INFLUENCE OF JOULE HEATINGAND MASS TRANSFER EFFECTS ON MHD MIXED CONVECTION FLOW OF CHEMICALLY REACTING FLUID ON A VERTICAL SURFACE

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ABSTRACT

This work is concerned with an analytical study of joule heating; chemical reaction and mass transfer effects on MHD mixed convection flow from a vertical surface have been discussed. The physical problem is represented mathematically by set of dimensionless governing equations and the developed mathematical model is solved by analytically using two-term harmonic and non-harmonic functions. Approximate solutions have been derived for the velocity, temperature, concentration profiles, skin - friction and rate heat transfer using multi-parameter perturbation technique.

KEYWORDS: Joule heating, MHD, Mixed convection,Chemical reaction, Vertical surface

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INTRODUCTION

Convective flow with simultaneous heat and mass transfer under the influence of a magnetic field and chemical reaction have attracted a considerable attention of researchers because such process exist in many branches of science and technology. Possible applications of this type of flow can be found in many industries viz. in the chemical industry, cooling nuclear reactors and magnetohydrodynamic (MHD) power generators. Free convection flow occurs frequently in nature. It occurs not only due to temperature difference, but also due to concentration difference or combination of these two. Many transport processes exit in industrial applications in which the simultaneous heat and mass transfer occur as a result of combined buoyancy effects of diffusion of chemical species. Free convection flows in a porous media with chemical reaction have wide applications in geothermal and oil reservoir engineering as well as in chemical reactors of porous structure.In view of the above (Azim et. al, 2010) discussed viscous Joule heating MHD conjugate heat transfer for a vertical flat plate in the presence of heat generation, (Ch Kesavaiah et. al, 2013) observed 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, (Chamka et. al, 2010) illustrated similarity solution for unsteady heat and mass transfer form a stretching surface embedded in a porous medium with suction/injection and chemical reaction, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) explained heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Chen, 2010) showed combined effect of joule heating and viscous dissipation on magnetohydrodynamic flow past a permeable stretching surface with free convection and radiative heat transfer,(Vijendra Singh and Shweta Agarwal, 2014)motivated study on heat Transfer for two types of viscoelastic fluid over an exponentially stretching sheet with variable thermal conductivity and radiation in porous medium, (Karunakar Reddy et. al, 2013) has been considered MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction,(EI-Hakiem and EI-Amin, 2001)measured the mass transfer effects on the non-Newtonian fluid past a vertical plate embedded in a porous medium with non-uniform surface heat flux, (Chenna Kesavaiah et. al, 2018) showed on MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects.

The boundary layer flow of non-Newtonian fluids due to a stretching surface has gained much importance in many engineering and industrial applications that include both metal and polymer sheets. The reason for such accelerating interest is due to its wide occurrence in various applications such as geophysics, biological sciences, chemical and petroleum industries etc. In rheological fluids, the constitutive relationships between stress and rate of strain are much complicated in comparison to the Navier-Stokes equations. Due to the complex nature of these fluids, it is not possible to predict the different characteristics of all the non-Newtonian fluids. Hence, different fluid models were proposed by various researchers, (Chenna Kesavaiah and Sudhakaraiah, 2014) has been considered the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Hayat et. al, 2014) reviewed on boundary layer flow of carreau fluid over a convectively heated stretching sheet, (Nadeem et. al, 2013) explained detailed information on MHD three-dimensional Casson fluid flow past a porous linearly stretching sheet, (Manhet. Et. al, 2020) illustrated the impact of MHD on hybrid nanometerial free convective flow within permeable region,(Srinivasa Raju, 2016) Combined influence of thermal diffusion and diffusion thermo on unsteady hydromagnetic free convective fluid flow past an infinite vertical porous plate in presence of chemical reaction,(Rajeswari et. al, 2009)reviewed on chemical reaction, heat and mass transfer on Nonlinear MHD boundary layer flow through a vertical porous surface in the presence of suction,(Chenna Kesavaiah and Satyanarayana, 2013) motivated study onMHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction,(Sharma and Chaudhary, 2008) described Hydromagnetic unsteady mixed convection and mass transfer flow past a vertical porous plate immersed in a porous medium with hall effect, (ChKesavaiah et. al, 2012) expounded on radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, (Reddy et. al, 2021)spell out on chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of heat source/sink and viscous dissipation, (Chenna Kesavaiah et. al, 2013) demonstrated on natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Olanrewaju et. al, 2012) displayed the internal heat generation effect on thermal boundary layer with a convective surface boundary condition, (ChKesavaiah et. al, 2012) motivated study on radiation and mass transfer effects on moving vertical plate with variable temperature and viscous Dissipation,(Mallikarjuna Reddy et. al, 2018) exported study on the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (ChennaKesavaiah, 2013) has been considered theradiation 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, (Chenna Kesavaiah and Venkateswarlu, 2020) has been studied the chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, Chenna Kesavaiah et. al, 2021) measured onradiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source.

The joule heating is referred to as electrically resistance heating or Ohmic heating because of its relationship with ohm's law. Electric stoves, cartridge heaters, soldering irons, electric fuses and incandescent light (glows when the filament is heated by joule heating) are the important practical applications of Joule heating.Numerous attempts has been made to understand the effects of joule heating with respect to cell death and device reliability. Erickson et al. performed combined experimental and numerical analysis of the joule heating and heat transfers at microchannel intersection in polydimethylsiloxane (PDMS) and hybrid PDMS/Glass micro fluidic systems and demonstrated that hybrid micro fluidic system helps in maintaining the uniform and low buffer temperature. (Ruchika Mehta et. al, 2022) has been considered Joule heating effect on radiating MHD mixed convection stagnation point flow along vertical stretching sheet embedded in a permeable medium and heat generation/absorption, (Vijayaragavan and Karthikeyan, 2017) motivated study on Joule heating and thermal radiation effects on chemically reacting Casson fluid past a vertical plate with variable magnetic field, (Deepak Kumar et. al, 2022) reviewed Numerical study of chemical reaction and heat transfer of MHD slip flow with Joule heating and Soret-Dufour effect over an exponentially stretching sheet, (Sharma, Rishu Gandhi, 2022) motivated study on combined effects of Joule heating and non-Uniform heat source/sink on unsteady MHD mixed convective flow over a vertical stretching surface embedded in a darcy-Forchheimer porous medium, (Chenna Kesavaiah et. al, 2022)observed that the radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, (Alam et. al, 2008)illustrated the effects of chemical reaction and thermophoresis on magneto-hydrodynamic mixed convective heat and mass transfer flow along an inclined plate in the presence of heat generation and or absorption with viscous dissipation and joule heating,(Chenna Kesavaiah et. al, 2022) has been considered the 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, (Khan et. al, 2017) reviewed on a modified homogeneous –heterogeneous reaction for MHD stagnation flow with viscous dissipation and Joule heating, (Chenna Kesavaiah et. al, 2022) considered chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties, (Tripathi and Sharma, 2020) impact on influence of heat and mass transfer on two-phase blood flow with Joule heating and variable viscosity in the presence of variable magnetic field, (Chenna Kesavaiah et. al, 2022) motivated study on chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer, (Rahman et. al, 2011)observed on MHD mixed convection with Joule heating effect in a Lid driven with a heated semi-circular source using the finite element technique, (Chenna Kesavaiah et. al, 2022) MHD Effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface.

The objective of the present study is the propagation of thermal energy through air and water solution in the presence of magnetic field and radiation has wide range of applications. The obtained results are discussed with the help of graphs to observe that the effect of various parameters like Grashof Number, Schmidt number, Prandtl number, Magnetic parameter, Radiation parameter and Chemical reaction parameter.

FORMULATION OF THE PROBLEM

We considered the mixed convection flow of an incompressible, electrically conducting viscous fluid radiating and chemically reacting 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

$$\frac{dv^*}{dy^*} = 0 \qquad (1)$$

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

$$\frac{dp^*}{dy^*} = 0 \Rightarrow p^* \text{ is independent of } y^* \, (3)$$

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

$$\rho C_p\left(v^*\frac{dT^*}{dy^*}\right) = k\frac{d^2T^*}{dy^{*2}} + \mu\left(\frac{du^*}{dy^*}\right)^2 - \frac{\partial q_r^{\,*}}{\partial y^*} + \sigma {B_0}^2 u^{*2} - Q_0(T^* - T_\infty) \qquad (5)$$

$$v^*\frac{dC^*}{dy^*} = D\frac{d^2C^*}{dy^{*2}} - Kr^*\left(C^* - C_\infty\right) (6)$$

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 diffusivity.

The radiative heat flux $q_r^{\,*}$ is given by equation (5) in the sprit of Cogly et.al [7]

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

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

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

Introducing the following non-dimensional quantities

$$\begin{aligned} &u = \frac{u^*}{v_0}, y = \frac{v_0\, y^*}{\nu}, \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, Sc = \frac{\nu}{D} \\ &C = \frac{C^* - C_\infty}{C_w - C_\infty}, \qquad E = \frac{v_0^2}{C_p (T_w - T_\infty)} \\ &F = \frac{4\nu I}{\rho C_p v_0^2}, M^2 = \frac{B_0{}^2 \nu^2 \sigma}{v_0{}^2 \mu}, \Pr = \frac{\mu C_p}{k} \quad (9) \\ &Gr = \frac{\rho\, \beta\, g \nu^2 (T_w - T_\infty)}{v_0^3 \mu}, \qquad Kr = \frac{Kr^* \nu}{v_0^2} \\ &Gm = \frac{\rho \beta^* g (C - C_\infty)}{v_0^3}, \qquad Q = \frac{\nu Q_0}{\rho C_p v_0{}^2} \end{aligned}$$

SOLUTION OF THE PROBLEM

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

$$\frac{d^2 u}{dy^2} + \frac{du}{dy} - M^2 u = - Gr\theta - Gm C \qquad (10)$$

$$\begin{aligned} &\frac{d^2\theta}{dy^2} + \Pr \frac{d\theta}{dy} - F \Pr \theta + \Pr \left(\frac{du}{dy} \right)^2 \quad (11) \\ &\qquad + \Pr E M^2 u^2 - \Pr Q \theta = 0 \end{aligned}$$

$$\frac{d^2 C}{dy^2} + Sc \frac{dC}{dy} - Sc Kr C = 0 \qquad (12)$$

where Gr is Grashoff number, $\Pr$ is Prandtl number, M is Magnetic parameter, F is Radiation parameter, Sc is Schmidt number, E is Eckert number, Kr is Chemical reaction parameter.

The corresponding boundary condition in dimensionless form are reduced to

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

The physical variables $u, \theta \; and \; C$ can be expanded in the power of Eckert number (E). This can be possible physically as E for the flow of an incompressible fluid is always less than unity. It can be interpreted physically as the flow due to the Joules dissipation is super imposed on the main flow. Hence we can assume

$$\begin{aligned} &u(y) = u_0(y) \; + E u_1(y) + 0\left(E^2\right) \\ &\theta(y) = \theta_0(y) \; + E\, \theta_1(y) + 0\left(E^2\right) \qquad (14) \\ &C(y) = C_0(y) + E\, C_1(y) + 0\left(E^2\right) \end{aligned}$$

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

$$u_0'' + u_0' - M^2 u_0 = - Gr\, \theta_0 - Gm C_0 \qquad (15)$$

$$\theta_0'' + \Pr \; \theta_0' - \left(F + Q\right) \Pr \theta_0 = 0 \; (16)$$

$$C_0'' + Sc\, C_0' - Kr C_0 = 0 \qquad (17)$$

$$u_1'' + u_1' - M^2 u_1 = -Gr\,\theta_1 - Gm\,C_1 \qquad (18)$$

$$\theta_1'' + \Pr\theta_{01}' - (F+Q)\Pr\theta_1 + \Pr u_0'^2 + \Pr M^2 u_0^2 u_{01}'^2 \qquad (19)$$

$$C_1'' + Sc\,C_1' - Kr C_1 = 0 \qquad (20)$$

and the corresponding boundary conditions are

$$\left.\begin{array}{l} u_0 = 0, \quad \theta_0 = 1,\ C_0 = 1 \\ u_1 = 0, \quad \theta_1 = 0,\ C_1 = 0 \end{array}\right\} \ y = 0$$
$$\left.\begin{array}{l} u_0 \to 0, C_0 \to 0,\ \theta_0 \to 0 \\ u_1 \to 0,\ \theta_1 \to 0, C_1 \to 0 \end{array}\right\} \ y \to \infty \qquad (21)$$

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

$$u_0 = A_1 e^{m_2 y} + A_2 e^{m_1 y} + A_3 e^{m_3 y}$$
$$\theta_0 = e^{m_2 y}; C_0 = e^{m_1 y}$$

$$\begin{aligned} u_1 = {} & A_{17} e^{m_3 y} + A_5 e^{2m_3 y} + A_1 e^{m_2 y} + A_6 e^{2m_2 y} \\ & + A_7 e^{2m_1 y} + A_8 e^{(m_2+m_3)y} + A_9 e^{(m_1+m_2)y} \\ & + A_{10} e^{(m_1+m_3)y} + A_{12} e^{2m_2 y} + A_{13} e^{2m_1 y} \\ & + A_{14} e^{(m_2+m_3)y} + A_{15} e^{(m_1+m_2)y} + A_{16} e^{(m_1+m_3)y} \end{aligned}$$

$$\begin{aligned} \theta_1 = {} & B_{13} e^{m_2 y} + B_1 e^{2m_3 y} + B_2 e^{2m_2 y} + B_3 e^{2m_1 y} \\ & + B_4 e^{(m_2+m_3)y} + B_5 e^{(m_1+m_2)y} + B_6 e^{(m_1+m_3)y} \\ & + B_7 e^{2m_3 y} + B_8 e^{2m_2 y} + B_9 e^{2m_1 y} \\ & + B_{10} e^{(m_2+m_3)y} + B_{11} e^{(m_1+m_2)y} + B_{12} e^{(m_1+m_3)y} \end{aligned}$$

$$C_1 = 0$$

$$\begin{aligned} u = {} & A_1 e^{m_2 y} + A_2 e^{m_1 y} + A_3 e^{m_3 y} + E\left\{A_{17} e^{m_3 y}\right. \\ & + A_5 e^{2m_3 y} + A_6 e^{2m_2 y} + A_7 e^{2m_1 y} + A_8 e^{(m_2+m_3)y} \\ & + A_9 e^{(m_1+m_2)y} + A_{10} e^{(m_1+m_3)y} + A_{11} e^{2m_3 y} \\ & + A_{12} e^{2m_2 y} + A_{13} e^{2m_1 y} + A_{14} e^{(m_2+m_3)y} \\ & \left. + A_{15} e^{(m_1+m_2)y} + A_{16} e^{(m_1+m_3)y}\right\} \end{aligned}$$

$$\begin{aligned} \theta = {} & e^{m_2 y} + E\left\{B_{13} e^{m_2 y} + B_1 e^{2m_3 y} + B_2 e^{2m_2 y}\right. \\ & + B_3 e^{2m_1 y} + B_4 e^{(m_2+m_3)y} + B_5 e^{(m_1+m_2)y} \\ & + B_6 e^{(m_1+m_3)y} + B_7 e^{2m_3 y} + B_8 e^{2m_2 y} + B_9 e^{2m_1 y} \\ & \left. + B_{10} e^{(m_2+m_3)y} + B_{11} e^{(m_1+m_2)y} + B_{12} e^{(m_1+m_3)y}\right\} \end{aligned}$$

$$C = e^{m_1 y}$$

Skin – friction:

The skin-friction coefficient at the plate is given by

$$\begin{aligned} \tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = {} & m_2 A_1 e + m_1 A_2 + m_3 A_3 \\ & + E\left\{m_3 A_{17} + 2m_3 A_5 + m_2 A_1\right. \\ & + 2m_2 A_6 + 2m_1 A_7 + (m_2+m_3) A_8 \\ & + (m_1+m_2) A_9 + (m_1+m_3) A_{10} + 2m_3 A_{11} \\ & + 2m_2 A_{12} + 2m_1 A_{13} + (m_2+m_3) A_{14} \\ & \left. + (m_1+m_2) A_{15} + (m_1+m_3) A_{16}\right\} \end{aligned}$$

Heat Transfer:

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

$$
\begin{aligned}
Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_2 + \; E\{ & m_2 B_{13} + 2m_3 B_1 \\
& + 2m_2 B_2 + 2m_1 B_3 + \left(m_2 + m_3\right) B_4 \\
& + \left(m_1 + m_2\right) B_5 + \left(m_1 + m_3\right) B_6 + 2m_3 B_7 \\
& + 2m_2 B_8 + 2m_1 B_9 + \left(m_2 + m_3\right) B_{10} \\
& + \left(m_1 + m_2\right) B_{11} + \left(m_1 + m_3\right) B_{12} \}
\end{aligned}
$$

RESULTS AND DISCUSSION

A study of velocity field, temperature field, heat transfer, mass transfer and skin friction of the MHD mixed convection flow of a viscous incompressible electrically conducting fluid over an infinite vertical porous plate in the presence of magnetic field with Ohmic heat has been carried out in the preceding sections, taking radiation and chemical reaction effect with heat generation taking an account. We have computed the numerical values of velocity, temperature, skin friction, heat and mass transfer. The values of Prandtl number (Pr) are taken 0.71 which represent air. The obtained results are illustrated in Figures(1) to (13). For numerical calculation we considered the numerical values for various parameters involved as $Kr = 1.0,\ Sc = 0.65,$ $Gr = 5.0,\ M = 5.0, Q = 1.0\ E = 0.01,\ F = 3.0$.

Velocity profiles:

Figures (1) to (8) illustrates velocity profiles for changing boundaries. Figure (1) depicts the impact of thermal Grashof number (Gr) on the speed that expanding Gr prompts higher speeds. From figure (2), it is understood that an increase in modified Grashof number (Gm) prompts an increment in momentum. This demonstrates the proportion of the thermal lightness power to thick power is Gr. Consequently, as Gr builds, the thermal lightness power increments. The proportion of solutal lightness power to thick power is solutal Gr. An expansion in fluid speed is portrayed with expanded estimations of Gr, portraying higher solutal lightness impacts than the viscosity impact in the relating force condition. Figure (3), shows the variation of velocity distribution with different values of chemical reaction parameter (Kr). It is observed that the velocity decreases with an increasing the chemical reaction parameterand the presence of the peak indicatesthat the maximum velocity takes place in the fluid body close to thesurface, but not at the surface itself. It is evident that an increase in thisparameter significantly alters the concentration boundary-layer thicknessbut does not change the momentum one.The impact of the Magnetic field (M) on velocity is portrayed in figure (4). On expanding M, it can unmistakably be seen that speed is diminishing. This can be ascribed to the Lorentz power. This resistive power is because of the magnetic field applied. On expanding the quality of the magnetic field, the velocity is found to essentially lessen to zero, showing the higher protection from the fluid stream. Figure (5) illustrates the effect of radiation parameter (F). It is observed from this figure that velocity goes on decreasing with the increase of radiation parameter N. Figure (6) depicts the velocity profiles with the variations in Schmidt number (Sc). Form this figure we see that velocity decreases as Schmidt number increases. Figure (7) portrays the impact of the heat generation parameter (Q) on the velocity profiles profile. Structure the figure shows that the velocity bends increment with an expansion of the Q esteems. Figure (8), illustrate the effect of velocity profile for different values of Prandtl number (Pr). It is observed that the velocity decreases with an increasing the Prandtl number (Pr). Temperature profiles are outlined in Figures (9)-(11). From figure (9), we observed that the effect of chemical reaction parameter (Kr) on the temperature profiles, when the values of Kr increase the temperature decreases. From figure (10), an expansion in radiation parameter (F) portrays a drop in temperature. In figure (10), the conduct of the heat age boundary on the temperature profile. It is discovered that the temperature increments with an expansion of heat source parameter (Q) esteems. From Figure (11) it is observed that as radiationparameter R increases, the temperature of the flow field decreases at allthe points in flow region. Hence, it is observed that the temperature forconducting air (Pr = 0.71) is higher than that of water (Pr = 7.0) this isbecause of the fact that thermal conductivity of the fluid decreases with increasing values of Prresulting decrease in thermal boundary layerthickness. Therefore, using radiation we can control temperaturedistribution and flow transport.Figures (12) and (13) shown that the concentration profiles for the impact of Chemical reaction parameter(Kr)and Schmidt number (Sc) separately. On expanding estimations of Sc and Kr, fixation is found to decrease. Because of the chemical reaction in the limit layer locale, the speed of the fluid diminishes. It very well may be perceived from this that the fixation field diminish is because of chemical species utilization. Additionally, lightness impacts will in general decrease, prompting a diminished speed of fluid stream accordingly. Table (1) shows that the skin friction and Nusselt number for various values of thermal Grashof number are noted. It is cleart that the thermal Grashof number increases in the both profiles increases.

Table (1): Skin friction and Nusselt number for Gr

Gr	τ	Nu
1.0	4.195	0.031
2.0	4.394	0.058
3.0	4.567	0.075
4.0	4.705	0.215

CONCLUSIONS

- It has been indicated that the fluid velocity diminishes with the M
- It has it was discovered that the fluid focus diminishes ascending in Sc and Kr.

APPENDIX

$$\alpha_1 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}\right)$$

$$\alpha_2 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\left(F + Q\right)\Pr}}{2}\right)$$

$$\alpha_3 = -\left(\frac{1 + \sqrt{1 + 4M^2}}{2}\right) A_1 = -\frac{Gr}{\alpha_2{}^2 + \alpha_2 - M^2}$$

$$A_2 = -\frac{Gr}{\alpha_1{}^2 + \alpha_1 - M^2}, A_3 = -\left(A_1 + A_2\right)$$

The other constants are not given here to save space.

REFERENCES

Azim M A, Manun A A, Rahman M M. Viscous Joule heating MHD conjugate heat transfer for a vertical flat plate in the presence of heat generation, Int. Commun. Heat Mass Trasnf., 2010; 37 (6): 666-674

Ch Kesavaiah Damala, P V Satyanarayana 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

Chamka A J, Aly A M, Mansour M A. Similarity solution for unsteady heat and mass transfer form a stretching surface embedded in a porous medium with suction/injection and chemical reaction, Chem. Eng. Commun., 2010; 197: 846-858

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

Chen C H. Combined effect of joule heating and viscous dissipation on magnetohydrodynamic flow past a permeable stretching surface with free convection and radiative heat transfer, J. Heat Transf., 2010; 132: 064503

Vijendra Singh and Shweta Agarwal. Heat Transfer for two types of viscoelastic fluid over an exponentially stretching sheet with variable thermal conductivity and radiation in porous medium, Heat Transfer for Two Types of Viscoelastic Fluid Thermal Science, 2014; 18(4): 1079-1093

Karunakar Reddy S, 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

EI-Hakiem M A, M.F.EI-Amin. Mass transfer effects on the non-Newtonian fluid past a vertical plate embedded in a porous medium with non-uniform surface heat flux", Heat and Mass Transfer, 2001; 37: 293-297

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

Hayat T, Sadia Asad, Mustafa M, Alsaedi A. Boundary layer flow of carreau fluid over a convectively heated stretching sheet, Applied Mathematics and Computation, 2014; 246: 12-22

Nadeem S, Rizwan UI Haq, Noreen Sher Akbar, Khan Z H. MHD three-dimensional Casson fluid flow past a porous linearly stretching sheet, Alexandria Engineering Journal, 2013; 52: 577-582

Vijayaragavan R, Karthikeyan S. Joule heating and thermal radiation effects on chemically reacting Casson fluid past a vertical plate with variable magnetic field, Research J. Engineering and Tech., 2017; 8 (4): 393-404

Reddy N N, Rao V S, Ravindra Reddy B. Chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of heat source/sink and viscous dissipation, Case Studies Thermal Engineering, 2021; 25

Olanrewaju P O, Arulogun O T, Adebimpe K. Internal heat generation effect on thermal boundary layer with a convective surface boundary condition, Amer. J. Fluid Dyn., 2012; 2 (1): 1-4

Manh T D, Nam N D, Abdulrahman G K, Moradi R, Babazadeh H. Impact of MHD on hybrid nanometerial free convective flow within permeable region, J. Therm. Anal. Calorim., 2020; 140: 2865-2873

Sharma B K, Chaudhary R C. Hydromagnetic unsteady mixed convection and mass transfer flow past a vertical porous plate immersed in a porous medium with hall effect, Engineering Transactions, 2008; 56 (1): 3-23

Srinivas Raju R. Combined influence of thermal diffusion and diffusion thermo on unsteady hydromagnetic free convective fluid flow past an infinite vertical porous plate in presence of chemical reaction, Journal of Institution of Engineers (India), Series C, 2016; 1-11

Rajeswari R, Jothiram B, Nelson V K. Chemical reaction, heat and mass transfer on Nonlinear MHD boundary layer flow through a vertical porous surface in the presence of suction, Applied Mathematical Sciences, 2009; 3 (49-52): 2469-2480

Chenna Kesavaiah D, P V 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

ChKesavaiah D, Satyanarayana P V and Venkataramana S (2012): Radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, International Journal of Scientific Engineering and Technology, 2012; 1 (6): 274-284,

Chenna Kesavaiah D, Satyanarayana P V, A Sudhakaraiah, Venkataramana S (2013): 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

ChKesavaiah 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

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

ChennaKesavaiah D, Satyanarayana P V 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, Vol. 2 (2), pp: 56-72

Ruchika Mehta, Ravindra Kumar, Himanshu Rathore, Jagdev Singh. Joule heating effect on radiating MHD mixed convection stagnation point flow along vertical stretching sheet embedded in a permeable medium and heat generation/absorption, 2022; 51 (8): 7369-7386

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

Chenna Kesavaiah D, Ikramuddin Sohail Md , Jahagirdar R S. MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects, Suraj Punj Journal For Multidisciplinary Research, 2018;8 (11): 46-62

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

Deepak Kumar, Sharad Sinha, Anil Sharma, Priyanka Agarwal, Praveen Kumar Dadheech. Numerical study of chemical reaction and heat transfer of MHD slip flow with Joule heating and Soret-Dufour effect over an exponentially stretching sheet, 2022, 51 (2): 1939-1963

B K Sharma, Rishu Gandhi. Combined effects of Joule heating and non-Uniform heat source/sink on unsteady MHD mixed convective flow over a vertical stretching surface embedded in a darcy-Forchheimer porous medium, Propulsion and Power Research, 2022; 11 (2): 276-292

Chenna Kesavaiah D, Govinda Chowdary P, Ashfar Ahmed, Devika B. Radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, NEUROQUANTOLOGY, 2022; 20 (11): 821-835

Alam M, Rahman M, Sattar M. Effects of chemical reaction and thermophoresis on magneto-hydrodynamic mixed convective heat and mass transfer flow along an inclined plate in the presence of heat generation and or absorption with viscous dissipation and joule heating, Can. J. Phys., 2008; 86 (9): 1057-1066

Chenna Kesavaiah D, Govinda Chowdary P, Rami Reddy G, Nookala Venu. 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, NEUROQUANTOLOGY, 2022; 20 (11): 800-815

Khan M I, Hayat T, Khan M I, Alsaedi A. A modified homogeneous –heterogeneous reaction for MHD stagnation flow with viscous dissipation and Joule heating, Int. J. Heat Mass Tran., 2017; 111: 310-317

Chenna Kesavaiah D, Karuna Prasad M, Bhaskar Reddy G, Nookala Venu. Chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties, NEUROQUANTOLOGY; 20 (11): 781-794

Tripathi B, Sharma B K. Influence of heat and mass transfer on two-phase blood flow with Joule heating and variable viscosity in the presence of variable magnetic field, Int. J. Comput. Methods, 2020; 17 (3), 1850139

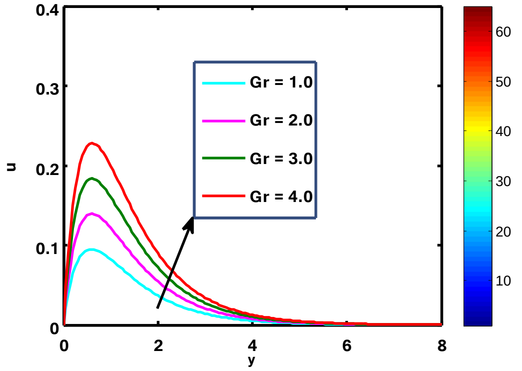
Chenna Kesavaiah D, Govinda Chowdary P, Chitra M, Nookala Venu.Chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer, NEUROQUANTOLOGY, 2022; 20 (8): 9425-9434

Rahman M M, Hakan F Oztop, Rahim N A, Saidur R, Khaled Al-Salem. MHD mixed convection with Joule heating effect in a Lid driven with a heated semi-circular source using the finite element technique, Numerical Heat Transfer Part A, 2011; 60 (6): 543-560

Chenna Kesavaiah D, Bhaskar Reddy G, Anindhya Kiran, Nookala Venu. MHD Effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface, NEUROQUANTOLOGY, 2022; 20 (8): 9442-9452

Deepak Kumar, Sharad Sinha, Anil Sharma, Priyanka Agarwal, Praveen Kumar Dadheech. Numerical study of chemical reaction and heat transfer of MHD slip flow with Joule heating and Soret-Dufour effect over an exponentially stretching sheet, 2022, 51 (2): 1939-1963

Vijayaragavan and Karthikeyan, 2017. Joule heating and thermal radiation effects on chemically reacting Casson fluid past a vertical plate with variable magnetic field, Research J. Engineering and Tech., 2017; 8 (4): 393-404



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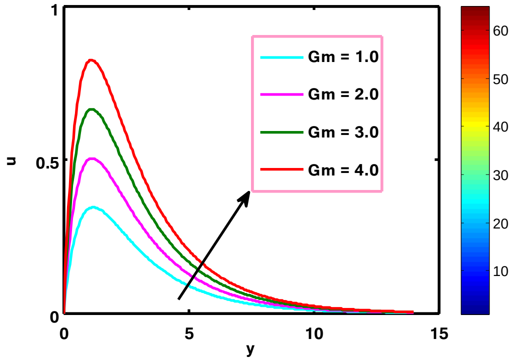

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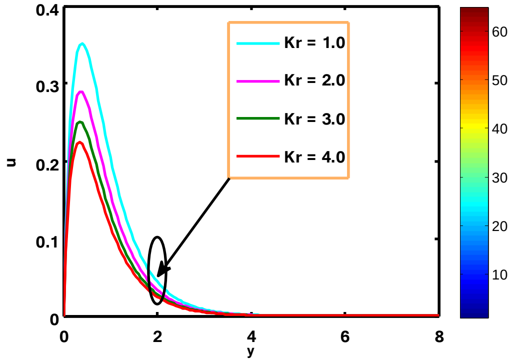

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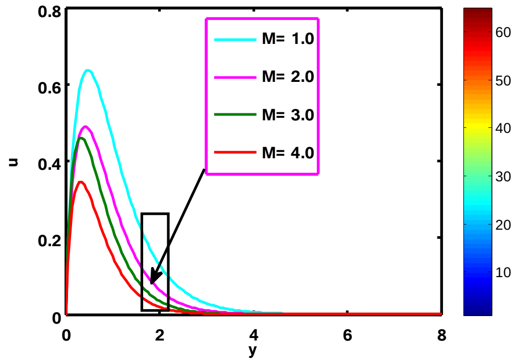

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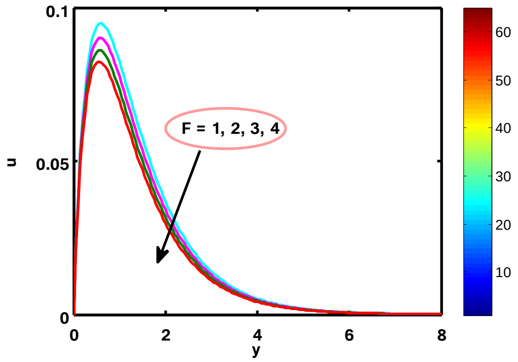

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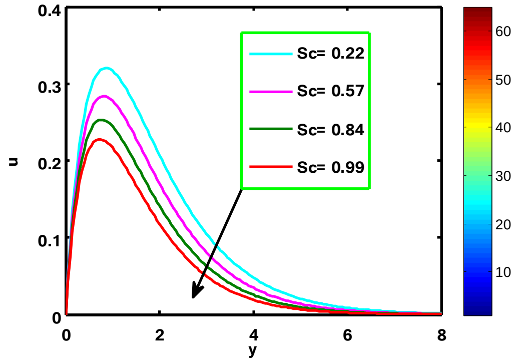

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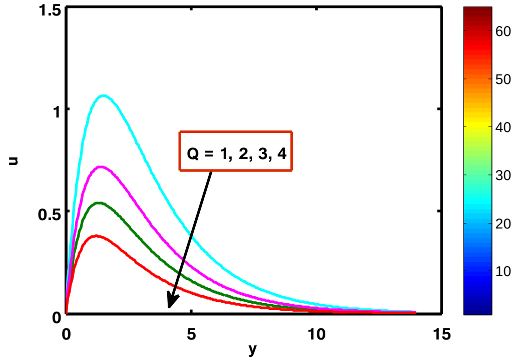

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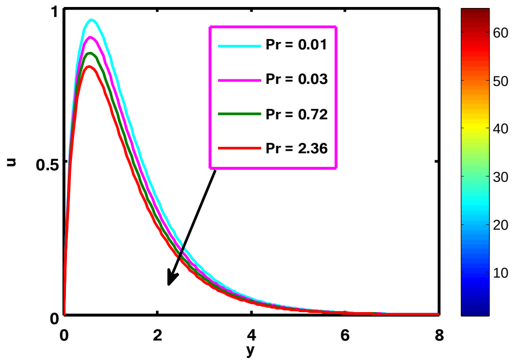

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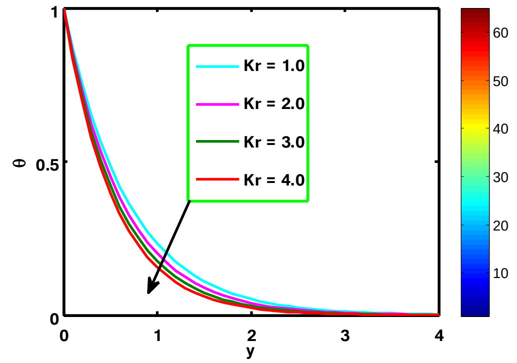

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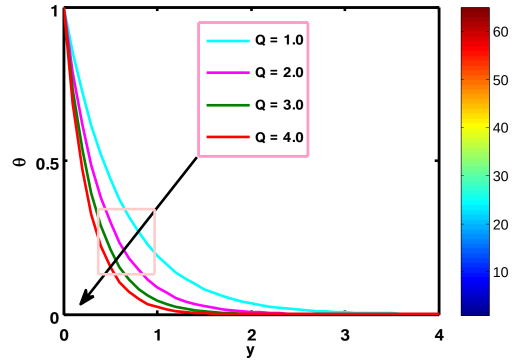

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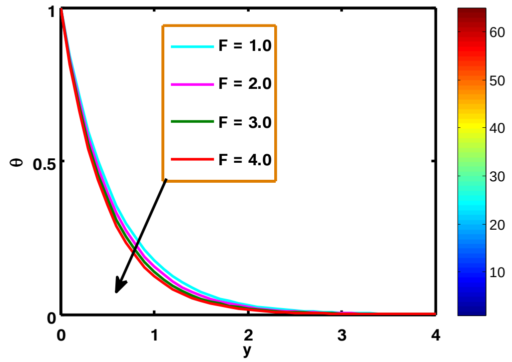

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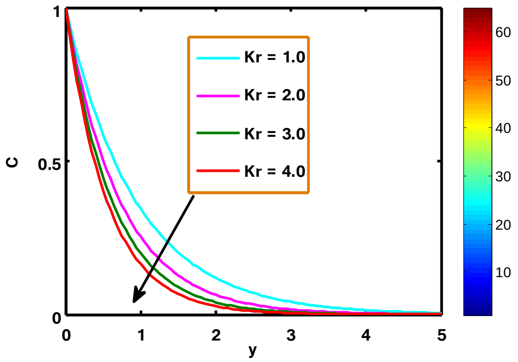

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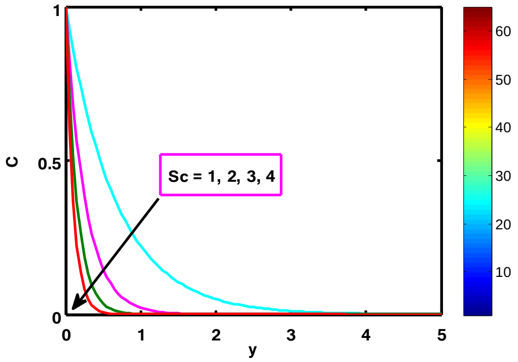

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