RADIATION AND MASS TRANSFER EFFECTS ON MHD MIXED CONVECTIVE FLOW FROM A VERTICAL SURFACE WITH HEAT SOURCE AND CHEMICAL REACTION

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ABSTRACT

The effects of radiation and mass transfer on MHD mixed convection flow of a vertical plate with heat source/heat absorption and chemical reaction has been is discussed. The governing equations are transformed into a system of nonlinear ordinary differential equations by using suitable perturbation technique. Graphical results for the velocity, temperature and concentration profiles based on the numerical solutions are presented and discussed. We also discuss the effects of various parameters on the skin-friction coefficient and the rate of heat and mass transfer at the surface.

Keywords: Mass transfer, Radiation, MHD, Chemical reaction and Heat absorption

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INTRODUCTION

For many mixed flows of practical importance in nature as well as in many engineering devices, the environment is thermally stratified. The discharge of hot fluid into enclosed regions often results in a stable thermal stratification with lighter fluid overlying denser fluid. The thermal stratification effects of heat transfer over a porous wedge are of interest in polymer extrusion processes, where the object, after passing through a die, enters the fluid for cooling below a certain temperature. Transport processes in porous media play a significant role in various applications, such as geothermal engineering, thermal insulation, energy conservation, petroleum industries, solid matrix heat exchangers, chemical catalytic reactors, and underground disposal of nuclear waste materials. In many transport processes in nature and in industrial applications, the heat and mass transfer with variable viscosity is a consequence of buoyancy effects caused by the diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production and food processing. In nature, the presence of pure air or water is impossible. Some foreign mass may be presented either naturally or mixed with air or water. A large amount of research work has been reported in this field. Particularly, the study of heat and mass transfer with chemical reactions is of considerable importance in the chemical and hydrometallurgical industries. In view of the above (Chenna Kesavaiah et. al, 2021) Radiative MHD Walter’s Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (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) Chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al. 2019) 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) Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Mallikarjuna Reddy et. al. 2018): Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (Chenna Kesavaiah and Sudhakaraiah, 2014): Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Rajaiah et. al, 2015)Chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium.

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. Changes in fluid density gradients may be caused by non-reversible chemical reaction in the system as well as by the differences in molecular weight between values of the reactants and the products. Some of the authors considered (Chenna Kesavaiah et. al, 2013) Natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Chenna Kesavaiah and Satyanarayana, 2013) MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (Chenna Kesavaiah et. al, 2013) 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, (Karunakar Reddy et. al, 2013) MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, Ch Kesavaiah et. al, 2013) 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, (Rajaiah and Sudhakaraiah (2015) Unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, Ch Kesavaiah et. al. 2012): Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, 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.

Chemical reactions can be modelled as either homogeneous or heterogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. A homogeneous reaction is one that occurs uniformly throughout a given phase. On the other hand, a heterogeneous reaction takes place in a restricted area or within the boundary of a phase. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. For example, the formation of smog is a first order homogeneous reaction. Consider the emission of nitrogen dioxide from automobiles and other smoke-stacks. This nitrogen dioxide reacts chemically in the atmosphere with unburned hydrocarbons (aided by sunlight) and produces peroxyacetylnitrate, which forms an envelop which is termed photo-chemical smog. Ch Kesavaiah et. al, 2011) 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) Viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, Chenna Kesavaiah et. al, 2021) MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, Rajaiah et. al. 2014) Unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating In the presence of suction or injection, Chenna Kesavaiah et. al, 2019) Radiation effect to MHD oscillatory flow in a channel filled through a porous medium with heat generation, (Rajaiah and Sudhakaraiah 2015) Radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, Chenna Kesavaiah et. al, 2017): Analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation, (Beg et. al, 2009) Magnetohydrodynamic convection flow from a sphere to a non-Darcian porous medium with heat generation or absorption effects: network simulation.

The use of magnetic field that influences heat generation/absorption process in electrically conducting fluid flows has many engineering applications. For example, many metallurgical processes which involve cooling of continuous strips or filaments, which are drawn through a quiescent fluid. The properties of the final product depend to a great extent on the rate of cooling. 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. Aliakbar et. al, 2009) The influence of thermal radiation on MHD flow of Maxwellian fluids above stretching sheets, (Cortell, 2008) Effects of viscous dissipation and radiation on the thermal boundary layer over a nonlinearly stretching sheet, (Ibrahim et. al, 2008): 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, (Mahd, 2010): Effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in a porous media with variable viscosity, (Makinde and Aziz, 2010): MHD mixed convection from a vertical plate embedded in a porous medium with a convective boundary condition, (Mohamed, 2009): Double-Diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects, (Pal and Talukdar 2010) Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with a thermal radiation and chemical reaction, (Patil and Kulkarni, 2008) Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. (Salem and Abd El-Aziz, 2008) Effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption, (Samad and Mohebujjaman, 2009) MHD heat and mass transfer free convection flow among a vertical stretching sheet in presence of magnetic field with heat generation.

In spite of all the previous studies, the unsteady MHD mixed convection radiation and mass transfer for a heat generation/absorption with radiation absorption in the presence of a reacting species over a vertical plate has received little attention. Hence, the main objective of this chapter is to investigate the effects of radiation, chemical reaction, heat source/sink parameter of an electrically conducting fluid over vertical plate subjected to variable suction. The plate is assumed to be embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field.

FORMULATION OF THE PROBLEM

We consider the mixed convection flow of an incompressible and electrically conducting viscous fluid and radiating fluid such that x^*-axis is taken along the plate in upwards direction and y^*-axis is normal to it. A transverse constant magnetic field is applied i.e. in the direction of y^*- axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x^*. Let u^* and v^* be the components of velocity in x^* and y^* directions, respectively, taken along and perpendicular to the plate. The governing equations of continuity, momentum and energy for a flow of an electrically conducting fluid along a hot, non-conducting porous vertical plate in the presence of concentration and radiation is given by

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$v^* = -v_0 \,\text{(Constant)} \tag{2}$$

$$\frac{\partial p^*}{\partial y^*} = 0 \Rightarrow p^* \text{ is independent of } y^* \tag{3}$$

$$\rho\left(v^*\frac{\partial u^*}{\partial y^*}\right) = \mu\frac{\partial^2 u^*}{\partial y^{*2}} + \rho g\,\beta(T^* - T_\infty) + \rho g\beta^*(C^* - C_\infty) - \sigma B_0^2 u^* \tag{4}$$

$$\rho C_p\left(v^*\frac{\partial T^*}{\partial y^*}\right) = k\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial {q_r}^*}{\partial y^*} - Q_0\left(T^* - T_\infty\right) + Q_l^*\left(C^* - C_\infty\right) \tag{5}$$

$$v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - Kr^*\left(C^* - C_\infty\right) \qquad (6)$$

Here, g is the acceleration due to gravity, T^* the temperature of the fluid near the plate, T_∞ the free stream temperature, C^* concentration, β the coefficient of thermal expansion, k the thermal conductivity, P^* the pressure, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ viscosity of the fluid, q^* the radiative heat flux, ρ the density, σ the magnetic permeability of fluid V_0 constant suction velocity, ν the kinematic viscosity and D molecular diffusitivity.

The radiative heat flux q_r^* is given by equation (5) in the spirit of (Cogly et.al, 1968)

$$\frac{\partial q_r^*}{\partial y^*} = 4(T^* - T_\infty)I \qquad (7)$$

where $I = \int_0^\infty K_{\lambda w} \frac{\partial e_{b\lambda}}{\partial T^*} d\lambda,\ K_{\lambda w} -$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function, I is absorption coefficient

The boundary conditions are

$$\begin{aligned} &y^* = 0 \ :\ u^* = 0, \quad T^* = T_w,\ C_\infty = C \\ &y^* \to \infty : u^* \to 0,\ T^* \to T_\infty,\ C^* \to C_\infty \end{aligned} \qquad (8)$$

Introducing the following non-dimensional quantities

$$u = \frac{u^*}{v_0}, y = \frac{v_0 y^*}{\nu}, M^2 = \frac{B_0{}^2 \nu^2 \sigma}{v_0{}^2 \mu}, Sc = \frac{\nu}{D}$$

$$\theta = \frac{T^* - T_\infty}{T_w - T_\infty}, \quad \Pr = \frac{\mu C_p}{k}, \quad C = \frac{C^* - C_\infty}{C_w - C_\infty}$$

$$Gr = \frac{\rho\beta g \nu^2 (T_w - T_\infty)}{v_0^3 \mu}, \qquad \phi = \frac{Q_0}{\rho C_p v_0^2} \qquad (9)$$

$$Gm = \frac{\rho\beta^* g(C - C_\infty)}{v_0^3}, \qquad R = \frac{4\nu I}{\rho C_p v_0^2}$$

$$Kr = \frac{Kr^* \nu}{v_0^2}, \qquad Q_l = \frac{Ql^*\left(C_w - C_\infty\right)\nu}{\rho C_p v_0^2 \left(T_w - T_\infty\right)}$$

SOLUTION OF THE PROBLEM

In the equations (4), (5), (6) and (8), we get

$$\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - M^2 u = -Gr\theta - GmC \qquad (10)$$

$$\frac{\partial^2 \theta}{\partial y^2} + \Pr\frac{\partial \theta}{\partial y} - \left(R + \phi\right)\Pr\theta + Q_l C = 0 \qquad (11)$$

$$\frac{\partial^2 C}{\partial y^2} + Sc\frac{\partial C}{\partial y} - ScKrC = 0 \qquad (12)$$

where Gr is Grashof number, Gm is the mass Groshof number, $\Pr$ is Prandtl number, M is magnetic parameter, R is Radiation parameter, Sc is Schmidt number, ϕ is heat source parameter, Kr is Chemical reaction parameter, Q_l is the heat absorption parameter.

The corresponding boundary condition in dimensionless form are reduced to

$$\begin{aligned} &y = 0: \quad u = 0, \quad \theta = 1,\ C = 1 \\ &y \to \infty : u \to 0,\ \theta \to 0, C \to 0 \end{aligned} \qquad (13)$$

The physical variables u, θ *and* C can be expanded in the power of $\left(\varepsilon << 1\right)$. This can be possible physically as ε for the flow of an incompressible fluid is always less than unity. 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

$$u=u_0(y)+\varepsilon e^{nt}u_1(y)\ +0(\varepsilon^2)+\ldots\ldots$$
$$\theta=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)\ +0(\varepsilon^2)+\ldots\ldots \quad (14)$$
$$C=C_0(y)+\varepsilon e^{nt}C_1(y)+0(\varepsilon^2)+\ldots\ldots$$

Using equation (14) in equations (10)–(12) and equating the coefficient of like powers of E, we have

$$u_0''+u_0'-M^2u_0=-Gr\,\theta_0-GmC_0 \quad (15)$$
$$\theta_0''+\Pr\,\theta_0'-(R+\phi)\Pr\theta_0=-Q_lC_0 \quad (16)$$
$$C_0''+ScC_0'-KrC_0=0 \quad (17)$$
$$u_1''+u_1'-M^2u_1=-Gr\,\theta_1-GmC_1 \quad (18)$$
$$\theta_1''+\Pr\theta_1'-(R+\phi)\Pr\theta_1=-Q_lC_1 \quad (19)$$
$$C_1''+ScC_1'-KrC_1=0 \quad (20)$$

The corresponding boundary conditions are

$$\begin{aligned} y=0:&\quad u_0=0,u_1=0,\theta_0=1\\ &\quad \theta_1=0,C_0=1,C_1=0\\ y\to\infty:&\quad u_0\to 0,u_1\to 0,\theta_0\to 0\\ &\quad \theta_1\to 0,\ C_0\to 1,C_1\to 0\end{aligned} \quad (21)$$

Solving equations (15) to (20) with the help of (21), we get

$$u_0=L_1e^{m_2y}+L_2e^{m_6y}+L_3e^{m_2y}+L_4e^{m_{10}y}$$
$$\theta_0=Z_1e^{m_2y}+Z_2e^{m_6y}$$
$$C_0=e^{m_2y}$$
$$u_1=0$$
$$\theta_1=0$$
$$C_1=0$$
$$u=L_1e^{m_2y}+L_2e^{m_6y}+L_3e^{m_2y}+L_4e^{m_{10}y}$$
$$\theta=Z_1e^{m_2y}+Z_2e^{m_6y}$$
$$C=e^{m_2y}$$

Skin – friction:

The skin-friction coefficient at the plate is given by

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=m_2L_1+m_6L_2+m_2L_3+m_{10}L_4$$

Heat Transfer:

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu=\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=m_2Z_1+m_6Z_2$$

Sherwood number

$$Sh=\left(\frac{\partial C}{\partial y}\right)_{y=0}=m_2$$

RESULTS AND DISCUSSION

Approximate solutions have been derived for the velocity, temperature field, concentration profiles, skin friction and Nusselt number using multi-parameter perturbation technique. The obtained results are discussed with the help of the graphs to observe the effect of various parameters like the thermal Grashof number(Gr), solutal Grashof number(Gm), the magnetic field parameter (M), absorption radiation parameter (Q_l), thermal radiation parameter (R), Prandtl number $(\Pr)$, heat absorption (ϕ), chemical reaction parameter (Kr) and Schmidt number (Sc) on the velocity, temperature and concentration profiles can be analyzed from Figures (1) - (17).

Velocity profiles:

Figure (1) shows the influence of thermal buoyancy force parameter Gr on the velocity. As can be seen from this figure, the velocity profile increases with increases in the values of the thermal buoyancy. We actually observe that the 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 Gr has the same effect on the velocity as Gr. From figure (2) we observe that the effect of magnetic field $\left(M\right)$is results in decreasing velocity distribution across the boundary layer because of the application of transfer magnetic field will result a restrictive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity.

The effect of increasing the value of the absorption parameter $\left(Q_l\right)$ on the velocity is shown in figure (3). We observe in this figure that increasing the value of the absorption of the radiation parameter due to increase in the buoyancy force accelerates the flow rate. Figure (4) depicts the effect of varying thermal radiation parameter $\left(R\right)$ on the flow velocity. We observe that the thermal radiation enhances convective flow. Figure (5) illustrates the influence of heat absorption coefficient ϕ on the velocity. Physically, the presence of heat absorption (thermal sink) effect has the tendency in resulting in a net reduction in the flow velocity. This behaviour is seen from Figure (5) in which the velocity increases as ϕ increases. The hydrodynamic boundary layer decreases as the heat absorption effects increase. The velocity profiles for different values of solutal Grashof number $\left(Gm\right)$ are described in figure (6). It is observed that an increasing in Gm leads to a rise in the values of velocity. In addition, the curves show that the peak value of velocity increases rapidly near the wall of the porous plate as soultal Grashof number increases, and then decays to the relevant free stream velocity. The influences of chemical reaction parameter $\left(Kr\right)$ on the velocity profiles across the boundary layer are presented in Figure (7). We see that the velocity distribution across the boundary layer decreases with increasing of chemical reaction parameter. Figure (8) shows the velocity profiles across the boundary layer for different values of Prandtl number $\left(\Pr\right)$. The results show that the effect of increasing values of Pr results in a decreasing the velocity. For different values of the Schmidt number$\left(Sc\right)$, the velocity profiles are plotted in figure (9). It is obvious that the effect of increasing values of Sc results in a decreasing velocity distribution across the boundary layer.

Temperature profiles:

The influence of heat absorption, Prandtl number, radiation absorption, thermal radiation chemical reaction parameter and Schmidt number on the temperature distribution is respectively, shown on figures (10) - (15). Figure (10) depicts the effects of heat absorption $\left(\phi\right)$ on the temperature distribution. It is observed that the boundary layer absorbs energy resulting in the temperature to fall considerably with increasing values of $\left(\phi\right)$. This is because when heat is absorbed, the buoyancy force decreases the temperature profile. Figure (11) temperature decreases with the increasing value of the Prandtl number (Pr). Prandtl number is very important for temperature profiles. It is clear that increasing Pr increases ϑ and the thickness of the thermal boundary layer. An increase Pr leads to a fall in the temperature. This emphasizes the influence of the injected flow in the cooling process. The effect of absorption of radiation parameter $\left(Q_l\right)$ on the temperature profile is shown on figure (12). It is seen from this figure that the effect of absorption of radiation is to increase 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 figure (13) we observe that the effect of thermal radiation $\left(R\right)$ is to enhance heat transfer as thermal boundary layer thickness decreases with increase in the thermal radiation. We observe that the effect of radiation parameter $\left(R\right)$ is to increase the temperature distribution in the thermal boundary layer. This is because the increase of *R* implies increasing of radiation in the thermal boundary layer, and hence increases the values of the temperature profiles in thermal boundary layer. Figure (14) is the graph of temperature profiles for different values of chemical reaction parameter $\left(Kr\right)$. It can easily be seen that the thermal boundary layer release the energy which causes the temperature of the fluid to decreases with increase in the chemical reaction parameter $\left(Kr\right)$. Lastly the effect of Schmidt number $\left(Sc\right)$ on the temperature field is displayed in figure (15). We see that the temperature profiles decrease with increasing values of $\left(Sc\right)$. This is because sucking decelerates fluid particles through the porous wall reducing the growth of the fluid boundary layer as well as thermal and concentration boundary layers.

Spices Concentration profiles:

The effect of reaction parameter Kr on the species concentration profiles for generative chemical reaction is shown in Figure 16. It is noticed for the graph that there is marked effect of increasing the value of the chemical reaction rate parameter Kr on concentration distribution in the boundary layer. It is clearly observed from this figure that the concentration of spices which is greater than 1 at the start of the boundary layer decreases slowly till it attains the minimum value of zero at the end of the boundary layer and this trend is seen for al the values of reaction parameter. Further, it is due to the fact that an increasing the value of the chemical reaction parameter Kr decreases the concentration of spices of the boundary layer. Schmidt number very important in concentration. Figure 17 gives the species concentration for different values of gasses like Sc it is observed that the concentration at all points in the flow field decreases exponentially with y and tends to zero as $y \to \infty$. A comparison of curves in the figure shows a decrease in concentration (C) with an increase in Sc Physically the increase of Sc means decrease of molecular diffusivity (D). That results in decrease of decrease of concentration boundary layer. Hence, the concentration of the species is higher for small values of Sc and lower for larger values of Sc. Figure (18) illustrates the effect of Prandtl number on the skin-friction of the fluid under consideration. As the Prandtl number decreases the ski-friction is found to be increasing. Figure (19) illustrates the effect of the Prandtl number on the Nusselt number of the fluid under consideration. As the Prandtl number increases, the Nusselt number decreases.

REFERENCES

Chenna Kesavaiah Damala, Venkateswarlu Bhumarapu, Oluwole Daniel Makinde. Radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, Engineering Transactions, 2021; 69 (4): 373–401

Rami Reddy G, Chenna Kesavaiah D, Venkata Ramana Musala and Bkaskara Reddy G. Hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, Indian Journal of Natural Sciences, 2021; 12 (68): 34975-34987

Chenna Kesavaiah D and Venkateswarlu B. Chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, International Journal of Fluid Mechanics Research, 2020; 47 (2): 153-169

Mallikarjuna Reddy B, Chenna Kesavaiah D and Ramana Reddy G V. Radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, Asian Journal of Applied Sciences, 2019; 7 (5), 597-607

Srinathuni Lavanya and Chenna Kesavaiah D. Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, International Journal of Pure and Applied Researches, 2017; 3 (1): 43 - 56

Mallikarjuna Reddy B, Chenna Kesavaiah D and Ramana Reddy G V. Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, ARPN Journal of Engineering and Applied Sciences, 2018; 13 (22): 8863-8872

Chenna Kesavaiah D and Sudhakaraiah A. Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, Scholars Journal of Engineering and Technology, 2014; 2(2): 219-225

Rajaiah M, Sudhakaraih A, Varma S V K, and Venkatalakshmi P. Chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium. i-manager's Journal on Mathematics, 2015; 4(1): 32-39

Chenna Kesavaiah D, Satyanarayana P V, Sudhakaraiah A, Venkataramana S. Natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, International Journal of Research in Engineering and Technology, 2013; 2 (6): 959-966

Chenna Kesavaiah D and Satyanarayana P V. MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, Indian Journal of Applied Research, 2013; 3 (7). 310-314

Chenna Kesavaiah D, P V Satyanarayana and S Venkataramana (2013): 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, International Journal of Scientific Engineering and Technology, 2013; 2 (2), pp: 56-72

Karunakar Reddy S, D Chenna Kesavaiah D and Raja Shekar M N. MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, International Journal of Innovative Research in Science, Engineering and Technology, 2013; 2 (4): 973- 981

Damala Ch Kesavaiah, Satyanarayana and P V and Sudhakaraiah A. 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, International Journal of Engineering Research, 2013; 2 (2): 113-118

Rajaiah M and Sudhakaraiah A. Unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, International Journal of Science and Research, 2015; 4 (2): 1503-1510

Ch Kesavaiah D, Satyanarayana P V, Gireesh Kumar J and Venkataramana S. Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, International Journal of Mathematical Archive, 2012; 3 (8): 3028-3035

Satyanarayana P V, Ch Kesavaiah D and Venkataramana S. Viscous dissipation and thermal radiation effects on an unsteady MHD convection flow past a semi-infinite vertical permeable moving porous plate, International Journal of Mathematical Archive, 2011; 2(4): 476-487

Ch Kesavaiah D, Satyanarayana P V and Venkataramana S. 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, Int. J. of Appl. Math and Mech, 2011; 7 (1): 52-69

Haranth Y and Sudhakaraiah A. Viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, International Journal of Science and Research, 2015; 4 (2): 2650-2654

Chenna Kesavaiah D, Ramakrishna Goud T, Nookala Venu, Seshagiri Rao Y V. MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, Journal of Mathematical Control Science and Applications, 2011; 7 (2): 393-404

Rajaiah M, Sudhakaraiah A, Venkatalakshmi P and Sivaiah M. Unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating In the presence of suction or injection, International Journal of Mathematics and Computer Research, 2014; 2 (5): 428-453

Chenna Kesavaiah D, Ramakrishna Goud T, Seshagiri Rao Y V, Nookala Venu (2019): Radiation effect to MHD oscillatory flow in a channel filled through a porous medium with heat generation, Journal of Mathematical Control Science and Applications, 2019;5 (2): 71-80

Rajaiah M and Sudhakaraiah A. Radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, International Journal of Science and Research, 2015; 4 (2): 1608-1613

Chenna Kesavaiah D, Ramakrishna Goud T, Nookala Venu, Seshagiri Rao Y V. Analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation, Journal of Mathematical Control Science and Applications, 2017; 3 (2): 113-126

Beg O A, Zueco J, Bhargava R and Takhar H S. Magnetohydrodynamic convection flow from a sphere to a non-Darcian porous medium with heat generation or absorption effects: network simulation, International Journal of Thermal Sciences, 2009; 48: 913-921

Aliakbar V, Alizadeh-Pahlavan A and Sadeghy K. The influence of thermal radiation on MHD flow of Maxwellian fluids above stretching sheets, Communications in Nonlinear Science and Numerical Simulation, Commun., 2109; 14 (3): 79-794.

Cortell R. Effects of viscous dissipation and radiation on the thermal boundary layer over a nonlinearly stretching sheet. Phys., Lett., A, 2008; 372: 631-636

F S Ibrahim, Elaiw A M and A A Bakar A A. 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. Communications in Nonlinear Science and Numerical Simulation, 2008; 13: 1056-1066

Mahd A. Effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in a porous media with variable viscosity. International Communications in Heat and Mass Transfer, 201; 37: 548-554

Makinde O D and Aziz A. MHD mixed convection from a vertical plate embedded in a porous medium with a convective boundary condition. International Journal of Thermal Sciences, 2010; 49: 1813-1820

Mohamed R A. Double-Diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects, Applied Mathematical Sciences, 2009; 3 (13): 629-651.

A Pal and B Talukdar. Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with a thermal radiation and chemical reaction, Communications in Nonlinear Science and Numerical Simulation, 2010; 15: 1813-1830.

Patil P M and Kulkarni P S. Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. International Journal of Thermal Sciences, 2008; 47: 1043-1054

Salem A M and Abd El-Aziz M. Effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption, Applied Mathematical Modelling, 2008; 32: 1236-1254.

Samad M A and Mohebujjaman M. MHD Heat and Mass Transfer Free Convection Flow among a Vertical Stretching Sheet in Presence of Magnetic Field with Heat Generation. Research Journal of Applied Science, Engineering and Technology, 2009; 1 (3): 98-106

Cogley A C, Vincenty W G and Gilles S E. AIAAJ, 1968; 6: 551

APPENDIX

$$m_2 = m_4 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}\right),$$

$$m_6 = m_8 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\left(R+\phi\right)\Pr}}{2}\right)$$

$$m_{10} = m_{12} = -\left(\frac{1+\sqrt{1+4M^2}}{2}\right)$$

$$Z_1 = -\frac{Q_l}{m_2{}^2 + \Pr m_2 - (R+\phi)\Pr}$$

$$Z_2 = 1 - Z_1$$

$$L_1 = -\frac{Gm}{m_2{}^2 + m_2 - M^2}$$

$$L_2 = -\frac{GrZ_2}{m_6{}^2 + m_6 - M^2}$$

$$L_3 = -\frac{GrZ_1}{m_2{}^2 + m_2 - M^2}$$

$$L_4 = -\left(L_1 + L_2 + +L_3\right)$$

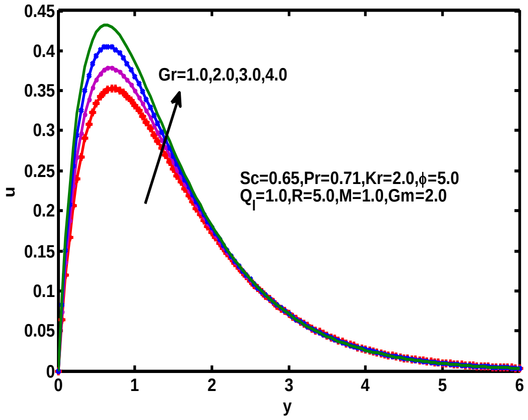

Figure 1: Velocity profiles for different values of Gr

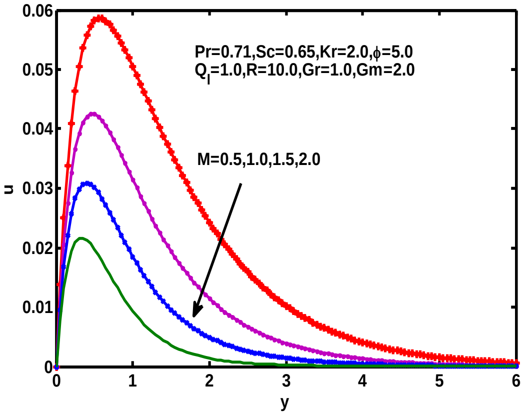

Figure 2: Velocity profiles for different values of M

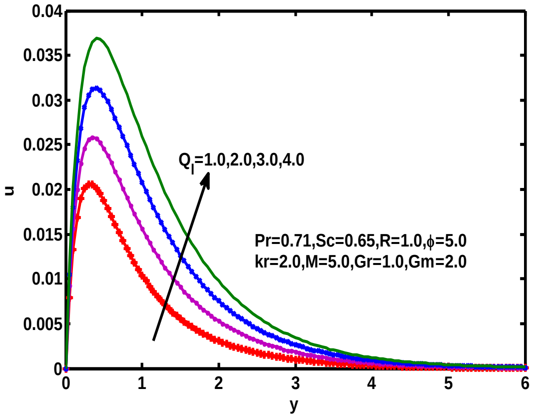

Figure 3: Velocity profiles for different values of Q_l

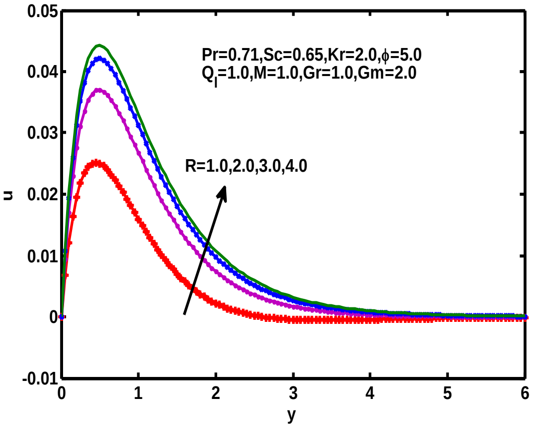

Figure 4: Velocity profiles for different values of R

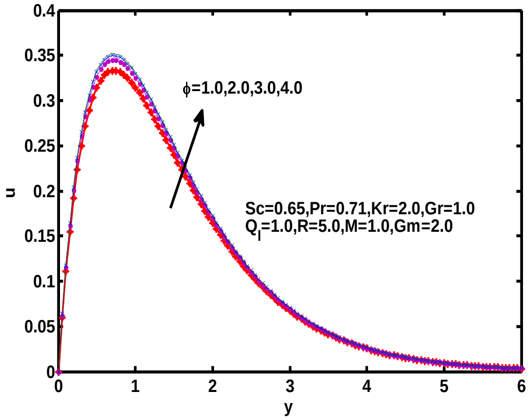

Figure 5: Velocity profiles for different values of ϕ

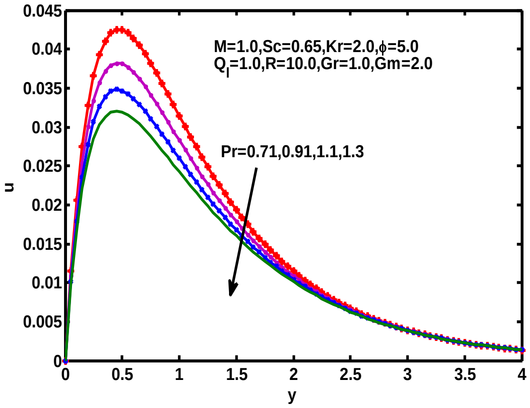

Figure 8: Velocity profiles for different values of Pr

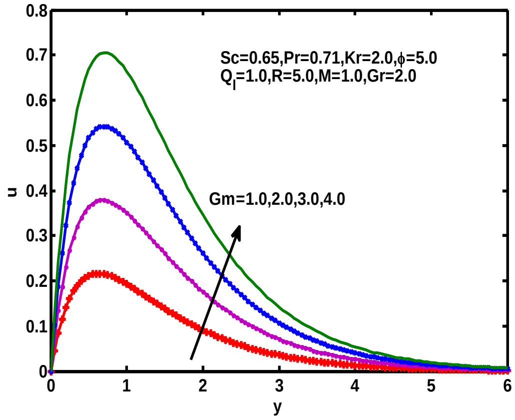

Figure 6:Velocity profiles for different values of Gm

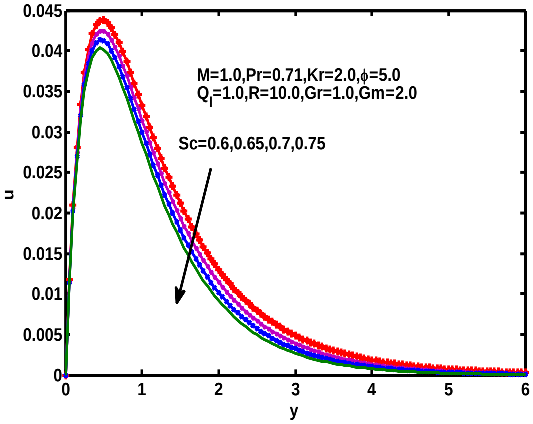

Figure 9: Velocity profiles for different values of Sc

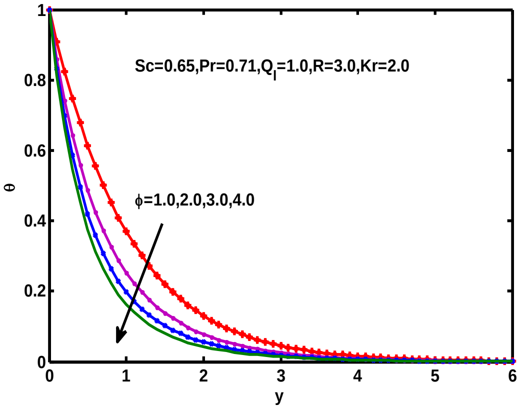

Figure 10: Temperature profiles for different values of ϕ

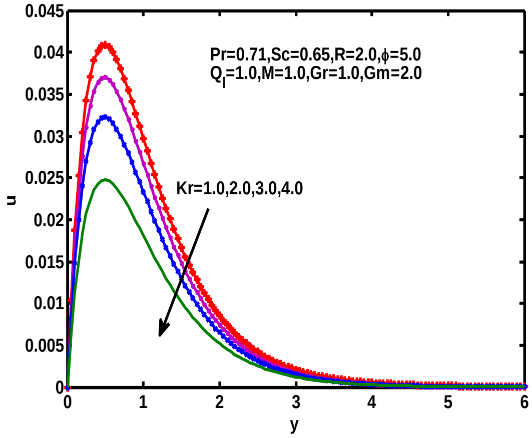

Figure 7: Velocity profiles for different values of Kr

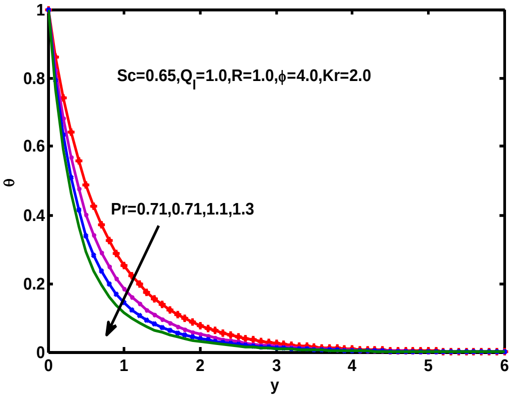

Figure 11: Temperature profiles for different values of Pr

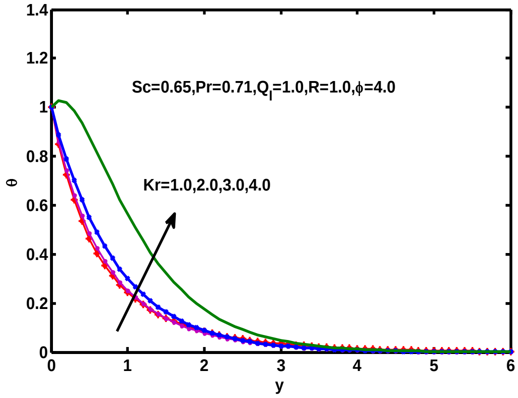

Figure 14: Temperature profiles for different values of Kr

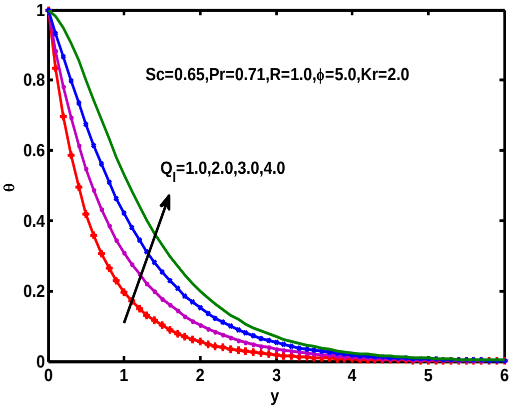

Figure 12: Temperature profiles for different values of Q_l

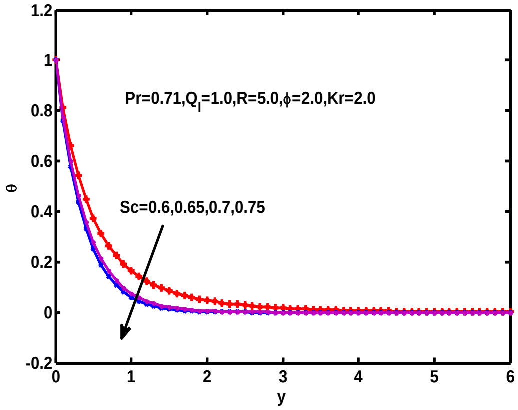

Figure 15: Temperature profiles for different values of Sc

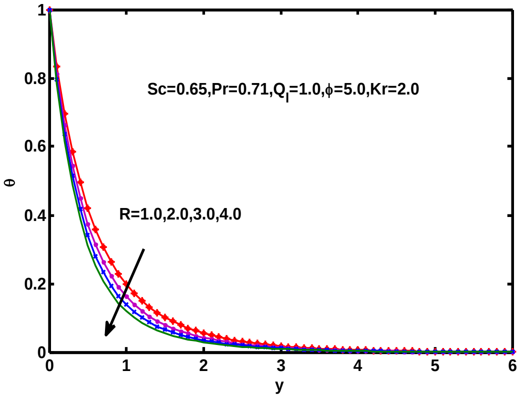

Figure 13: Temperature profiles for different values of R

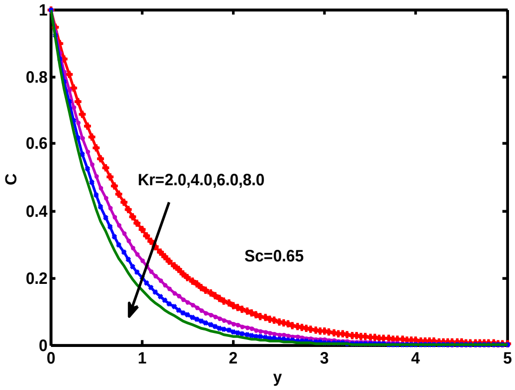

Figure 16: Concentration profiles for different values of Kr

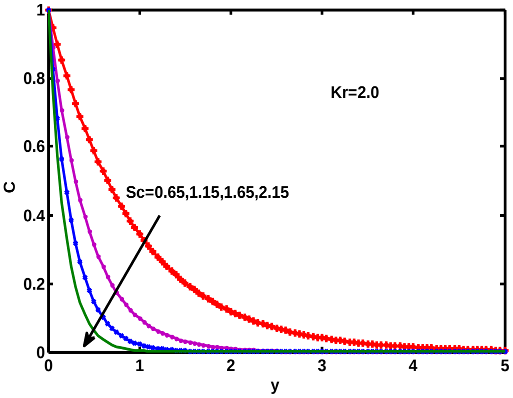

Figure 17: Concentration profiles for different values of Sc

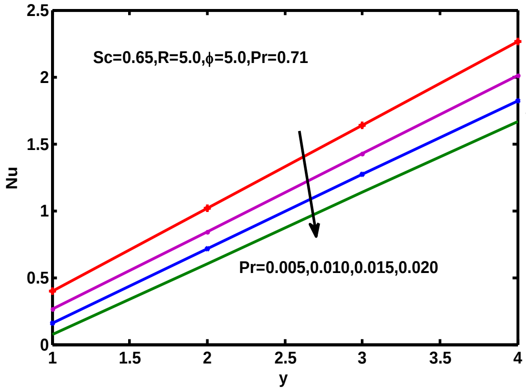

Figure 19: Nusselt number for Pr versus Q_l

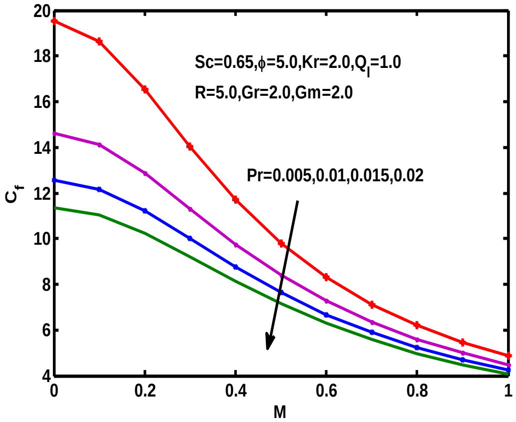

Figure 18: Skin friction for different values of Pr versus M