# Magneto-convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration

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***Abstract*** — *A numerical analysis is carried out for an unsteady free convective, radiative, chemically reactive, radiation absorption, viscous, incompressible and electrically conducting fluid past an exponentially accelerated vertical porous plate in the presence of sink. The set of non-dimensional governing equations along with boundary conditions are solved numerically. The effect of various physical parameters on flow quantities are studied with the help of graphs. For the physical interest, the variations in skin friction, Nusselt number and Sherwood number are also studied through tables.*

**Keywords —** *Numerical study; MHD; Radiation; radiation absorption; Chemical reaction.*

## I. Introduction

The study of MHD flows with simultaneous heat and mass transfer has been attracting many researchers of engineering science and applied Mathematics due to extensive applications of such flows in the field of geophysics, aerodynamics, engineering and industries. Kim [1] considered an unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Khan et al., [2] analyzed MHD boundary layer flow of a nanofluid containing gyro tactic microorganisms past a vertical plate with Navier slip. Jha [3] deliberated MHD free convection mass transform flow through a porous medium. Seth et al., [4] studied MHD natural convection flow past an impulsively Moving vertical plate with ramped wall temperature in the presence of thermal diffusion with heat absorption. Seth et al., [5] found effects of thermal radiation and rotation on unsteady hydromagnetic free convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium. Rao et al., [6] analysed chemical effects on an unsteady MHD free convection fluid past a semi-infinite vertical plate embedded in a porous medium with heat absorption. Muthucumaraswamy and Meenakshisundaram [7] studied theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature. Kandaswamy et al., [8] considered Chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. Raju and Varma [9] analysed Soret effects due to natural convection in anon-Newtonian fluid flow in porous medium with heat and mass transfer. Umamaheswar et al., [10] studied Unsteady MHD free convective Visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and Ohmic heating. Afify [11] studied free convective flow and mass transfer over a stretching sheet with chemical reaction. Chamkha and Ahmed [12] analyzed Similarity solution for unsteady MHD flow near a stagnation point of a three dimensional porous body with heat and mass transfer, heat generation/ absorption and chemical reaction. Kandaswamy [13] considered Effects of chemical reaction, heat and mass transfer in boundary layer flow over a porous wedge with heat radiation in presence of suction or injection. Makinde [14] studied free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. Anjalidevi [15] effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate.

## II. FORMULATION OF THE PROBLEM

We consider a viscous incompressible, electrically conducting, heat absorbing/generating and chemically reacting Newtonian fluid flow past an infinite vertical porous. A magnetic field of uniform strength is applied perpendicular to the plate. Let $x^*$-axis is taken along the plate in the vertically upward direction and the $y^*$-axis is taken perpendicular to the plate. At time $t \leq 0$, the plate is maintained at the temperature higher than ambient temperature $T_\infty$ and the fluid is at rest. At time $t > 0$, the plate is linearly accelerated with increasing time in its own plane and also At time $t^*>0$ the temperature and Concentration of the plate $y^{*}=0$ is raised to

$$T_\infty^* + \left(T_w^* - T_\infty^*\right) e^{a^* t^*} \text{ and } C_\infty^* + \left(C_w^* - C_\infty^*\right) e^{a^* t^*}$$

with time t and thereafter remains constant and that of $y^{*}\rightarrow\infty$ is lowered to $T_\infty^*$ and $C_\infty^*$. It is assumed that the effect of viscous dissipation is negligible. By usual Boussineq's and boundary layer approximation, the unsteady flow is governed by the following equations:

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

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

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

The corresponding initial and boundary conditions are

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

Where $a = \frac{a^* \nu}{u_0^2}$

The non-dimensional quantities are as follows:

$$u = \frac{u^*}{u_0}, t = \frac{t^* u_0^2}{\nu}, y = \frac{y^* u_0}{\nu}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},$$

$$C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, Gr = \frac{\nu g\beta\left(T_w^* - T_\infty^*\right)}{u_0^3},$$

$$Gm = \frac{\nu g\beta^*\left(C_w^* - C_\infty^*\right)}{u_0^3}, M = \frac{\sigma B_0^2 \nu}{\rho u_0^2},$$

$$K = \frac{k_p^* u_0^2}{\nu^2}, \Pr = \frac{\rho\nu C_p}{k_T}, Q = \frac{Q^* \nu}{\rho C_p u_0^2},$$

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

$$\chi = \frac{Q_l \nu\left(C_w^* - C_\infty^*\right)}{\rho C_p u_0^2\left(T_w^* - T_\infty^*\right)}, Sc = \frac{\nu}{D}, Kr = \frac{K_r^* \nu}{u_0^2}.$$

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

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

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - R\theta - Q\theta + \chi C \quad (6)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - Kr\,C \quad (7)$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{ll} u = 0, \theta = 0, C = 0 & \text{for all } y, t \le 0 \\ t > 0: u = e^{at}, \theta = e^{at}, C = e^{at} & \text{at } y = 0 \\ u \to 0, \theta \to 0, C \to 0 & \text{as } y \to \infty \end{array}\right\} \quad (8)$$

## III. METHOD OF SOLUTION

Equations (5) -(7) are 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:

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

$$\frac{\theta_{i,j+1} - \theta_{i,j}}{\Delta t} = \frac{1}{\Pr}\frac{\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j}}{(\Delta y)^2} - R\theta_{i,j} - Q\theta_{i,j} + \chi C_{i,j}. \quad (10)$$

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

Here, the suffix i refers to y and j to time. The mesh system is divided by taking Δy = 0.1. From the initial condition in (8), we have the following equivalent:

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

The boundary conditions from (8) are expressed in finite-difference form as follows

$$u(0,j)=e^{at}, \theta(0,j)=e^{at}, C(0,j)=e^{at} \text{ for} \forall j$$

$$u(i_{\max},j)=0, \theta(i_{\max},j)=0, C(i_{\max},j)=0 \text{ for} \forall j \qquad (13)$$

(Here $i_{max}$ was taken as 200)

First the velocity at the end of time step viz, u (i, j+1)(i=1,200) is computed 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 skin-friction in non-dimensional form is given by

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

**Rate of heat transfer:**

The dimensionless rate of heat transfer is given by

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

**Rate of mass transfer:**

The dimensionless rate of mass transfer is given by

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

## IV. RESULT AND DISCUSSION

In order to disclose the effects of various parameters on the dimensionless velocity field, temperature field, concentration field, skin friction, Nusselt number and Sherwood number. The effects of various physical parameters such as magnetic parameter (M), permeability parameter, Prandtl number (Pr), heat sink (Q), radiation parameter (R), radiation absorption parameter ( $\chi$ )and chemical reaction parameter (Kr) on velocity, temperature and concentration are exhibited in the figures 1-7 and studied by choosing arbitrary values. The influence of these parameters on skin friction, Nusselt number and Sherwood number are also shown in Tables 1–3. Figures 1&2 display the variations of the fluid velocity under the effects of different parameters. In figure 1, velocity profiles are displayed with the variation in magnetic parameter. From this figure it is noticed that velocity gets reduced by the increase of magnetic parameter. When an electrically conducting fluid moves in the presence of an applied magnetic field, a magnetic force, called Lorentz force, is generated in the flow field whose tendency is to resist the fluid motion. Due to this reason fluid velocity is getting retarded on increasing magnetic parameter (*M*). Fig.2 depicts the variations in velocity profiles for different values of Permeability parameter. From this figure it is noticed that, velocity increases as K increases.

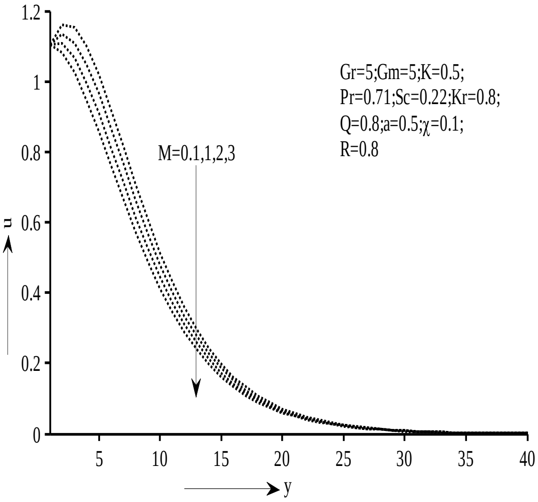


Fig.1: Effect of magnetic parameter on velocity

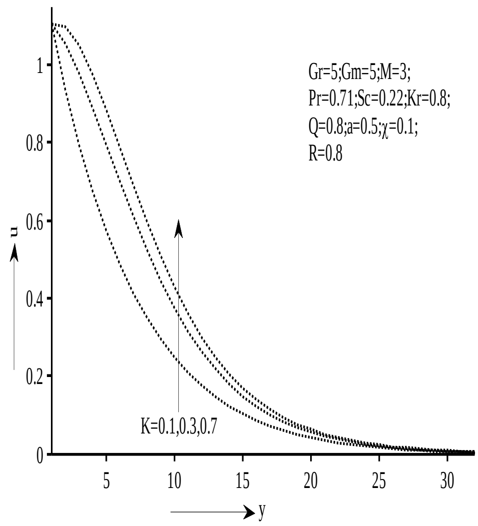


Fig.2: Effect of permeability parameter on velocity

Figures 3-6 display the variations of the fluid temperature under the effects of different parameters.Fig.3 indicates that a rise in Pr substantially reduces the temperature in the viscous fluid. It can be found from Fig.3 that the thickness of thermal boundary layer decreases on increasing Pr. Fig.4 depicts the effect of heat absorption on temperature. It is noticed that the temperature decreases as an increase in the heat absorption parameter. The central reason behind this effect is that the heat absorption causes a decrease in the kinetic energy as well as thermal energy of the fluid. The momentum and thermal boundary layers get thinner in case of heat absorbing fluids. It shows reverse effect in the case of heat generation parameter.Fig.5 shows the effect of radiation parameter on temperature distribution. It shows that the temperature reduces with increasing values of radiation parameter. The effect of radiation absorption parameter on temperature is demonstrated in fig.6. It is observed that temperature increases as an increase in radiation absorption parameter. Figure 7 exhibits the variation of the fluid concentration under the effect of chemical reaction. From Fig.7, we observe that the concentration(C) decreases as chemical reaction (Kr) increases. Table.1 show numerical values of skin-friction for various of Grashof number (Gr), modified Grashof number (Gm), magnetic parameter (M), permeability parameter (K), Prandtl number (Pr), heat sink (Q), radiation parameter (R), radiation absorption parameter ( $\chi$ ), Schmidt number (Sc) and chemical reaction parameter (Kr).

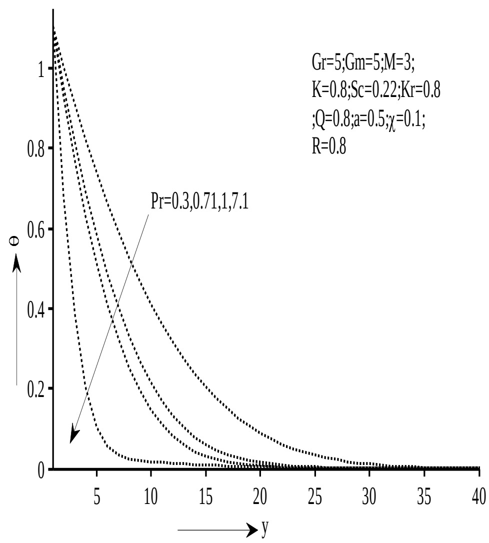


Fig.3: Effect of Prandtl number on temperature

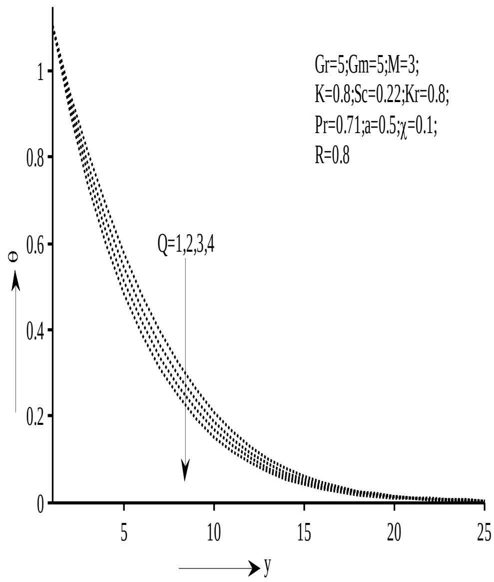


Fig.4: Effect of heat sink on temperature

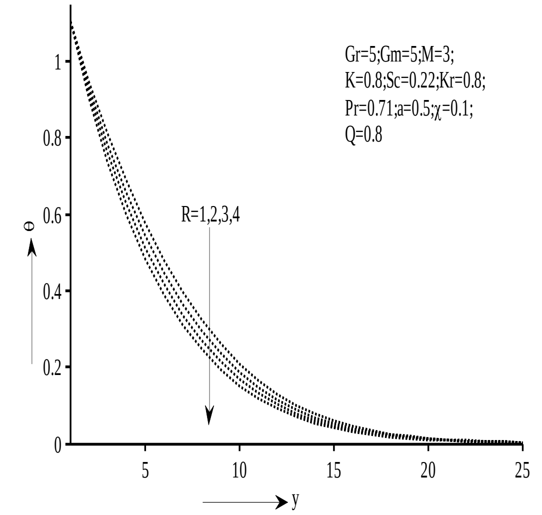


Fig.5: Effect of radiation parameter on temperature

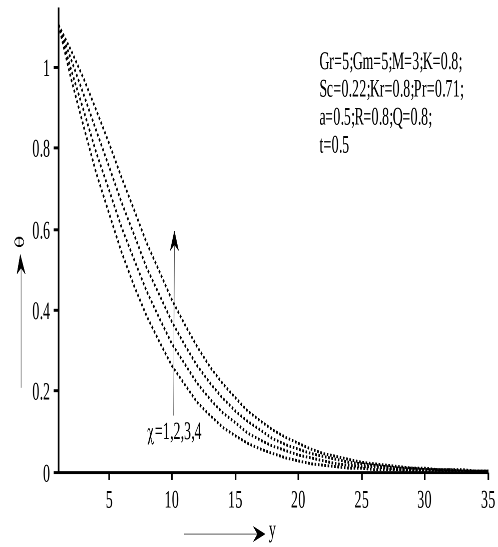


Fig.6: Effect of radiation absorption parameter on temperature

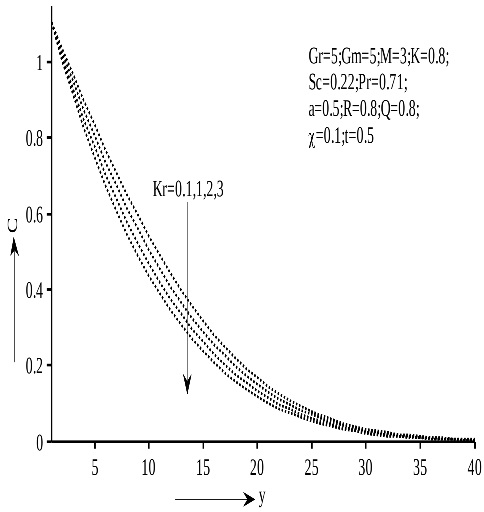


Fig.7: Effect of chemical reaction on concentration

From table.1, we observed that the skin-friction increases with an increase in magnetic parameter, Prandtl number, heat sink, radiation parameter, Schmidt number and chemical reaction parameter whereas it decreases under the influence of Grashof number, modified Grashof number, permeability parameter, radiation absorption parameter.

Table.2 demonstrate numerical values of Nusselt number (Nu) for different values of Prandtl number (Pr), heat sink (Q), radiation parameter (R) and radiation absorption parameter ( $\chi$ ). From table.2, we noticed that the Nusselt number increases with an increase in Prandtl number, heat sink and radiation parameter whereas it decreases under the influence of radiation absorption parameter. Table.3 show numerical values of Sherwood (Sh) for distinct values of Schmidt number (Sc) and chemical reaction parameter (Kr). It can be noticed from table 3, that the Sherwood enhances with rising values of Schmidt number and chemical reaction parameter.

## V. CONCLUSION

In this paper we have considered a numerical study of magneto-convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration. Explicit finite difference method is employed to solve the equations governing the flow. From the present numerical investigation, following conclusions have been drawn:

a. Velocity increases with an increase in permeability of the porous medium while decrease in the existence of magnetic parameter.
b. Temperature increases in the presence of radiation absorption parameter while decrease in the presence of Prandtl number, heat sinks and radiation parameter.
c. Concentration decreases with an increase in chemical reaction parameter.
d. A significance increase is seen in Skin friction for magnetic parameter, Prandtl number, heat sink, radiation parameter, Schmidt number and chemical reaction parameter while it has reverse tendency for Grashof number, modified Grashof number, permeability parameter and radiation absorption parameter.
e. The rate of heat transfer increase with Prandtl number, heat sink and radiation parameter while it shows adverse effect in the case of radiation absorption parameter.

The rate of mass transfer increases with Schmidt number, chemical reaction parameter.

## REFERENCES


[1] Kim. Y.J., Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction, Int. J. Eng. Sci., vol.38,pp. 833– 845, 2000.

[2] Khan, W.A., Makinde, O.D., & Khan, Z.H., MHD boundary layer flow of a nanofluid containing gyro tactic microorganisms past a vertical plate with Navier slip, International journal of heat and mass transfer, vol. 74, pp. 285-291, 2014.

[3] Jha, B.K., MHD free convection mass transform flow through a porous medium, Astrophysics and space science, vol. 175(2), pp. 283-289, 1991.

[4] Seth, G. S., & Ansari, Md. S., MHD natural convection flow past an impulsively Moving vertical plate with ramped wall temperature in the presence of thermal diffusion with heat absorption, Int. J. Appl. Mech. Eng., vol. 15(1), pp. 199-215, 2010.

[5] Seth, G.S., Nandkeolyar, R., & Ansari, Md. S., Effects of thermal radiation and rotation on unsteady hydromagnetic free convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium, J. Appl. Fluid Mech., vol.6(1), pp. 27-38, 2013.

[6] Rao, J.A., Sivaiah, S., and Raju, R. S., Chemical effects on an unsteady MHD free convection fluid past a semi-infinite vertical plate embedded in a porous medium with heat absorption, JAFM, vol. 5(3), pp. 63-70, 2012.

[7] Muthucumaraswamy, R., and Meenakshisundaram, S., Theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature, Theoret. Appl. Mech, vol. 33(3), pp. 245-257,2006.

[8] Kandaswamy, R., Periaswamy, K., and Sivagnana, P. K., Chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection, International Journal of Heat and Mass Transfer., vol. 48, pp. 1388-1394, 2005.

[9] Raju, M. C., and Varma, S. V. K., Soret effects due to natural convection in anon-Newtonian fluid flow in porous medium with heat and mass transfer, Journal of Naval architecture and Marine Engineering,Vol.11(2),pp.147-156, 2014.

[10] Umamaheswar, M., Varma, S. V. K., and Raju, M.C., Unsteady MHD Free Convective Visco-Elastic Fluid Flow Bounded By an Infinite Inclined Porous Plate In The Presence Of Heat Source, Viscous Dissipation And Ohmic Heating, International journal of Advanced Science and Technology, Vol. 61, pp. 39-52, 2013.

[11] Afify, A.A., MHD free convective flow and mass transfer over a stretching sheet with chemical reaction, Heat Mass Transfer, Vol. 40, pp. 495-500, 2004.

[12] Chamkha, A. J., and Ahmed, S. E., Similarity solution for unsteady MHD flow near a stagnation point of a three dimensional porous body with heat and mass transfer, heat generation/ absorption and chemical reaction, Journal of Applied Fluid Mechanics, Vol. 4(2), pp. 87-94, 2011.

[13] Kandaswamy, R., Wahib, B., Md Raj, and Azme, B. K., Effects of chemical reaction, heat and mass transfer in boundary layer flow over a porous wedge with heat radiation in presence of suction or injection, Theatrical Applied Mechanics Belgrade, vol. 33, pp. 123-148, 2006.

[14] Makinde, O. D., Free convection flow with thermal radiation and mass transfer past a moving vertical porous plate, Int. Commun. Heat Mass Transfer, Vol. 32, pp. 1411–1419, 2005.

[15] Anjalidevi, S. P., and Kandasamy, R., Effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate, Heat and Mass Transfer, Vol. 35(6), pp. 465–467, 1999.

**TABLE.1: VARIATIONS IN SKIN FRICTION FOR DIFFERENT VALUES OF FLOW PARAMETERS**

| Gr | Gm | M | K | Pr | Q | R | $\chi$ | Sc | Kr | $\tau$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4089 |
| 10 | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.1769 |
| 15 | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 5.9450 |
| 20 | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 5.7131 |
| **5** | 10 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.0873 |
| **5** | 15 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 5.7657 |
| **5** | 20 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 5.4441 |
| **5** | 5 | 0.5 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3082 |
| **5** | 5 | 1 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3284 |
| **5** | 5 | 2 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3687 |
| **5** | 5 | 3 | 0.1 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.7533 |
| **5** | 5 | 3 | 0.3 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4920 |
| **5** | 5 | 3 | 0.5 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4389 |
| **5** | 5 | 3 | 0.8 | 1 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4414 |
| **5** | 5 | 3 | 0.8 | 3 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.5400 |
| **5** | 5 | 3 | 0.8 | 7.1 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.5870 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.5 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4088 |
| **5** | 5 | 3 | 0.8 | 0.71 | 1 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4090 |
| **5** | 5 | 3 | 0.8 | 0.71 | 2 | 0.8 | 0.8 | 0.22 | 0.8 | 6.4094 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.1 | 0.8 | 0.22 | 0.8 | 6.4086 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.5 | 0.8 | 0.22 | 0.8 | 6.4088 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 1 | 0.8 | 0.22 | 0.8 | 6.4090 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.5 | 0.22 | 0.8 | 6.4091 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 1 | 0.22 | 0.8 | 6.4087 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 2 | 0.22 | 0.8 | 6.4081 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3844 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3567 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3284 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.60 | 0.8 | 6.4775 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.78 | 0.8 | 6.4999 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.96 | 0.8 | 6.5188 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 1 | 6.4089 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 2 | 6.4093 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 3 | 6.4096 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3843 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3565 |
| **5** | 5 | 3 | 0.8 | 0.71 | 0.8 | 0.8 | 0.8 | 0.22 | 0.8 | 6.3282 |

**TABLE.2: VARIATIONS IN NUSSELT NUMBER**

| Pr | Q | R | $\chi$ | Nu |
|---|---|---|---|---|
| 0.71 | 0.8 | 0.8 | 0.8 | 5.3506 |
| 1 | 0.8 | 0.8 | 0.8 | 6.7109 |
| 3 | 0.8 | 0.8 | 0.8 | 12.8171 |
| 7.1 | 0.8 | 0.8 | 0.8 | 16.6389 |
| 0.71 | 0.1 | 0.8 | 0.8 | 5.3234 |
| 0.71 | 0.3 | 0.8 | 0.8 | 5.3312 |
| 0.71 | 0.5 | 0.8 | 0.8 | 5.3390 |
| 0.71 | 1 | 0.8 | 0.8 | 5.3583 |
| 0.71 | 0.8 | 0.5 | 0.8 | 5.3391 |
| 0.71 | 0.8 | 1 | 0.8 | 5.3584 |
| 0.71 | 0.8 | 2 | 0.8 | 5.3970 |
| 0.71 | 0.8 | 0.8 | 0.1 | 5.3882 |
| 0.71 | 0.8 | 0.8 | 0.5 | 5.3667 |
| 0.71 | 0.8 | 0.8 | 1 | 5.3398 |
| 0.71 | 0.8 | 0.8 | 0.8 | 4.7099 |
| 0.71 | 0.8 | 0.8 | 0.8 | 3.9897 |
| 0.71 | 0.8 | 0.8 | 0.8 | 3.2610 |
| 0.71 | 0.8 | 0.8 | 0.8 | 2.5243 |

**TABLE.3: VARIATIONS IN SHERWOOD NUMBER**

| Sc | Kr | Sh |
|---|---|---|
| 0.22 | 0.8 | 2.9641 |
| 0.60 | 0.8 | 4.7048 |
| 0.78 | 0.8 | 5.5240 |
| 0.96 | 0.8 | 6.3379 |
| 0.22 | 0.1 | 2.9460 |

| | | |
|---|---|---|
| 0.22 | 0.3 | 2.9512 |
| 0.22 | 0.5 | 2.9563 |
| 0.22 | 0.9 | 2.9693 |
| 0.22 | 0.8 | 2.3060 |
| 0.22 | 0.8 | 1.5674 |
| 0.22 | 0.8 | 0.8215 |
| 0.22 | 0.8 | 0.0688 |
| 0.22 | 0.8 | 2.9969 |
| 0.22 | 0.8 | 3.0356 |
| 0.22 | 0.8 | 3.0769 |
| 0.22 | 0.8 | 3.1210 |

## NOMENCLATURE

| | |
|---|---|
| a | Constant |
| $Cp$ | Specific heat at constant pressure |
| $C$ | Concentration |
| $Gr$ | Thermal Grashof number |
| $Gm$ | modified Grashof number |
| $g$ | Acceleration due to gravity |
| M | magnetic parameter |
| $k_p^*$ | Permeability of the medium |
| $k_T$ | Thermal diffusivity |
| Pr | Prandtl number |
| $K$ | porosity parameter |
| Q | heat absorption parameter |
| R | radiation parameter |
| D | molecular diffusivity |
| Sc | Schmidt number |
| Kr | Chemical reaction parameter |
| Nu | Nusselt number |
| Sh | Sherwood number |
| t | Time |
| $u$ | Velocity of the fluid |
| $y$ | Coordinate axis normal to the plate |
| **Greek symbols** | |
| $\beta$ | Volumetric coefficient of thermal expansion |
| $\beta^*$ | Volumetric coefficient of concentration expansion |
| $\theta$ | Temperature |
| $\mu$ | Coefficient of viscosity |
| $\nu$ | Kinematic viscosity |
| $\rho$ | Density of the fluid |
| $\tau$ | skin friction |
| $\sigma$ | Electrical conductivity |
| $\chi$ | Radiation absorption parameter |
| **Subscripts** | |
| s | surface of the plate |
| $\infty$ | Conditions in the free stream |