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ASPECTS OF MHD FLOW IN PARABOLIC FORM UNDER VISCOUS DISSIPATION AND CHEMICAL REACTION

T.RAMANJANEYULU [1*], L.HARI KRISHNA[2]

[1] Department of Mathematics, JNT University Anantapur, Ananthapuramu, Andhra Pradesh, India

[2] Department of Mathematics, Annamachrya Institute of Technology and Sciences, Rajmpeta, Andhra Pradesh, India

* corresponding author

Abstract

The physical properties of MHD flow across a perpendicular porous plate in parabolic motion have been drawn out in a theoretical investigation. Thermal radiation, mass diffusion, radiation absorption, and chemical reaction are considered in this analysis. The governed equations of the flow are transformed to non-dimensional form and resolved through finite difference scheme in explicit form. The nature of the flow in terms of velocity, concentration and temperature in addition to skin friction, Sherwood number and Nusselt number is described with the help of graphs and tables. An assessment with published outcomes is done and noticed good contract in it. The concentration of the fluid decreases as the chemical reaction parameter and Schmidt number enhances. For growing Prandtl number, radiation parameter, radiation absorption, and chemical reaction parameter values, Nusselt number increases.

Keywords: MHD; Parabolic motion; Thermodynamic radiation; Radiation absorption and chemical reaction'

Introduction

MHD has gained the interest of engineering scientists, as well as applied mathematics researchers in the context of significant applications in engineering, aerodynamics, geophysics, and aeronautics. Solar cookers and solar concentrators are some of the applications of parabolic motion. A solar cooker with a parabolic concentrator can be used for a variety of tasks, including baking, roasting, and distilling. Solar concentrators are used to speed up the vanishing of misuse water, as well as in foodstuff dealing out and the production of drinking water from brackish and salt water. Barik [1] studied the effects of chemical reaction and radiation effects on MHD free convective flow past an impulsively moving vertical plate with ramped wall temperature and concentration. Chandra Reddy et al. [3,4,5] analyzed the MHD flows under the existence of variety of physical parameters by using Laplace transform technique as well as numerical method. Durga Prasad et al. [5] have initiated three dimensional slip flow of a chemically reacting casson fluid flowing over a porous slender sheet with a non-uniform heat source or sink. Prasad et al. [6] studied 3D flow of Carreau polymer fluid over variable thickness sheet in a suspension of microorganisms with Cattaneo-Christov heat. Prasad et al. [7] investigated combined effects of brownian motion and thermophoresis parameters on three-dimensional (3D) Casson nanofluid flow across the porous layers slendering sheet in a suspension of graphene nanoparticles. Hari and Harshad [8] analyzed MHD parabolic subsequent evaluation of fluid flow under ramping wall temperature and ramped wall concentration. Jagadha et al. [9] investigated Newtonian Carreau nanofluid through stretching cylinder considering the first-order chemical reaction. Kataria et al. [10] explained heat and mass transfer in magnetohydrodynamic (MHD) Casson fluid flow past over an oscillating vertical plate embedded in porous medium with ramped wall temperature. Kumar et al. [11] analyzed on three-dimensional magnetized slip flow of Carreau non-Newtonian fluid flow through conduction and radiative chemical reaction. Madhusudhan et al. [12] explored heat and mass transfer mechanism on three-dimensional flow of inclined magneto Carreau nanofluid with chemical reaction. Mahdy [13] investigated the consequence of chemical reaction and heat production from a perpendicular shortened cone in an absorbent medium with an unstable thickness. Muralidharn et al. [14] investigated about parabolic started flow past a perpendicular plate with consistent heat flux and changeable mass dispersion. Muthucumaraswamy and Sivakumar [15] studied the impact of thermal energy and chemical reaction on a MHD parabolic flow past an infinitely hot vertical plate. Obulesu et al. [16] explained about MHD heat and mass transfer steady flow of a convective fluid through a porous plate in the presence of diffusion thermo and aligned magnetic field. Patel [17,18,19,20,21] discussed MHD heat and mass transfer effect of Casson, Carreau, micro polar fluid under the influence of hall current, Soret effect and thermal radiation. Prabhakar Reddy [22] discovered unstable MHD free convection flows passed over countless vertical isothermal plate under dissipative effects, radiation and chemical reaction. Raju et al. [23] investigated transpiration effects on MHD flow over a stretched cylinder with Cattaneo–Christov heat flux with suction or injection. Raju et al. [24] explained mathematical model of convective flow through pores in a horizontal channel with an insulated bottom wall and Joule's heating as well as viscous dissipation. Ramana Reddy et al. [25] studied radiation and chemical reaction effects on MHD flow along moving vertical porous plates. Sinha and Mondal [26] examined the influence of slip velocity on magnetohydrodynamic flow of blood and heat transfer through a permeable capacity. Sivakumar et al. [27] studied influence of partial slip and dissipation on MHD radiative Ferro-fluid over a non-linear permeable convectively heated stretching sheet. Sivaraj and Benazir [28] analyzed unsteady magnetohydrodynamics mixed convective oscillatory flow of Casson fluid in a porous asymmetric wavy channel. Raju et al. [29] explored analytical and numerical study of unsteady MHD free convection flow over an exponentially moving vertical plate with heat absorption. Srinivasacharya et al. [30] reported chemical reaction and radiation effects on mixed convection heat and mass transfer over a vertical plate in power-law fluid saturated porous medium. Umamaheswar et al. [31] examined unsteady magnetohydrodynamic free convective double-diffusive viscoelastic fluid flow past an inclined permeable plate in the presence of viscous dissipation and heat absorption. Umamaheswar et al. [32] analyzed of MHD transient free convection flow of a Newtonian fluid past an infinite vertical porous plate. Upadhya et al. [33] investigated mass transfer analysis of two-phase flow in a suspension of microorganisms. Visalakshi and Vasanthabhavam [34] discussed heat and mass transfer effects on flow past parabolic started vertical plate with constant heat flux.

The flows in parabolic mode play a vital role in petroleum industries and chemical reactors in purification processes. Based on the importance, the survey mentioned above is done and noticed some points which are not considered. Hence the study of Prabhakar Reddy et al. [22] is taken and extended. The novelty of this analysis is the accumulation of radiation absorption and chemical reaction.

Formulation of the problem

Under thermal and solutal buoyancy, an unsteady condition of MHD incompressible viscous fluid flow in parabolic mode has been investigated. Thermal radiation, viscous dissipation, radiation absorption and chemical reaction are taken into account and the flow passes over an isothermal upright plate. The direction of the plate is treated as x^* - axis and its normal position as y^* - axis. A crosswise fascinating field of potency B_o is applied to the stream. At instance $t^* \le 0$, the temperature and concentration of the plate and the liquid are maintained at the same level T_∞^* and C_∞^* respectively. At time $t^* > 0$, the plate initiated with velocity $u_0 A^2 t^{*^2}$ in its own plane against the gravitational field. The temperature and the concentration rise to $\left(T_w^* - T_\infty^*\right)e^{At^*} + T_\infty^*$ and $\left(C_w^* - C_\infty^*\right)e^{At^*} + C_\infty^*$ respectively. A chemically reactive species which transforms according to a simple reaction involving the concentration is emitted from the plate and diffuses into the fluid. Under the usual Boussinesq's approximation and boundary layer approximations, the unsteady parabolic starting motion is governed by the following equations (Prabhakar Reddy et al[22]) (Muthucumaraswamy and Sivakumar[15])

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

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k_T \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q^*}{\partial y^*} + Q_l\left(C^* - C_\infty^*\right) + \mu\left(\frac{\partial u^*}{\partial y^*}\right)^2 \tag{2}$$

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - \left(C^* - C_\infty^*\right)K_r^* \tag{3}$$

The initial and boundary conditions are as follows.

$$\left.\begin{array}{l} u^* = 0, T^* = T_\infty^*, C^* = C_\infty^* \qquad \text{for all } t^* \le 0, y^* \\ t^* > 0 : u^* = u_0 A^2 t^{*2}, T^* = T_\infty^* + \left(T_w^* - T_\infty^*\right)e^{At^*}, \\ C^* = C_\infty^* + \left(C_w^* - C_\infty^*\right)e^{At^*} \quad \text{at } y^* = 0 \\ u^* \to 0, T^* \to T_\infty^*, C^* \to C_\infty^* \quad \text{as } y^* \to \infty \end{array}\right\} \tag{4}$$

Where $A = \frac{u_0^2}{\nu}$

The following are the non-dimensional equations

$$u = \frac{u^*}{u_0}, t = \frac{t^* u_0^2}{\nu}, y = \frac{y^* u_0}{\nu}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \mathrm{C} = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, Gr = \frac{\nu g \beta \left(T_w^* - T_\infty^*\right)}{u_0^3},$$

$$Gm = \frac{\nu g \beta^* \left(C_W^* - C_\infty^*\right)}{u_0^3}, M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, K = \frac{k_p^* u_0^2}{\nu^2}, \mathrm{Pr} = \frac{\rho \nu C_p}{k_T},$$

$$\frac{\partial q^*}{\partial y^*} = 4\left(T^* - T_\infty^*\right)\mathrm{I}^*, R = \frac{4\nu I^*}{\rho C_p u_0^2}, Q = \frac{Q^* \nu}{\rho C_p u_0^2}, \chi = \frac{Q_l \nu \left(C_w^* - C_\infty^*\right)}{\rho C_p u_0^2 \left(T_w^* - T_\infty^*\right)},$$

$$Sc = \frac{\nu}{D}, Kr = \frac{K_r^* \nu}{u_0^2},, Ec = \frac{\nu}{Cp\left(T_w^* - T_\infty^*\right)}, Kr = \frac{K_r^* \nu}{u_0^2}$$

After introducing the non-dimensional quantities into the equations (1) - (3) these equations reduces to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\,\theta + Gm\,C - M\,u - \frac{1}{K}u \tag{5}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial y^2} - R\theta + \chi C + Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{6}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - CKr \tag{7}$$

In addition, the corresponding boundary conditions are given by

$$\left.\begin{array}{l} u = 0, \theta = 0, C = 0\, for\ all\, y, t \le 0 \\ t > 0: u = t^2, \theta = e^t, C = e^t \mathrm{at} y = 0 \\ u \to 0, \theta \to 0, C \to 0 \mathrm{as} y \to \infty \end{array}\right\} \tag{8}$$

Method of solution:

Equations (5)-(7) are non-linear partial differential equations and are to be solved by using the initial and boundary conditions (8). However exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (5)-(7) are as follows:

$$\frac{u_{.i,j+1} - u_{.i,j}}{\Delta t} = Gr\,\theta_{i,j} + Gm\,C_{i,j} + \frac{u_{.i-1,j} - 2u_{.i,j} + u_{.i+1,j}}{(\Delta y)^2} - M\,u_{.i,j} - \frac{1}{K}u_{.i,j} \tag{9}$$

$$\frac{\theta_{.i,j+1}-\theta_{.i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{.i,j}+\theta_{i+1,j.}}{(\Delta y)^2}-R\theta_{.i,j.}-\chi C_{i,j.}+Ec\left(\frac{u_{i,j.+1}-u_{i,j.}}{\Delta y}\right)^2 \qquad (10)$$

$$\frac{C_{.i,j+1}-C_{.i,j}}{\Delta t}=\frac{1}{Sc}\frac{C_{i-1,j}-2C_{.i,j}+C_{i+1,j}}{(\Delta y)^2}-Kr\,C_{.i,j} \qquad (11)$$

Here the suffix i means y, and suffix j refers to time. Taking y = 0.1, the mesh system is partitioned with the subsequent equivalent from the preliminary condition in (8):

$$\theta(i.,0)=0, C(i.,0)=0, u(i.,0)=0 \quad \text{for all } i \qquad (12)$$

From (8), the following are the boundary conditions in finite-difference form:

$$\theta(0,j)=e^t, u(0,j)=t^2, C(0,j)=e^t \text{ for all } j$$

$$\theta(i_{\max imum},j)=0, u(i_{\max imum},j)=0, C(i_{\max imum},j)=0 \text{ for all } j$$

(at this point i_{max} was full as 200)

Velocity at the end of each time step, $u_{i,j+1}$ (i=1-200), is derived first from (9) in terms of velocity, temperature and concentration at points on the earlier time-step. Then θ (i, j +1) is computed from (10) and C (i, j +1) is computed from (11). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

Skin-friction:

The non-dimensional form of skin friction is given by

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{,y=0}, where\ \tau=\frac{\tau^1}{\rho u_0^2}$$

Rate of heat transfer:

The non-dimensional rate of heat transport can be expressed as follows

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

Rate of mass transfer:

In order to calculate the dimensionless mass transfer rate, follow these steps:

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

Result and discussion

In the present study, the variations in velocity, temperature and concentration are observed with the help of graphs and tables. It is noticed from Figure 1 that the concentration of the liquid declines when the chemical reaction parameter values are increasing. From Figure 2 it is evident that the concentration of the fluid declines as Schmidt digit values increases. Figure 3 shows that the temperature of the liquid decreases as Eckert number increases. It is obvious from the Figure 4 as radiation parameter values increase, the fluid temperature decreases. Figure 5 exhibits that as Prandtl values increase, the temperature of the fluid falls. Figure 6 reveals that the velocity of the fluid decreases as magnetic parameter values are increasing. This happens due to the retarding force named as Lorentz force occurred by the magnetic field. Figure 7 and Figure 8 shows that the velocity of the fluid increases when Grashof number and modified Grashof number increase. Table. 1 reveals that the Sherwood number values are increases as Schmidt number and chemical reaction values are increasing. Table.2 exhibits that the Nusselt number increases for increasing values of Prandtl number, radiation absorption, radiation parameter and chemical reaction. Table. 3 shows that the skin friction values are decreasing for increasing values of Grashof number, modified Grashof number and it increases for raising values of magnetic parameter, Prandtl number, radiation absorption parameter, chemical reaction parameter and radiation. A comparison has been made with the previously published results by considering the impacts of radiation and Schmidt number on skin friction coefficient and found an excellent agreement in it. It is clearly depicted in Table 4 and observed that an increment in thermal radiation and Schmidt number leads to decrease the skin friction coefficient.

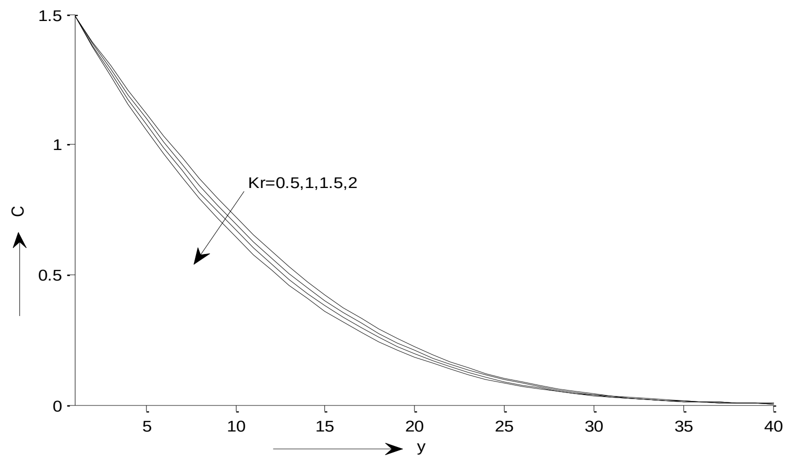

Figure 1. Consequence of Kr on concentration

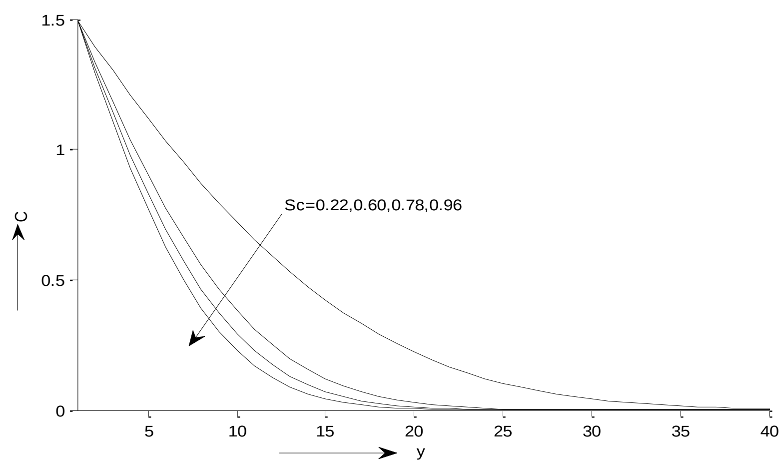

Figure 2. Consequence of Sc on concentration

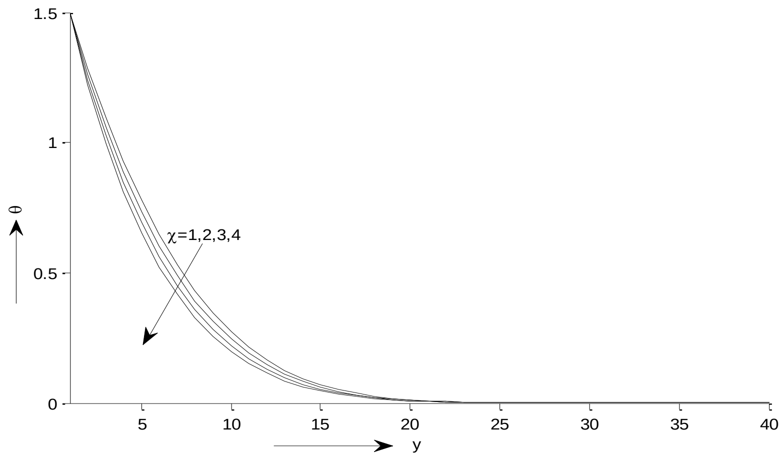

Figure 3. Consequence of χ on Temperature

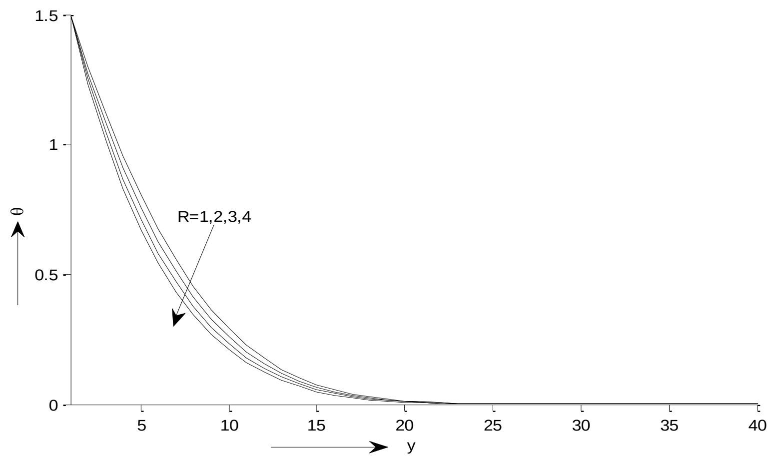

Figure 4. Consequence of R on Temperature

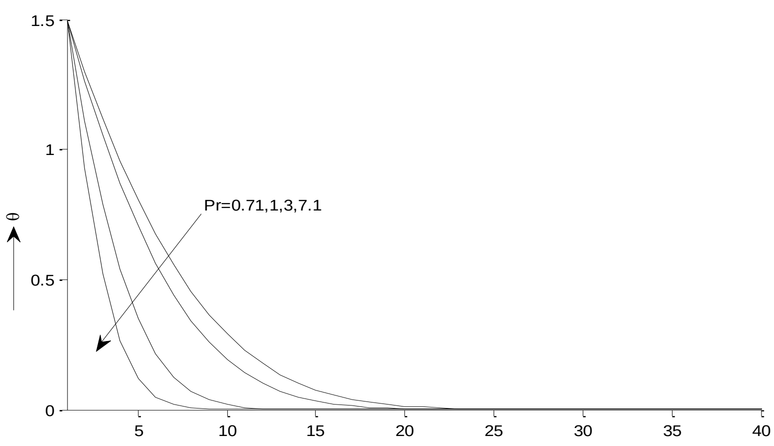

Figure 5. Consequence of Pr on Temperature

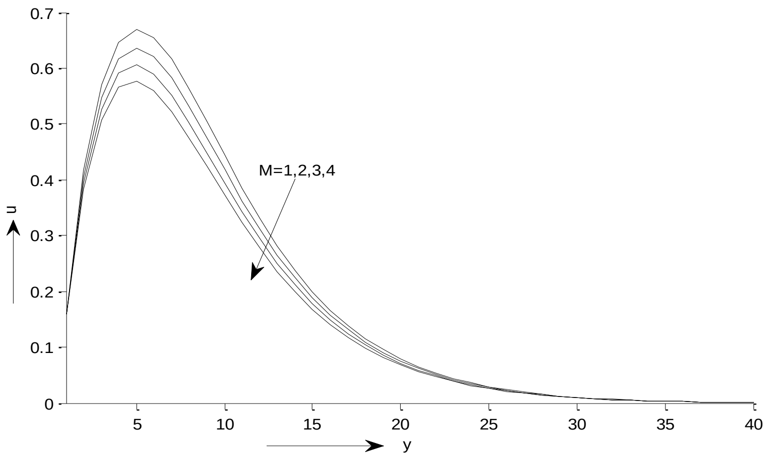

Figure 6. Consequence of M on Velocity

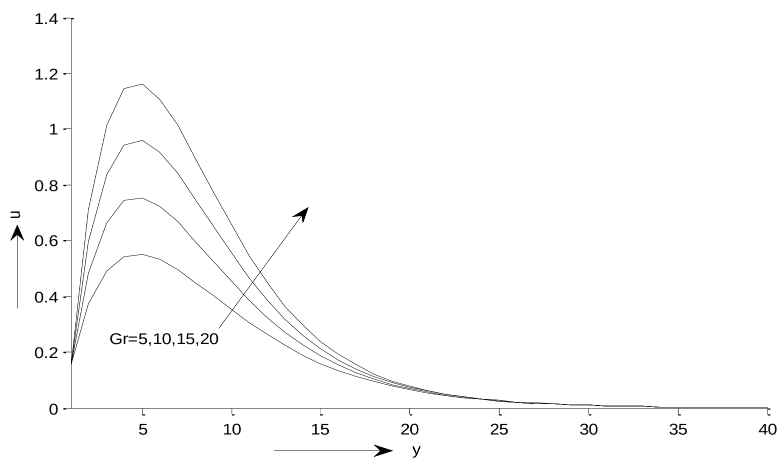

Figure 7. Consequence of Gr on Velocity

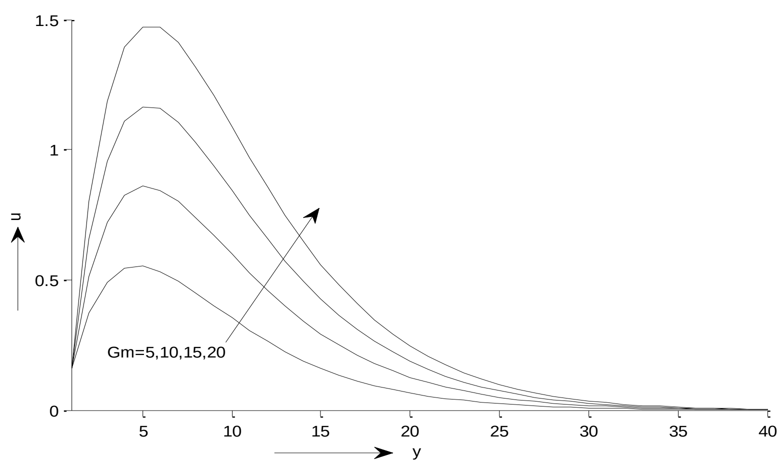

Figure 8. Consequence of Gm on Velocity

Table 1. Sherwood number variations

Sc	Kr	Sh
0.22	0.5	0.6924
0.66	0.5	1.1993
0.78	0.5	1.3038
0.96	0.5	1.14464
0.22	1	0.8163
0.22	1.5	0.9315
0.22	2	1.0396

Table 2: Variations in Nusselt number

Pr	χ	R	Kr	Nu
0.71	0.5	1	0.5	1.6447
1	0.5	1	0.5	1.9542
3	0.5	1	0.5	3.3954
0.71	0.5	1	0.5	1.6447
0.71	1	1	0.5	1.8397
0.71	1.5	1	0.5	2.0226
0.71	0.5	1	0.5	1.6447
0.71	0.5	2	0.5	2.0226
0.71	0.5	3	0.5	2.3575
0.71	0.5	1	0.5	1.6447
0.71	0.5	1	1	1.6457
0.71	0.5	1	1.5	1.6466

Table 3. Skin Friction Variations

Gr	Gm	M	Pr	χ	Kr	R	τ
5	5	5	0.71	0.5	0.5	1	-3.1818
10	5	5	0.71	0.5	0.5	1	-4.8830
15	5	5	0.71	0.5	0.5	1	-6.6039
5	10	5	0.71	0.5	0.5	1	-5.1907
5	15	5	0.71	0.5	0.5	1	-7.2050
5	20	5	0.71	0.5	0.5	1	-9.2249
5	5	1	0.71	0.5	0.5	1	-4.0191
5	5	2	0.71	0.5	0.5	1	-3.7693
5	5	3	0.71	0.5	0.5	1	-3.5500
5	5	5	0.71	0.5	0.5	1	-3.1818
5	5	5	1	0.5	0.5	1	-3.0950
5	5	5	3	0.5	0.5	1	-2.7808
5	5	5	0.71	0.5	0.5	1	-3.1818
5	5	5	0.71	1	0.5	1	-3.1401
5	5	5	0.71	1.5	0.5	1	-3.1018
5	5	5	0.71	0.5	1	1	-3.1448
5	5	5	0.71	0.5	1.5	1	-3.1107
5	5	5	0.71	0.5	2	1	-3.0793
5	5	5	0.71	0.5	0.5	1	-3.1448

5	5	5	0.71	0.5	0.5	2	-3.1018
5	5	5	0.71	0.5	0.5	3	-3.0338

Table 4: Comparison of present results with published results

R	Sc	**τ** (Results of Prabhakar Reddy et al[22])	**τ** (Present results)
1	0.22	3.039136	3.02988
	0.60	2.623584	2.61489
	0.78	2.503094	2.50089
2	0.22	2.739832	2.72584
	0.60	2.325818	2.31848
	0.78	2.206034	2.20148
3	0.22	2.555062	2.54982
	0.60	2.141444	2.14136
	0.78	2.021912	2.02188

Conclusion

This analysis is based on the following facts:

1. The speed of the liquid declines for growing values of M, but it displays converse tendency in the case of Gr and Gm.
2. The temperature of the fluid declines for growing values of Prandtl digit, radiation parameter and heat absorption.
3. The concentration of the fluid decreases as the chemical reaction parameter and Schmidt number enhances.
4. Sherwood number grows for raising values of chemical reaction parameter and Schmidt number enhances.
5. For growing Prandtl number, radiation parameter, radiation absorption, and chemical reaction parameter values, Nusselt number increases.

Nomenclature:

A, a	Constants
Cp	Specific heat at constant pressure [J.kg^{-1} K^{-1}]
Gr	Thermal Grashof number
Gm	mass Grashof number
g	Acceleration due to gravity [m.s^{-2}]
k_T	Thermal conductivity [W.m^{-1}.K^{-1}]
B_o	Magnetic field parameter
Pr	Prandtl number
K	porosity parameter
K_r	Chemical reaction parameter
R	radiation parameter
M	magnetic parameter
D	molecular diffusivity
Nu	Nusselt number
U	Velocity of the plate [m.s^{-1}]
T	Time [s]
θ	Temperature [K]
C	Concentration [g/ml]
Y	Coordinate axis [m]

Greek symbols

B	Thermal volumetric coefficient [K^{-1}]
M	Coefficient of viscosity [Pa.s]
χ	Radiation absorption
N	Kinematic viscosity [m^2.s^{-1}]
P	Density of the fluid [kg.m^{-3}]

D_1	thermal diffusivity	T	skin friction
E_c	Eckert number	Σ	Electrical conductivity [ohm^{-1} s^{-1}]
Sc	Schmidt number		**Superscript**
Sh	Sherwood number	*	Dimensional

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