*Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 89, Issue 2 (2022) 56-75

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

# MHD Heat and Mass Transfer Steady Flow of a Convective Fluid Through a Porous Plate in The Presence of Multiple Parameters

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**ARTICLE INFO**

***Article history:***
Received 22 July 2021
Received in revised form 6 October 2021
Accepted 25 October 2021
Available online 30 November 2021

***Keywords:***
MHD; thermo-diffusion; heat source or heat sink; porous medium and Joule effect

**ABSTRACT**

The main aim of this investigation is to study thermo diffusion, heat source/sink, Joule and chemical effects on heat transfer in MHD mixed convection flow and mass transfer past an infinite vertical plate with ohmic heating and viscous dissipation have been studied. We consider the mixed convection flow of an incompressible and electrically conducting viscous fluid such that x* -axis is taken along the plate in upward direction and y* -axis is normal to it. A transverse constant magnetic field is applied i.e., in the direction of y*-axis. Approximate solutions have been derived for velocity, temperature, concentration profiles, skin friction, rate of heat transfer and rate of mass transfer using perturbation technique. The obtained results are discussed with the help of graphs to observe the effect of various parameters like Grashof number (Gr), the modified Grashof number (Gm), magnetic parameter (M), Permeability parameter(K), Prandtl number (Pr), Heat Sink(Q), Radiation Parameter (F), Soret parameter (S0), Eckert number (E),Schmidt number(Sc) and Chemical reaction parameter(K0) taking two cases viz. Fluid velocity, temperature and concentration profiles are comparison with Pr=0.71(Air) and Pr =7 (Water) various parameters in cooled and heated plates. Case I: when Gr > 0 (flow on cooled plate), and Case II: Gr < 0, (flow on heated plate). Both the fluid velocity and concentration rising with the increment values of Soret parameter in the fluids Air and Water and also discussed skin friction, Nusselt number and Sherwood number in the fluid’s mercury, electrolytic solution, air and water. The novelty of this study is the consideration of simultaneous occurrence of radiation, heat absorption as well as thermo- diffusion in the magnetic field. It varies in several aspects such as non-dimensional parameters, analytical solutions, and graphical solutions, the analytic solution using the Perturbation technique, and numerical solution using Matlab software for the profile.

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https://doi.org/10.37934/arfmts.89.2.5675

## 1. Introduction

The prevalent process i.e., thermal diffusion, also widely known as the Soret process effect is the trend of a mixture which is convection free to get separated under a temperature gradient keeping its magnitude small. It also specifies the thermo reactive deposition or diffusion process and also the Toyota diffusion process which is a process that comprises modification of high-temperature surface that shapes a solid, skinny, wear-resilient layer of carbides, nitrides, or carbonitrides on steels as well as on other materials (which contains carbon) such as alloys of nickel and cobalt, carbides which are cemented, and carbides which are bonded by steel. In this course, the nitrogen and carbon present in the steel substrate diffuses into a deposited layer with an element which forms carbide such as vanadium, niobium, tungsten etc. It also reacts with elements which form nitride in the coating which is deposited in order to configure a non-porous, coating which is metallurgically bonded at the surface of the substrate.

With the knowledge of Soret and Dufour result, Krishna Murthy and Kumar [1] considered MHD Double Diffusive free convection process besides a perpendicular wavy surface entrenched in a doubly stratified fluid-saturated medium which is porous in nature. Umamaheswar *et al.,* [2] scrutinized the chemical influence on MHD fluid flow which is doubly diffusive past a porous plate which is rotating in nature. Seth *et al.,* [3] studied beautifully on MHD boundary heat and mass transfer flow on natural convection together with the effects of Soret in addition to hall current past a plate which is inclined and porous in nature with moveable suction. An intensive study on MHD fluid with visco-elastic flow bygone an infinite perpendicular plate taking in account the chemical reaction and radiation has been carried out by Raju *et al.,* [4]. In presence of the Soret effect, Reddy *et al.,* [5] surveyed the MHD heat generating flow in a doubly diffusive flow of convection. Chandra Reddy *et al.,* [6] deliberately discussed the outcomes of buoyancy on chemically reactive magneto Nano fluid past a vertical plate which moves effectively. Agarwalla and Ahmed [7] studied MHD transfer of mass flow past an inclined plate in which velocity and temperature varies which is rooted in a medium (porous). An analytical study on forced convection in a channel which is partially filled with porous material which is porous taking in account of the magnetic field has been examined by Bhargavi and Reddy [8]. Sheikholeslami *et al.,* [9] analyzed the results of Lorentz forces on NEPCM heat transfer during the solidification process in an energy storage system which porous in nature. The study on MHD boundary layer flow of a Radiative stretching cylinder and transfer of heat of a viscous incompressible fluid with thermal conductivity which vary has been discussed by Sharma and Gupta [10]. Kumar and Kumar [11] discussed the fascinating and novel characteristics of MHD convective nanofluid flow past a porous medium over a stretching sheet. A detailed study on MHD convection flow and mass transfer past a plate which is infinite, vertical and porous in nature has been carried by Kalapana and Vijaya [12]. Obulesu *et al.,* [13] studied the Hall current effects on a convective flow of magnetohydrodynamics past a plate which is porous along with thermal radiation and absorption and chemical reaction. Raghunath *et al.,* [14] conferred both the transfer of heat and mass on MHD flow which is unsteady past a medium (porous) between two vertical plates which is also porous in nature. MHD visco-elastic fluid flow which is double diffusive past a plate (infinite, vertical and porous) under the influence of radiation and absorption has been discussed extensively by Obulesu and Sivaprasad [15]. Raghunath *et al.,* [16] strikingly investigated MHD second grade fluid flow over an infinite permeable plate implanted in a porosity medium. Under the influence of thermophoresis effect, hall current effects on a convective MHD flow through a plate which is porous and also with thermal radiation and chemical reaction have been discussed openly and widely by Obulesu and Prasad [17]. In presence of Ohmic heating, Reddy *et al.,* [18] thoroughly studied the diffusion of thermal and chemical effects with simultaneous mass diffusion in a mixed convection flow. Goud *et al.,* [25] studied thermal radiation and Joule heating effects on a magnetohydrodynamic Casson nanofluid flow in the presence of chemical reaction through a non-linear inclined porous stretching sheet. Kumar *et al.,* [26] discussed Thermal radiation impact on MHD heat transfer natural convective nano fluid flow over an impulsively started vertical plate. Goud *et al.,* [27] studied Radiation effect on MHD boundary layer flow due to an exponentially stretching sheet. MHD viscous dissipative fluid flows in a channel with a stretching and porous plate with radiation effect has been discussed by Goud *et al.,* [27].

There is an extensive array of appliances on the dissemination of thermal energy over mercury, solution of electrolyte, water and air in the occurrence of magnetic field, effect of chemical, absorption and thermal diffusivity. It is therefore, proposed to study in this present paper the effects of mass and heat transfer of a natural convection fluid flow through a plate which is porous in nature in the manifestation of multiple parameters. This study is an expansion work of Reddy *et al.,* [18]. The originality of this study lies in the contemplation of instant occurrence of radiation, heat absorption as well as thermo- diffusion.

## 2. Mathematical Formulation

In the present problem, we have considered a fluid which is viscous, incompressible, electrically conducting and radiating in nature past a medium (porous) which inhabit a \ region of the space which is semi- infinite and bounded by a surface which is also vertical and infinite. Along the surface is the x- axis which is in an upward direction and the axis which is normal to it is the y- axis. In the direction of the latter axis, a transverse effect is imposed by the strength of uniform magnetic field ($B_0$) in addition to radiation and Joule heating. The fluid properties are presumed to be stable keeping its density excluded in the term which includes the body force. Additionally, species which are chemically reactive is assumed to be secreted from the surface (vertical) into a field whose flow is hydrodynamic and that it diffuses into the fluid, where it experiences a reaction which is chemically homogenous. The reaction is presumed to take place throughout in the stream. Conclusively, the flow that is developed past a medium which is supposed to be highly porous is presided by the equations given below:

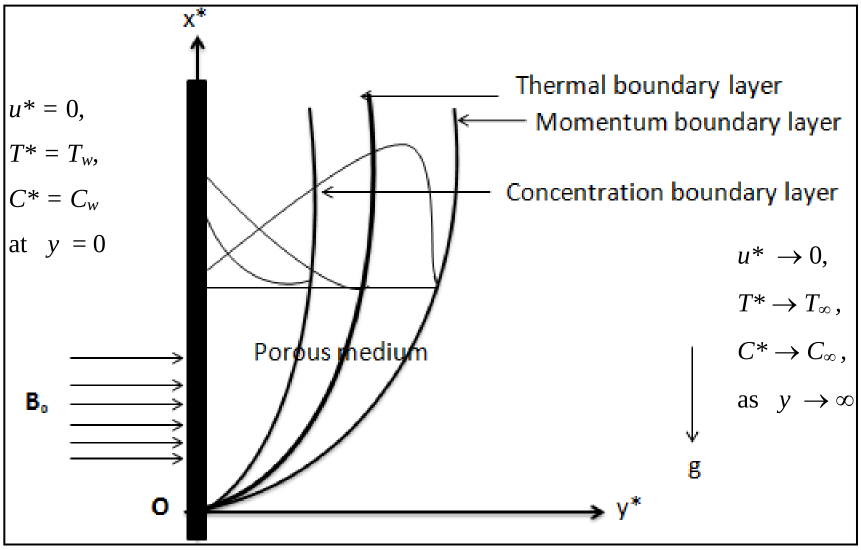

**Fig. 1.** Physical model of the problem

Basic Equations: The equations governing the flow of a viscous incompressible and electrically conducting fluid in the presence of magnetic field are

Equation of continuity:

$$\overline{\nabla} \cdot \overline{q} = 0$$

Momentum equation:

$$\rho\left[\left(\overline{q} \cdot \overline{\nabla}\right)\overline{q}\right] = -\overline{\nabla} p + \overline{J} \times \overline{B} + \rho \overline{g} + \mu \nabla^2 \overline{q} - \left[\frac{\mu}{k^*}\right]\overline{q}$$

Ohm’s law:

$$\overline{J} = \sigma\left[\overline{E} + \left(\overline{q} \times \overline{B}\right)\right]$$

Gauss’ law of magnetism:

$$\overline{\nabla} \cdot \overline{B} = 0$$

Energy equation:

$$\rho C_p\left[\left(\overline{q} \cdot \overline{\nabla}\right)T^*\right] = K \nabla^2 T^* + \mu(\nabla . \overline{q})^2 - \nabla q_r^* + \mu \nabla^2 \overline{q}^2 - Q^*\left(T^* - T_\infty^*\right)$$

Species continuity equation:

$$\left(\overline{q} \cdot \overline{\nabla}\right)C^* = D_M \nabla^2 C^* + K^*(C_\infty^* - C^*) + \frac{D_M K_T}{T_M} \nabla^2 T^*$$

Based on the above basic equations the following derived mathematical formulation has been done.

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

$$v' \frac{\partial u'}{\partial y'} = \vartheta \frac{\partial^2 u'}{\partial y'^2} + g\beta_T (T' - T_\infty') + g\beta_C (C' - C_\infty') - \frac{\sigma B_0^2}{\rho} u' - \vartheta \frac{u'}{K_P} \tag{2}$$

$$v' \frac{\partial T'}{\partial y'} = \frac{K}{\rho C_p} \frac{\partial^2 T'}{\partial y'^2} + \frac{\vartheta}{C_p} (\frac{\partial u'}{\partial y'})^2 - \frac{1}{\rho C_p} \frac{\partial q_r'}{\partial y'} + \frac{\sigma B_0^2}{\rho C_P} u'^2 - \frac{Q_1}{\rho C_p} (T' - T_\infty') \tag{3}$$

$$v' \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} - K_C (C' - C_\infty') + D_1 \frac{\partial^2 T'}{\partial y'^2} \tag{4}$$

The relevant boundary conditions are given as follows

$$\begin{array}{llll} u' = 0 & T' = T_w, & C' = C_w & at\ \ y' = 0 \\ u' \to 0 & T' \to T_\infty, & C' \to C_\infty & as\ \ y' \to \infty \end{array} \tag{5}$$

Eq. (1) gives that $v' = const. = -v_0 (v_0 > 0)$ (6)

In the optically thick limit, the fluid tends not absorb its own radiation which they emit as there is no self-absorption. In other words, they absorb radiation emitted by the boundaries. Cogley *et al.,* [19] showed the similar approach as above, for a non-gray gas near equilibrium as given below.

$$\frac{\partial q_r}{\partial y'} = 4(T' - T'_\infty)\int_0^\infty K_{\lambda w} \frac{de_{b\lambda}}{dT'} d\lambda = 4I_1(T' - T'_\infty) \tag{7}$$

We introduce the quantities (non-dimensional) as follows,

$$u = \frac{u'}{v_0}, y = \frac{v_0 y'}{\vartheta}, \theta = \frac{T' - T'_\infty}{T_w - T'_\infty}, \phi = \frac{C' - C'_\infty}{C_w - C'_\infty}, \Pr = \frac{\mu C_p}{K}, Sc = \frac{\vartheta}{D}, M = \frac{\sigma B_0^2 \vartheta}{\rho v_0^2},$$
$$Gr = \frac{\vartheta g \beta_T (T_w - T'_\infty)}{v_0^3}, Gm = \frac{\vartheta g \beta_C (C_w - C'_\infty)}{v_0^3},\ E = \frac{v_0^2}{C_P (T_w - T'_\infty)},\ K = \frac{v_0^2 K_P}{\vartheta^2}$$
$$K_0 = \frac{\vartheta K_C}{v_0^2}, F = \frac{4I_1 \vartheta^2}{K v_0^2}, Q = \frac{Q_1 v^2}{K v_0^2}, S_0 = \frac{D_1 (T_w - T'_\infty)}{\vartheta (C_w - C'_\infty)} \tag{8}$$

The governing Eq. (2)-(4) which are in the form of non-dimensional trims down to

$$u'' + u' = \text{-}\,\mathrm{Gr}\,\theta\ \text{-}\,\mathrm{Gm}\,\phi\ + \mathrm{M_1 u} \tag{9}$$

$$\theta'' + \Pr\theta' - (\mathrm{F} + \mathrm{Q})\,\theta = \text{-}\,\mathrm{Pr}u^{1^2}\ \text{-}\,\mathrm{PrM}u^2 \tag{10}$$

$$\phi'' + Sc\phi' - \mathrm{ScK_0}\phi = \text{-}\mathrm{S_0\ Sc}\,\theta'' \tag{11}$$

Where $M_1 = M + 1 / K$.

The analogous boundary conditions are set by

$$\begin{array}{llll} u = 0, & \theta = 1, & \phi = 1 & at\ \ y = 0 \\ u \to 0, & \theta \to 0, & \phi \to 0 & as\ y \to \infty \end{array} \tag{12}$$

## 3. Solution of the Problem

In this study simple perturbation method is used to solve the coupled nonlinear system Eq. (9)-(11) together with the help of boundary conditions (12). The governing Eq. (9)-(11) are then expanded in terms of powers of E which is significantly very small.

$$\begin{aligned} u &= u_0 + Eu_1 + O(E^2), \\ \theta &= \theta_0 + E\theta_1 + O(E^2), \\ \phi &= \phi_0 + E\,\phi_1 + O(E^2) \end{aligned} \tag{13}$$

Substituting the Eq. (13) to Eq. (9)-(11) and expanding the same way keeping the higher orders of E neglected, the following equations are achieved.

Zero order terms:

$$u_0'' + u_0' = -\mathrm{Gr}\,\theta_0 - \mathrm{Gm}\,\phi_0 + \mathrm{M_1 u_0} \tag{14}$$

$$\theta_0'' + \Pr\theta_0' - (\mathrm{F}+\mathrm{Q})\,\theta_0 = 0 \tag{15}$$

$$\phi_0'' + Sc\ \phi_0' - \mathrm{ScK_0}\phi_0 = -\mathrm{S_0\ Sc}\,\theta_0'' \tag{16}$$

First order terms:

$$u_1'' + u_1' = -\mathrm{Gr}\,\theta_1 - \mathrm{Gm}\,\phi_1 + \mathrm{M_1 u_1} \tag{17}$$

$$\theta_1'' + \Pr\theta_1' - (\mathrm{F}+\mathrm{Q})\,\theta_1 = -\mathrm{Pru}_0^{1^2} - \mathrm{PrM}u_0^2 \tag{18}$$

$$\phi_1'' + Sc\phi_1' - ScK_0\phi_1 = -S_0 Sc\theta_1'' \tag{19}$$

The corresponding boundary conditions are

$$\begin{aligned} &u_0 = 0,\quad u_1 = 0,\quad \theta_0 = 1,\quad \theta_1 = 0,\qquad \phi_0 = 1,\ \phi_1 = 0 \qquad at\ y = 0 \\ &u_0 \to 0,\ u_1 \to 0,\quad \theta_0 \to 1,\ \theta_1 \to 0,\qquad \phi_0 \to 1,\ \phi_1 \to 0 \quad as\, y = \infty \end{aligned} \tag{20}$$

Solving the Eq. (14)-(19) under the boundary conditions set in Eq. (20), the following solutions are obtained

$$\theta_0 = e^{-m_1 y} \tag{21}$$

$$\phi_0 = -A_1 e^{-m_1 y} + A_2 e^{-m_2 y} \tag{22}$$

$$u_0 = A_3 e^{-m_1 y} - A_4 e^{-m_2 y} + A_5 e^{-m_3 y} \tag{23}$$

$$\begin{aligned} \theta_1 = {} & A_{18}\, e^{-2m_1 y} + A_{19}\, e^{-2m_2 y} + A_{20}\, e^{-2m_3 y} + A_{21} e^{-\delta_1 y} + A_{22} e^{-\delta_2 y} \\ & + A_{23} e^{-\delta_3 y} + A_{24} e^{-m_1 y} \end{aligned} \tag{24}$$

$$\begin{aligned} \phi_1 = {} & A_{25} e^{-m_1 y} + A_{26}\, e^{-2m_1 y} + A_{27}\, e^{-2m_2 y} + A_{28}\, e^{-2m_3 y} + A_{29} e^{-\delta_1 y} + A_{30} e^{-\delta_2 y} \\ & + A_{31} e^{-\delta_3 y} + A_{32} e^{-m_2 y} \end{aligned} \tag{25}$$

$$\begin{aligned} u_1 = {} & A_{33}e^{-m_1 y} + A_{34}e^{-m_2 y} + A_{35}\, e^{-2m_1 y} + A_{36}\, e^{-2m_2 y} + A_{37}\, e^{-2m_3 y} + A_{38}e^{-\delta_1 y} + A_{39}e^{-\delta_2 y} \\ & + A_{40}e^{-\delta_3 y} + A_{41}e^{-m_3 y} \end{aligned} \tag{26}$$

Substituting Eq. (21)-(26) in Eq. (13) we obtain the velocity, temperature and concentration field as given below

$$\begin{aligned} u = {} & A_3 e^{-m_1 y} - A_4 e^{-m_2 y} + A_5 e^{-m_3 y} + E[A_{33}e^{-m_1 y} + A_{34}e^{-m_2 y} + A_{35}\, e^{-2m_1 y} \\ & + A_{36}\, e^{-2m_2 y} + A_{37}\, e^{-2m_3 y} + A_{38}e^{-\delta_1 y} + A_{39}e^{-\delta_2 y} + A_{40}e^{-\delta_3 y} + A_{41}e^{-m_3 y}] \end{aligned} \tag{27}$$

$$\begin{aligned} \theta = {} & e^{-m_1 y} + E[A_{18}\, e^{-2m_1 y} + A_{19}\, e^{-2m_2 y} + A_{20}\, e^{-2m_3 y} + A_{21}e^{-\delta_1 y} + A_{22}e^{-\delta_2 y} \\ & + A_{23}e^{-\delta_3 y} + A_{24}e^{-m_1 y}] \end{aligned} \tag{28}$$

$$\begin{aligned} \phi = {} & -A_1 e^{-m_1 y} + A_2 e^{-m_2 y} + E[A_{25}e^{-m_1 y} + A_{26}\, e^{-2m_1 y} + A_{27}\, e^{-2m_2 y} \\ & + A_{28}\, e^{-2m_3 y} + A_{29}e^{-\delta_1 y} + A_{30}e^{-\delta_2 y} + A_{31}e^{-\delta_3 y} + A_{32}e^{-m_2 y}] \end{aligned} \tag{29}$$

*Skin Friction:*

At the surface the skin friction (non- dimensional) is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0}$$

$$\begin{aligned} \tau = {} & [-m_3 A_5 + m_2 A_4 - m_1 A_3] \\ & + E[m_1 A_{33} - m_2 A_{34} - 2m_1 A_{35} - 2m_2 A_{36} - 2m_3 A_{37} - \delta_1 A_{38} - \delta_2 A_{39} - \delta_3 A_{40} - m_3 A_{41}] \end{aligned} \tag{30}$$

*Nusselt Number:*

At the surface, in terms of Nusselt number the rate of heat transfer is given by

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

$$Nu = m_1 + E[m_1 A_{24} + 2m_1 A_{18} + 2m_2 A_{19} + 2m_3 A_{20} + \delta_1 A_{21} + \delta_2 A_{22} + \delta_3 A_{23}] \tag{31}$$

*Sherwood Number:*

At the wall, in terms of Sherwood number the rate of mass transfer is given by

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

$$Sh = [m_2 A_2 - m_1 A_1] + E[m_1 A_{25} + 2m_1 A_{26} + 2m_2 A_{27} + 2m_3 A_{28} + \delta_1 A_{29} + \delta_2 A_{30} + \delta_3 A_{31} + m_2 A_{32}] \tag{32}$$

## 4. Results and Discussion

An imperial study in velocity, temperature and concentration field pertaining to the effects of the mixed MHD convection flow on both mass and heat transfer of a fluid (viscous, incompressible, conducting) past a vertical plate (infinite and porous) in addition of magnetic field, radiation, absorption and chemical effects has been done extensively in the preceding sections. The numerical figures are portrayed for two cases of Gr during cooling and heating of the plate. The values of Prandtl number (Pr) are taken as 1, 0.025, 0.71 and 7, which represents electrolytic friction, Mercury, Air, Water, heat and mass transfer respectively. The mercury level is taken as the reading of 20°C temperature and 1 atmosphere pressure and the value of Eckert number is taken as 0.02. The values of Sc are taken to be 0.22, 0.30, 0.60 and 0.78 which represents for hydrogen, helium, water vapour and ammonia respectively. Some other values such as Gr=5, Gm=5, K=1, $K_0$ **=**1, M=2, F=1, Q=1 are also taken into consideration. The obtained results are elucidated and explained in Figure 2 to Figure 23.

In order to reveal the influences of various parameters on the three profiles (i.e., velocity, temperature and concentration) through Figure 2 to Figure 23 study and efforts have been done by choosing various arbitrary values of the parameters. The influences of these parameters on skin friction, Nusselt number and Sherwood number are also shown in Table 1 to Table 3.

From Figure 2 to Figure 23 depict the velocity, temperature and concentration profiles for fluid flow on cooled and heated plates respectively.

Effect of M and Sc are shown in Figure 2 to Figure 5 on fluid velocity for Pr = 0.71 and Pr =7. We observe that the velocity gradient at the surface decreases with the enhancement of magnetic parameter and Schmidt number. An opposite phenomenon is noted in the case of cooled and heated plates, from Figure 6 to Figure 11 shows the effect of K, Gm and $S_0$ for fluid velocity for Pr = 0.71 and Pr =7 respectively. We observed that there is an upsurge in fluid velocity for increasing values of K, Gm and $S_0$.

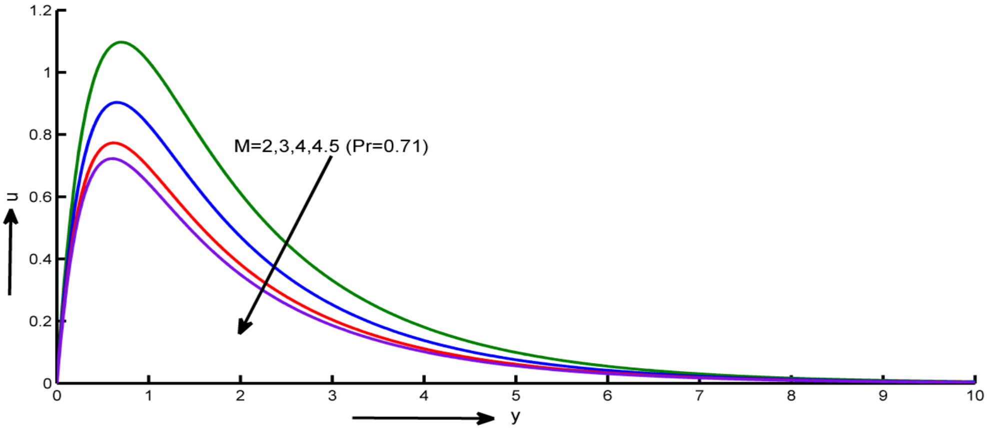

**Fig. 2.** Velocity profile for Gr = 5.0 (Sc=0.22, Gm=5, K=1, $K_0$=1, F=1, Q=1 and $S_0$=1)

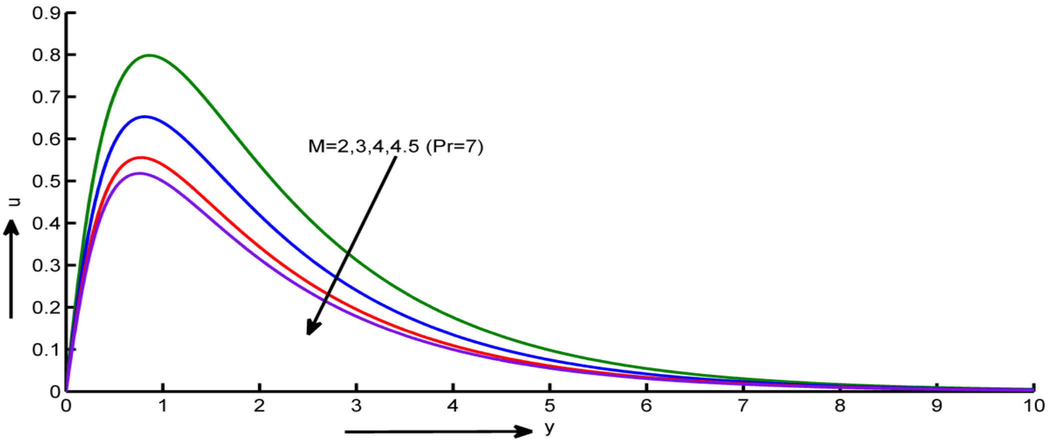

**Fig. 3.** Velocity profile for Gr = -5.0 (Sc=0.22, Gm=5, K=1, $K_0$=1, F=1, Q=1 and $S_0$=1)

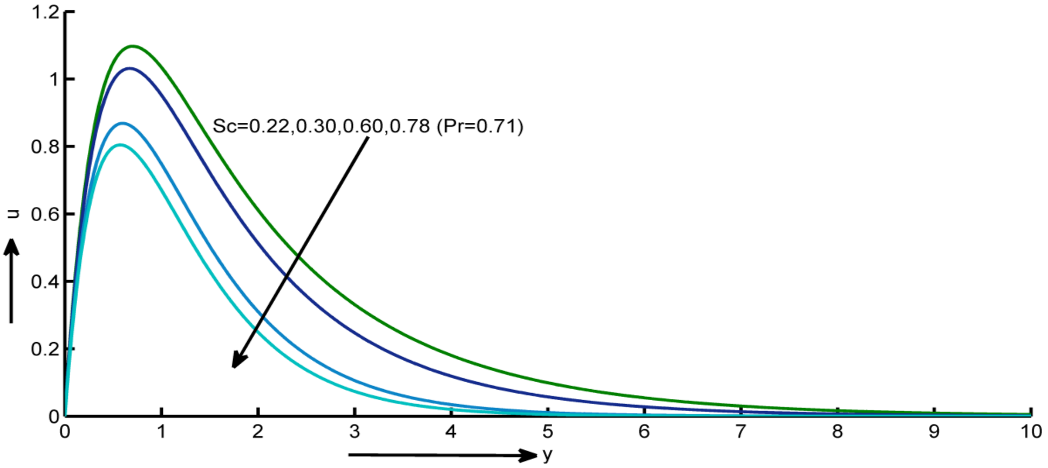

**Fig. 4.** Velocity profile for Gr = 5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

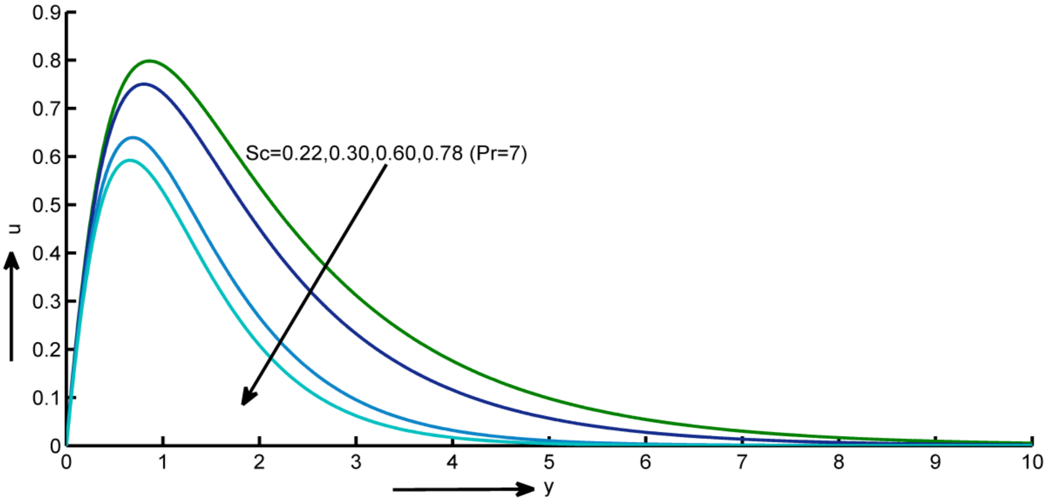

**Fig. 5.** Velocity profile for Gr = -5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

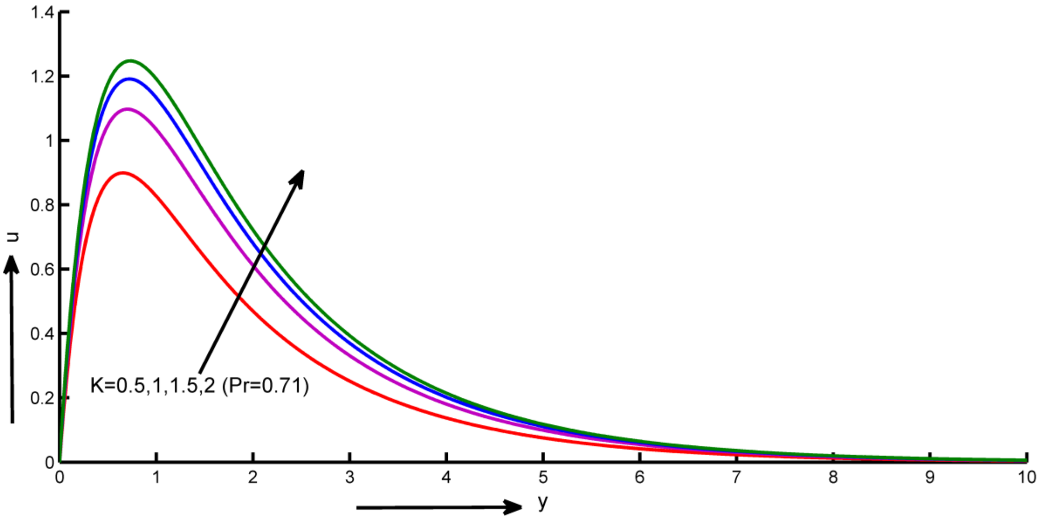

**Fig. 6.** Velocity profile for Gr = 5.0 (Sc=0.22, Gm=5, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

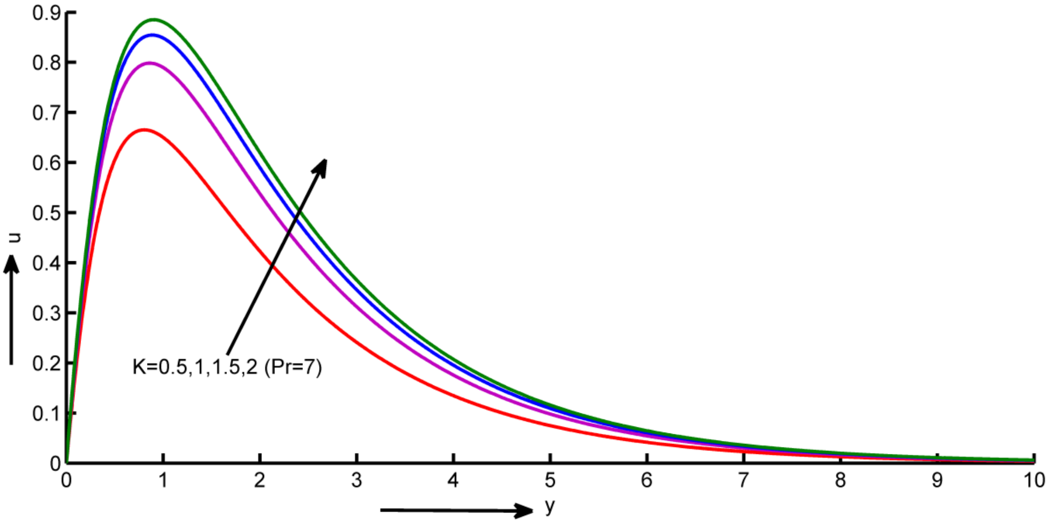

**Fig. 7.** Velocity profile for Gr = -5.0 (Sc=0.22, Gm=5, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

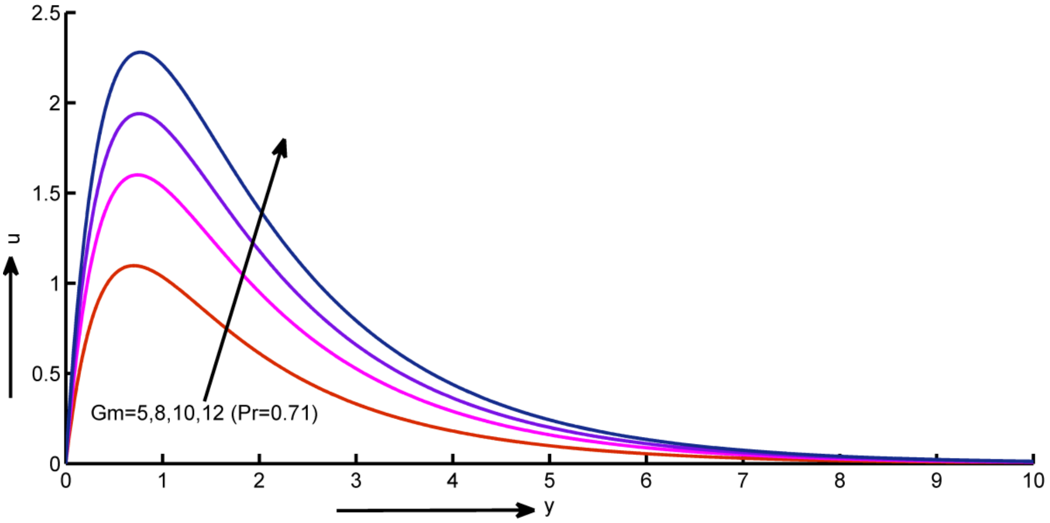

**Fig. 8.** Velocity profile for Gr = 5.0 (Sc=0.22, K=1, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

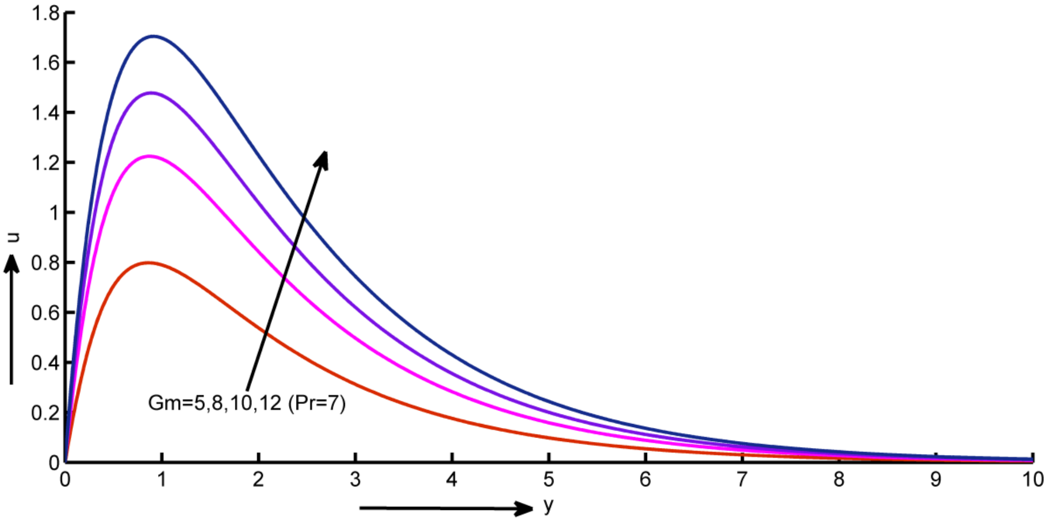

**Fig. 9.** Velocity profile for Gr = -5.0 (Sc =0.22, K=1, M=2, $K_0$=1, F=1, Q=1 and $S_0$=1)

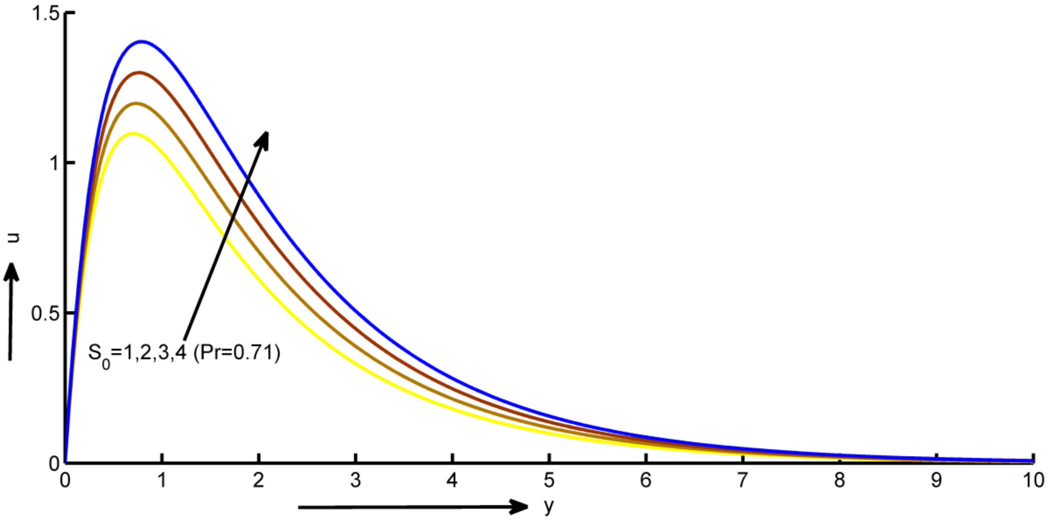

**Fig. 10.** Velocity profile for Gr = 5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1 and Sc=0.22)

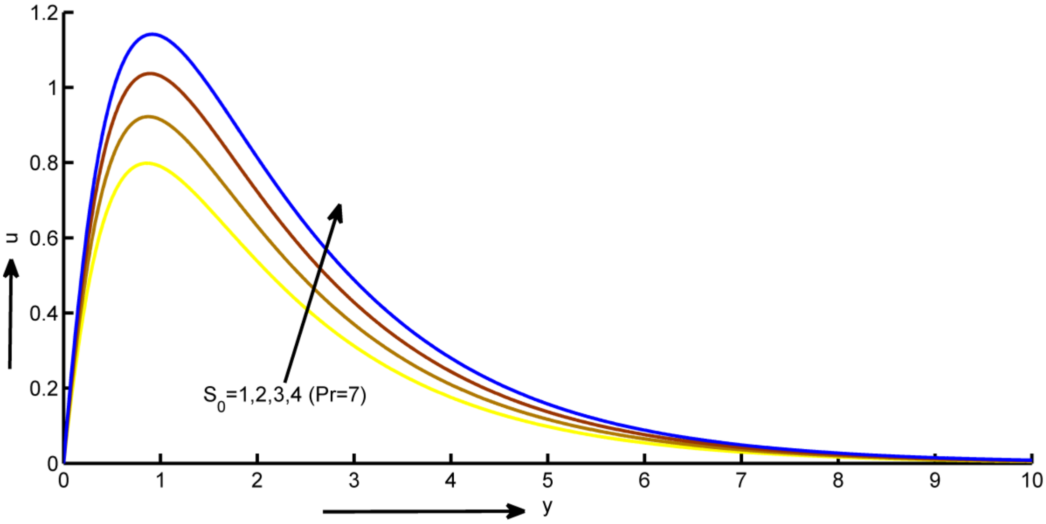

**Fig. 11.** Velocity profile for Gr = -5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1 and Sc=0.22)

In Figure 12 to Figure 17, the effects of Pr, F and Q on temperature profiles are shown graphically for Gr = 5 and Gr = -5. It is perceived that for the plates, if there is a rise in the Prandtl number, radiation parameter and heat absorption parameter, a fall in the temperature for Pr = 0.71 and Pr =7 is noted. The reason lies in the fact that with the increase of the said parameters there is a decrease in the thickness of thermal boundary layer.

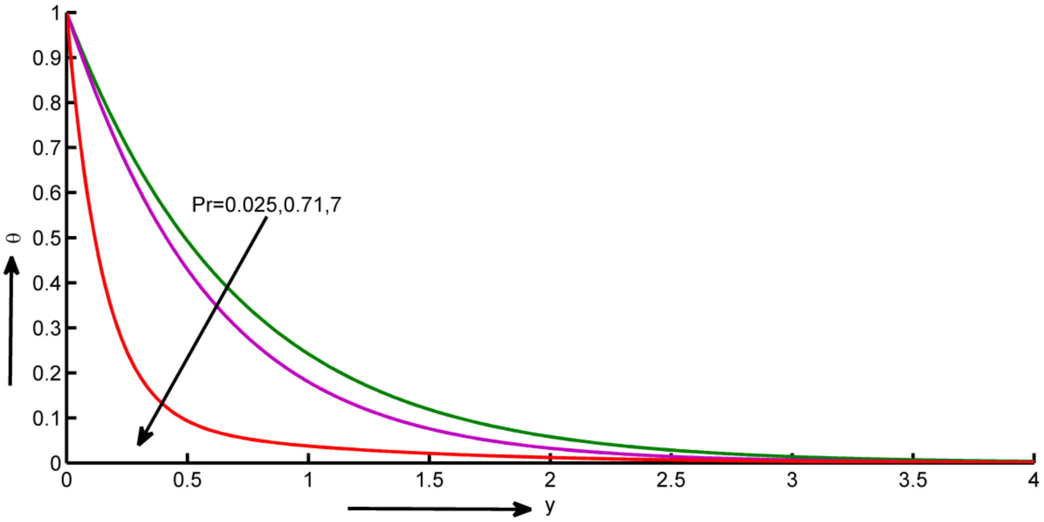

**Fig. 12.** Temperature profile for Gr = 5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1, So=1 and Sc=0.22)

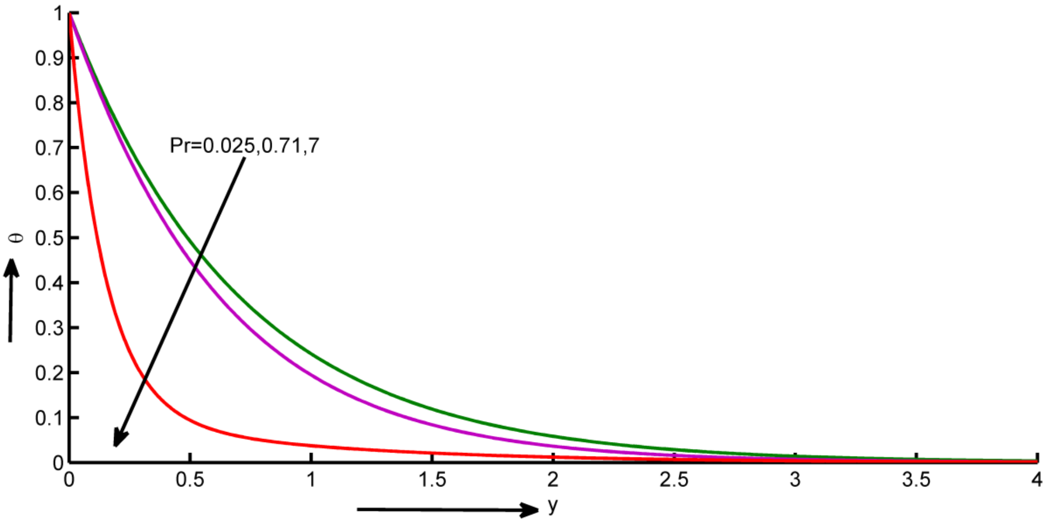

**Fig. 13.** Temperature profile for Gr = -5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, Q=1, $S_0$=1 and Sc=0.22)

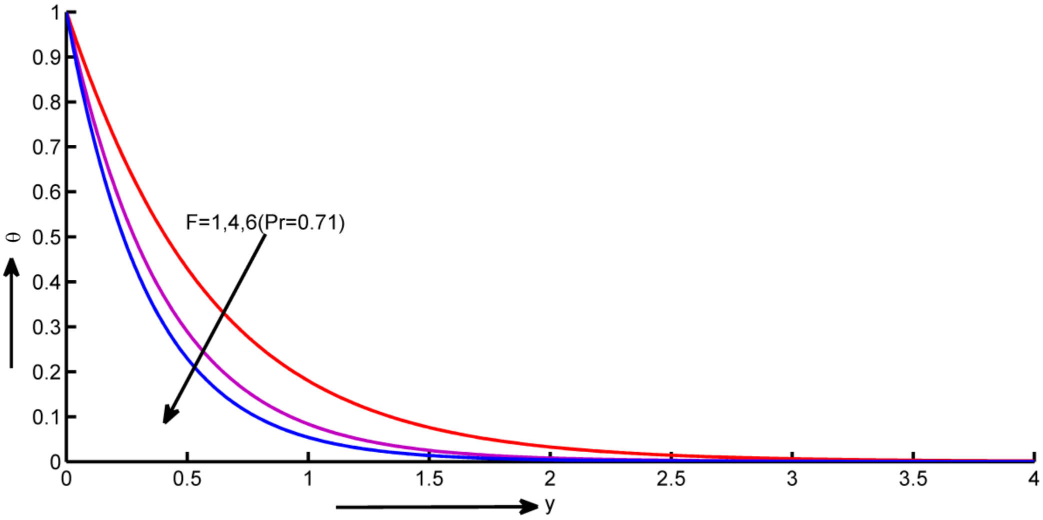

**Fig. 14.** Temperature profile for Gr = 5.0 (Gm=5, K=1, M=2, $K_0$=1, Q=1, $S_0$=1 and Sc=0.22)

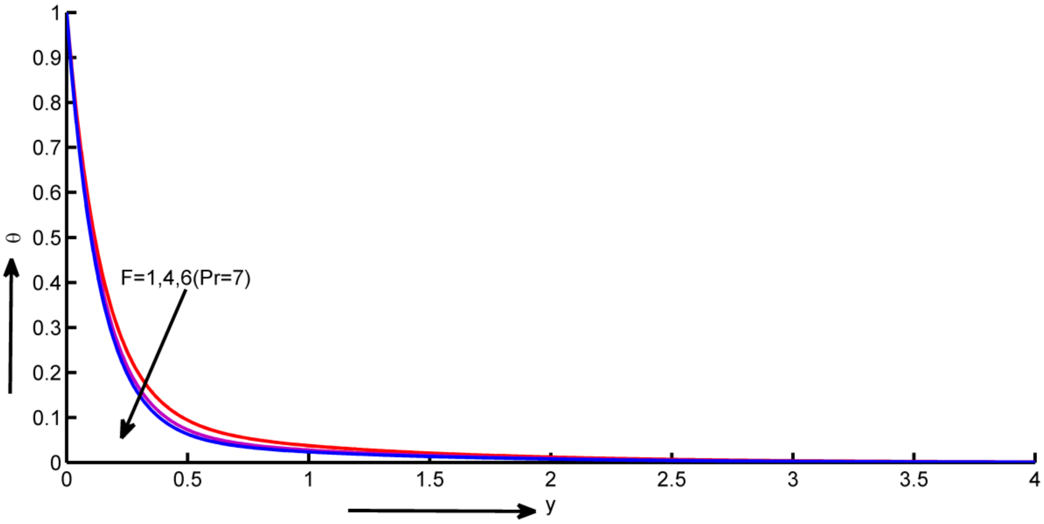

**Fig. 15.** Temperature profile for Gr =- 5.0 (Gm=5, K=1, M=2, $K_0$=1, Q=1, $S_0$=1 and Sc=0.22)

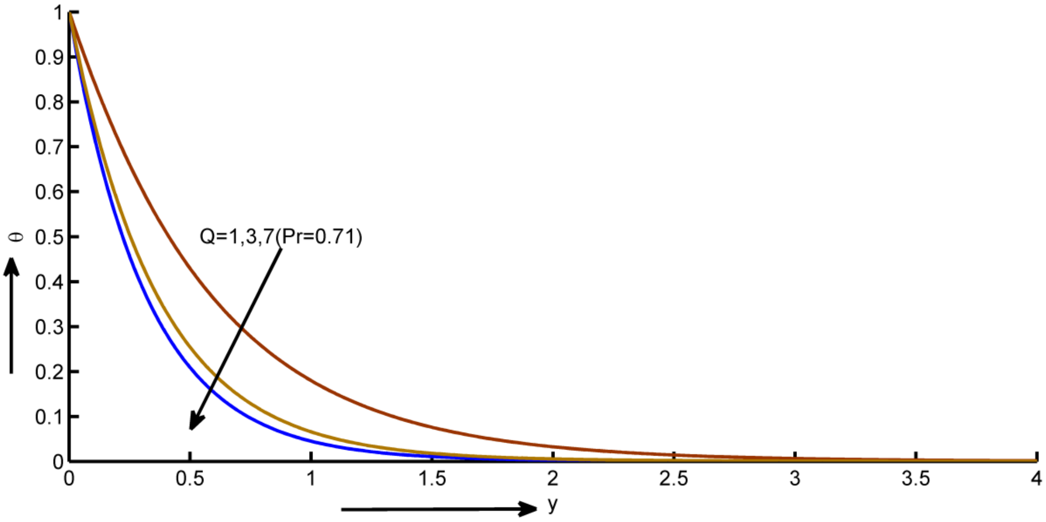

**Fig. 16.** Temperature profile for Gr = 5.0 (Gm=5, K=1, M=2, $K_0$=1, F=1, $S_0$=1 and Sc=0.22)

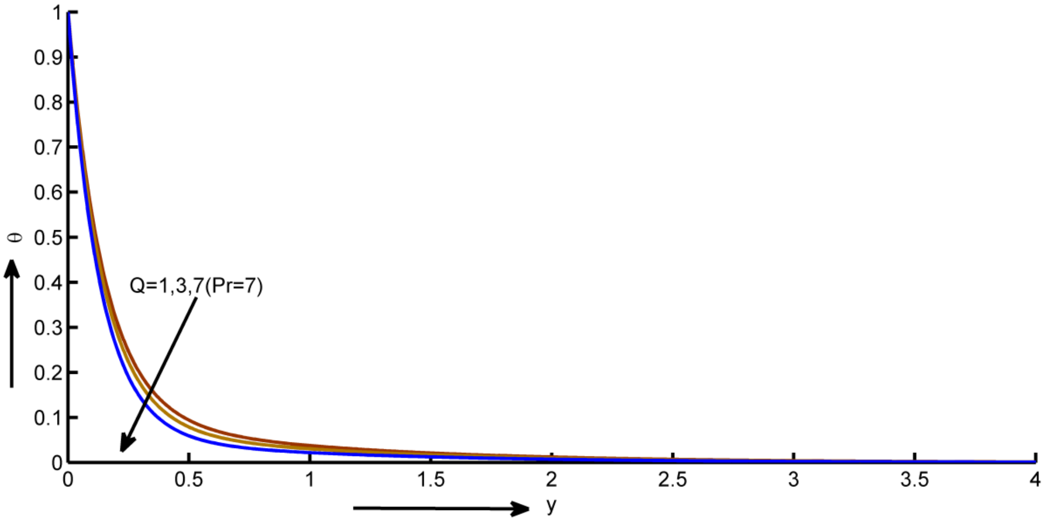

**Fig. 17.** Temperature profile for Gr = -5.0 (Gm=5, K=1, M=2, $K_0$=1, Q=1, $S_0$=1 and Sc=0.22)

Figure 18 to Figure 23 give the insight of species concentration curve for various values of $K_0$, Sc and $S_0$. It is to be noted that in the flow field the concentration falls steadily with y and it tends to zero as y → ∞. A contrast assessment of curves in Figure 18 to Figure 23 depicts a decrease in concentration with an upsurge in chemical reaction parameter and Sc. Substantially, the increase of Sc means down fall of D which results in the decrease of boundary layer of the concentration. Therefore, the concentration of the species is higher and lower for small and large values of Sc respectively and this is analogous to the increasing effects of the Prandtl number on the thickness of boundary layer of temperature. The concentration fall level is due to the chemical reaction parameter and its increment values. For both (cooled and heated) plates, the concentration profile gets hiked due to $S_0$.

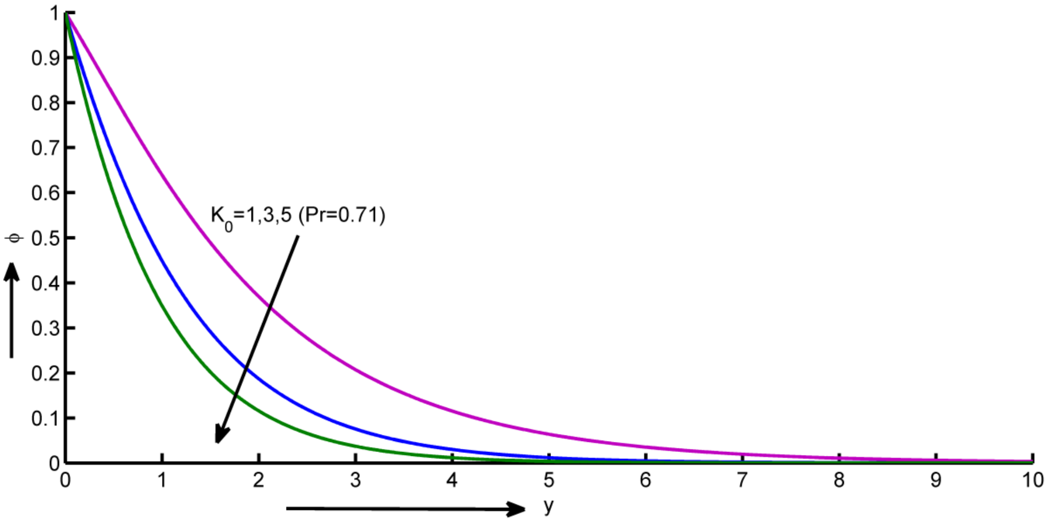

**Fig. 18.** Concentration profile for Gr = 5.0 (Gm=5, K=1, M=2, Q=1, F=1, $S_0$=1 and Sc=0.22)

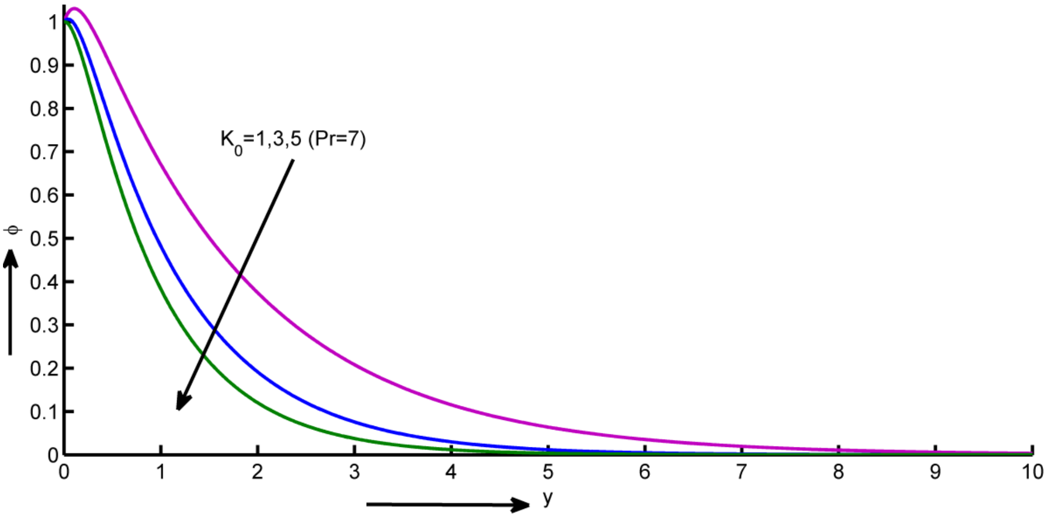

**Fig. 19.** Temperature profile for Gr =- 5.0 (Gm=5, K=1, M=2, Q=1, F=1, $S_0$=1 and Sc=0.22)

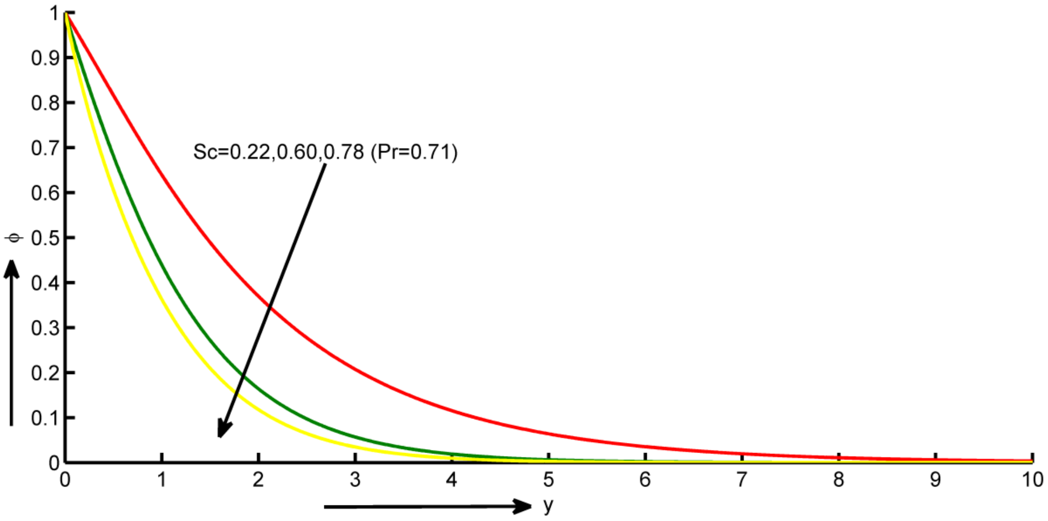

**Fig. 20.** Temperature profile for Gr = 5.0 (Gm=5, K=1, M=2, Q=1, F=1, $S_0$=1 and $K_0$=1)

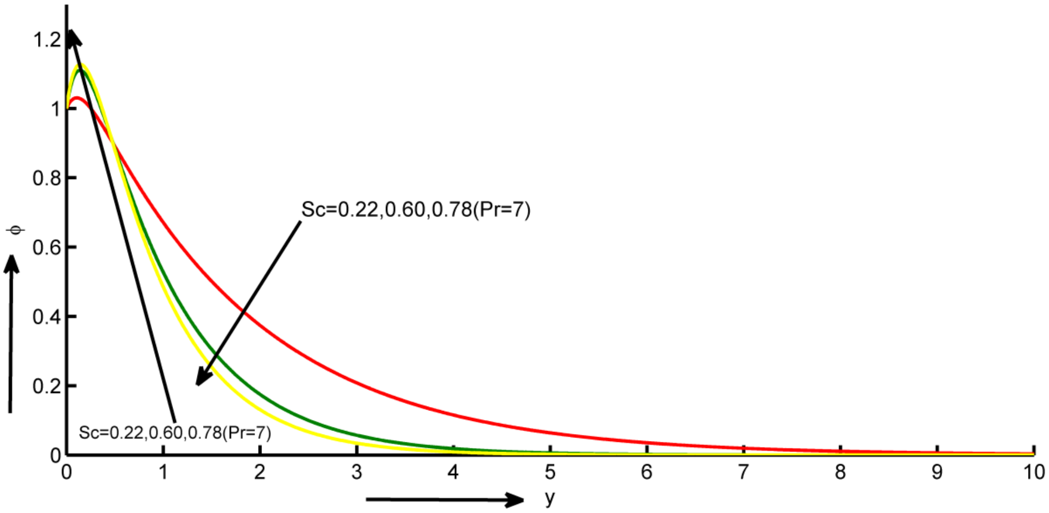

**Fig. 21.** Temperature profile for Gr = -5.0 (Gm=5, K=1, M=2, Q=1, F=1, $S_0$=1 and $K_0$=1)

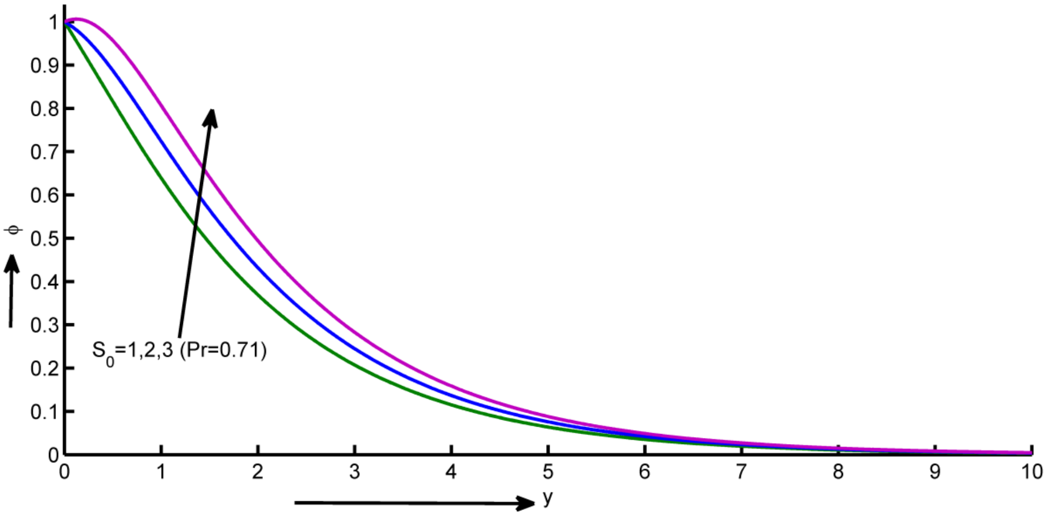

**Fig. 22.** Temperature profile for Gr = 5.0 (Gm=5, K =1, M=2, Q=1, F=1, Sc=0.22 and $K_0$=1)

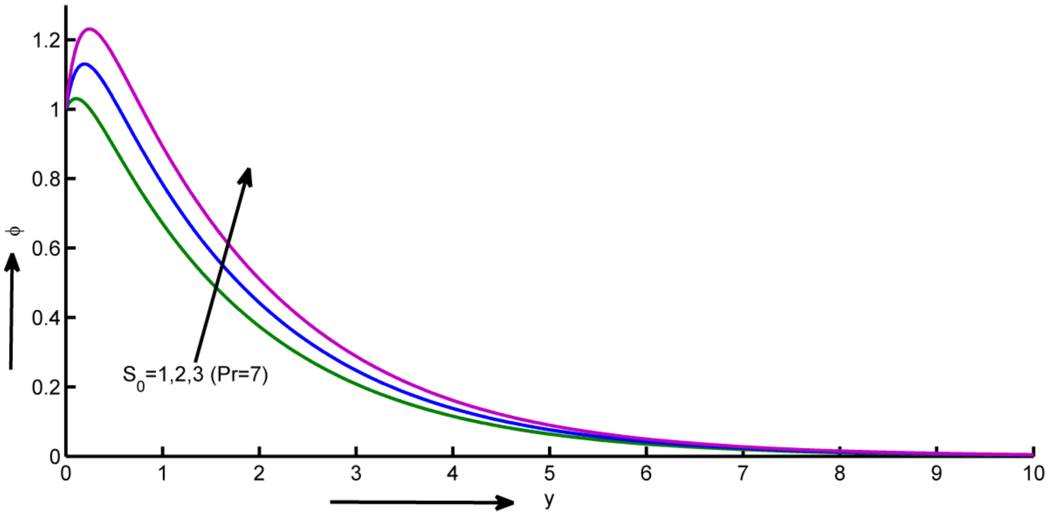

**Fig. 23.** Temperature profile for Gr = -5.0 (Gm=5, K =1, M=2, Q=1, F=1, Sc=0.22 and $K_0$=1)

Table 1, Table 2 and Table 3 validates the influences of *M, So, K, Gm, F, Q* and *Sc* on skin friction, rate of heat and mass transfer respectively.

It is evident from Table 1 that an increasing value of *M* decreases the effect of skin-friction for mercury, electrolytic solution, air and water for (cooled plate and heated) the plates. But an increase in *K* and *Gm* enhances the skin-friction however rise in the values of *K,* diminishes the skin friction in only electrolytic solution.

In Table 2 rate of heat transfer and its variations are shown. It increases with the rising values of *F* and *Q.* But in the case of the fluid flow on heated plate, *Nu* decreases with increase in $S_0$ for mercury, electrolytic solution, air, water and decreases for air, water.

The variations in rate of mass transfer are shown in Table 3. It increases with rising values of $K_0$ in both cooled and heated plates for fluids of mercury, electrolytic solution, air and water, but in the case of mercury, electrolytic solution, air, *Sh* increases with an increment in *Sc* but diminishes in the fluid for both plates. Similarly, increasing trend in $S_0$ for cooled plate is observed when the values of *Sh* falls in the fluid’s mercury, electrolytic solution, air and water but in heated plate an opposite trend is noted for *Sh*.

**Table 1**
Variations in Skin friction

| *Gm* | *M* | *K* | *Skin Friction $\tau$ (Gr=5)* | | | | *Skin Friction $\tau$ (Gr= -5)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water |
| 5 | | | 6.5075 | 6.3490 | 7.3516 | 5.6751 | 2.8328 | 2.9321 | 2.9802 | 4.1199 |
| 10 | | | 10.4560 | 10.4235 | 12.1723 | 10.2210 | 6.7658 | 6.5525 | 6.7373 | 7.4989 |
| 15 | | | 14.4038 | 14.5136 | 17.0227 | 14.7317 | 10.6878 | 9.8858 | 10.3002 | 10.1199 |
| | 2 | | 6.5075 | 6.3490 | 7.3516 | 5.6751 | 2.8328 | 2.9321 | 2.9802 | 4.1199 |
| | 3 | | 5.7299 | 5.5649 | 6.1709 | 4.9709 | 2.3762 | 2.5952 | 2.5430 | 3.5463 |
| | 4 | | 5.1984 | 5.0447 | 5.4704 | 4.4962 | 2.0857 | 2.3078 | 2.2456 | 3.1664 |
| | | 2 | 7.0617 | 7.0966 | 6.9600 | 6.2316 | 3.1751 | 2.5338 | 3.2115 | 4.4645 |
| | | 3 | 7.2847 | 7.6694 | 7.2098 | 6.4633 | 3.3163 | 1.3869 | 3.2578 | 4.5953 |
| | | 4 | 7.4052 | 8.2918 | 7.3516 | 6.5907 | 3.3933 | -0.3661 | 3.2610 | 4.6640 |

**Table 2**
Variations in Nusselt Number

| $S_0$ | *F* | *Q* | *Nusselt Number Nu (Gr=5)* | | | | *Nusselt Number Nu (Gr= -5)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water |
| 1 | | | 1.4091 | 1.5740 | 1.6245 | 6.1734 | 1.4178 | 1.2624 | 1.5358 | 6.2551 |
| 2 | | | 1.4098 | 1.6582 | 1.6152 | 5.7578 | 1.4141 | 0.9660 | 1.4241 | 5.8518 |
| 3 | | | 1.4099 | 1.6925 | 1.6071 | 5.2751 | 1.4098 | 0.6197 | 1.2936 | 5.3814 |
| | 4 | | 1.8510 | 2.6302 | 2.4460 | 6.7311 | 1.3445 | 2.5898 | 2.3204 | 6.8069 |
| | 6 | | 2.6516 | 3.0822 | 2.9409 | 7.0466 | 2.6406 | 3.0984 | 2.9445 | 7.1191 |
| | | 3 | 1.9850 | 2.2331 | 0.6403 | 6.5589 | 1.9746 | 1.9437 | -1.9104 | 6.6365 |
| | | 5 | 2.4299 | 2.8740 | 2.7269 | 6.8932 | 2.3685 | 2.8768 | 2.7062 | 6.9673 |
| | | 6 | 2.6516 | 3.0822 | 2.9409 | 7.0466 | 2.6406 | 3.0984 | 2.9445 | 7.1191 |

**Table 3**
Variations in Sherwood Number

| *Sc* | $K_0$ | $S_0$ | **Sherwood Number Sh (Gr=5)* | | | | **Sherwood Number Sh (Gr= -5)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water | Pr=0.025 Mercury | Pr=1.0 Electrolytic solution | Pr=0.71 Air | Pr=7 Water |
| 0.22 | | | 0.4054 | 0.3667 | 0.3608 | -0.6481 | 0.4035 | 0.4338 | 0.3754 | -0.6661 |
| 0.30 | | | 0.4959 | 0.4202 | 0.4265 | -0.9395 | 0.4943 | 0.5733 | 0.4695 | -0.9682 |
| 0.60 | | | 0.9047 | 0.6327 | 0.7222 | -1.8236 | 0.9112 | 1.5080 | 1.0227 | -1.9234 |
| | 0.5 | | 0.2469 | 0.2182 | 0.2080 | -0.7642 | 0.2447 | 0.2712 | 0.2154 | -0.7801 |
| | 1.5 | | 0.5289 | 0.4830 | 0.4803 | -0.5474 | 0.5273 | 0.5605 | 0.5001 | -0.5670 |
| | 3 | | 0.8116 | 0.7498 | 0.7542 | -0.2979 | 0.8106 | 0.8499 | 0.7850 | -0.3216 |
| | | 2 | 0.2188 | 0.1046 | 0.1250 | -1.7067 | 0.2169 | 0.4041 | 0.2071 | -1.7481 |
| | | 4 | -0.1539 | -0.4007 | -0.3128 | -3.1048 | -0.1502 | 0.8589 | 0.0633 | -3.2091 |
| | | 6 | -0.5231 | -0.6650 | -0.6241 | -3.2517 | -0.5063 | 2.2155 | 0.2579 | -3.4406 |

## 5. Conclusion and Application

In the presence of thermal diffusion, absorption and radiation, heat source or sink and chemical reactions, discussions on mixed MHD convection flow of heat as well as mass transfer past an infinite plate which is vertical and porous with effects of Ohmic heating and dissipation of viscosity in have been taken care of in this paper. The equations governed by the flow are firstly transformed to dimensionless form and are further elucidated using the perturbation method. The outcomes are depicted graphically for various range of values of the parameters that are considered during the examination of the problem. The present investigation can be summarized as follows:

- Velocity decreases with an increase value of $Sc$, $M$ while it reverses effect values of $Gm$, $K$, $S_0$ in both cooled and heated plates for fluids of air and water.
- Temperature falls with a rising values of $Pr$, $F$, *and* $Q$ *for* both plates in air, water.
- Concentration decreases with enhancing values of $Sc$, $K_0$ while it reverses effect of $S_0$ for both plates in air and water.
- Skin friction coefficient decreases with rising values of magnetic field parameter (M) for both cooled and heated plate in mercury, electrolytic solution, air and water, while it reverses effect values of modified Grashof number (Gm), permeability parameter (K) in both cooled and heated plates for fluids are Air, Water, mercury and electrolytic solution.
- The rate of heat transfer of mercury, electrolytic solution, air and water, an increase with the rising values of heat absorption (Q) and radiation parameter (F), for cooled and heated plate. But in the case of the fluid flow on heated plate, decreases with increase in Soret parameter ($S_0$) for mercury, electrolytic solution, air, water and also decreases for air, water and an increase for fluids mercury, electrolytic solution.
- The rate of mass transfer increases with rising values of chemical reaction parameter ($K_0$) in both cooled and heated plates for fluids of mercury, electrolytic solution, air and water.
- the rate of mass transfer increases in mercury, electrolytic solution, air and decreases in the fluid of Water for both plates when raising the values of Schmidt number (Sc). Similarly, enhancement of the values of Soret parameter ($S_0$) for cooled plate, Sherwood number fall down in the fluid's mercury, electrolytic solution, air and water but in heated plate decrease for fluids mercury, water and increases in electrolytic solution air.

The consequences of the current study can be practically used in numerous chemical engineering process developments for example aeration, vaporization and condensation of substances, sublimation and crystal evolution along with the removal of thin films. Also, in several industrial applications they are being frequently used, e.g., polymer production, creation of ceramics or glassware and processing of foods.

The absolute presence of unadulterated air/water in nature is relatively not possible. The mixture of various foreign mass is certainly present either in air or water which sometimes causes the effect of Soret and Chemical effects. For example, ammonia, ethyl alcohol, benzene etc., react with air as soon as they interact under certain circumstances. The flow of air is caused by the water-vapor which is present in nature can be cited as one of biggest example. It is also triggered by the alterations in dilutions of material composition.

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