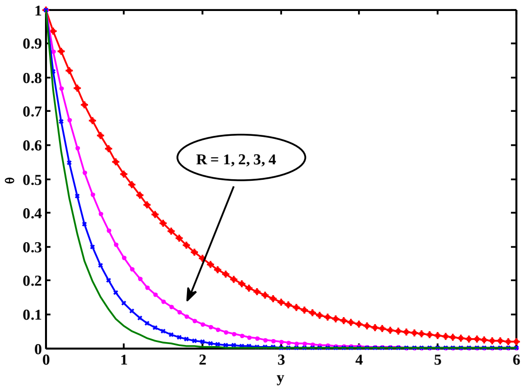


Fig. (13): Temperature profiles R

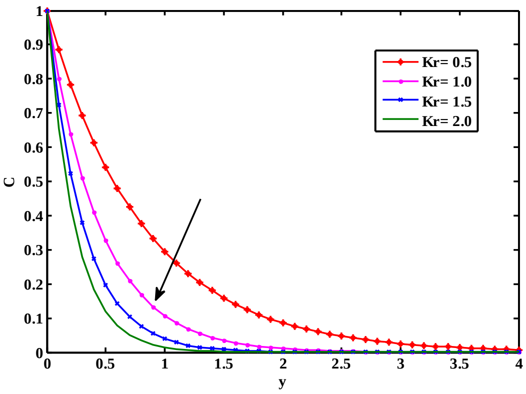


Fig. (16): Concentration profiles for Kr

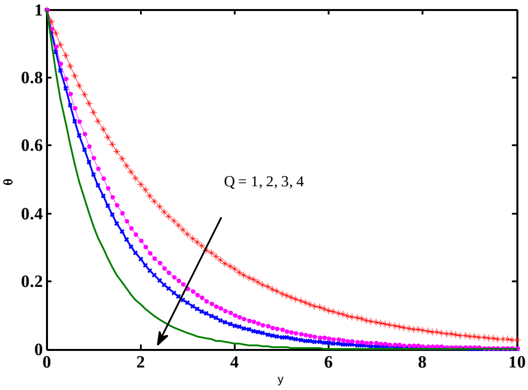
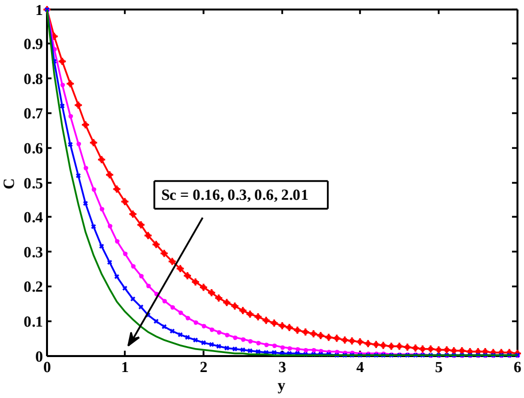


Fig. (14): Temperature profiles for Q



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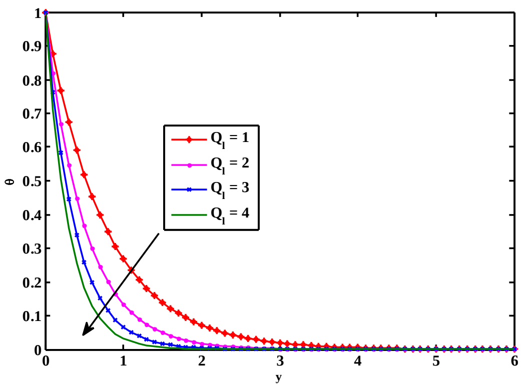

Fig. (15): Temperature profiles for Q_l