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MHD Transient Free Convection Aligned Magnetic and Chemically Reactive Flow past a Porous Inclined Plate with Radiation and Temperature Gradient Dependent Heat Source in Slip Flow Regime

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Abstract:*This work focuses on the unsteady MHD free convection Aligned magnetic flow of a viscous fluid past a inclined porous plate embedded with porous medium in presence of chemical reaction. In obtaining the solution, the terms regarding radiation effect, temperature gradient dependent heat source are taken into account of energy equation and chemical reaction parameter is taken into account of concentration equation. The Permeability of the porous medium and the suction velocity are considered to be as exponentially decreasing function of time. The effects of the various fluid flow parameters on velocity, temperature and concentration fields with in the boundary layer have been analyzed with the help of graphs. The local skin-friction coefficient and the rates of heat and mass transfer coefficients are also derived and discussed through tables.*

Keywords*: Aligned Magnetic, Chemical Reaction, MHD, Radiation.*

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I. Introduction

Convective flow through porous media is a branch of research undergoing rapid growth in fluid mechanics and heat transfer, because of its important applications in environmental, geophysical and energy related engineering problems. Prominent applications are the utilization of geothermal energy, the control of pollutant spread in groundwater, the design of nuclear reactors, compact heat exchangers, solar power collectors, heat transfer associated with the deep storage of nuclear waste and high performance insulations for buildings, as well as the heat transfer from stored agricultural products that release energy as a result of metabolism of the products. Free convection arises in the fluids when temperature changes causedensity variation leading to buoyancy forces acting on the fluid elements. Themost common example of free convection is the atmospheric flow which isdriven by temperature differences. Sometimes along with the free convectioncurrents caused by differences in temperature and the flow is also affected by thedifferences in concentration or material constitution. This type of flow hasapplications in many branches of science and engineering. The study of suchflow under the influence of magnetic field has attracted the interest of manyinvestigators in view of its application in MHD generators, plasma studies, andnuclear reactors. Hydro-magnetic heat and mass transfer by natural convectionfrom a permeable surface embedded in a fluid saturated porous medium wasstudied by Chamkha [1-3]. The fluid under consideration occurs in somechemical reactions e.g. air and benzene react chemically, so also water andsulphuric acid. During such chemical reactions, there is always generation ofheat. Combining heat and mass transfer problems with a chemical reaction haveimportance in many processes and have therefore received a considerableamount of attention in recent years. In many chemical engineering processeschemical reactions take place between a foreign mass and working fluid whichmoves due to the stretch of a surface. The order of the chemical reactionsdepends on several factors. One of the simplest chemical reactions is the firstorderreaction in which the rate of the reaction is directly proportional to thespecies concentration. The chemical reactions can be codified as eitherheterogeneous or homogenous processes. In most cases of chemical reactions thereaction rate depends on the concentration of the species itself. If the rate ofreaction is directly proportional to the concentration then the reaction is said tohomogeneous reaction or first order reaction. The analysis of the nonlinear MHDflow with heat and mass transfer characteristics of an incompressible, viscous, electrically conducting, and Boussinesq's fluid on a vertical stretching surfacewith a chemical reaction and thermal stratification effects was obtained byKandasamy et al. [4]. The heat and mass transfer characteristics of the naturalconvection about a vertical surface embedded in a saturated porous mediumsubjected to a chemical reaction taking into account the Soret and Dufour effectwas analyzed by Postelnicu [5]. Hossain [6] have studied the effect of radiationon free convection from a porous vertical plate. Ibrahim et al. [7] investigatedthe effect of the chemical reaction and radiation absorption on the unsteadyMHD free convection flow past a semi-infinite vertical permeable moving platewith the heat source and suction.In many practical applications, the particle adjacent to a solid surface nolonger takes the velocity of the surface. The particle at the surface has a finitetangential velocity; it "slips" along the surface. The flow regime is called the slipflow regime and this effect cannot be neglected. Using these assumptions,Sharma and Chaudary [8] discussed the free convection flow past a vertical platein slip-flow regime and also discussed the free convection flow past a verticalplate in slip-flow regime and also discussed its various applications forengineering purpose. Also, Sharma [9] investigated the effect of periodic heatand mass transfer on the unsteady free past a vertical flat plate convection flowin slip-flow regime when suction velocity oscillates in time. Coupled non-linearpartial differential equations governing free convection flow, heat and masstransfer has been obtained analytically using the perturbation technique. Thefluids considered in this investigation are air (Pr = 0.71) and water (Pr = 7) in thepresence of Hydrogen (Sc = 0.22).Magneto hydro-dynamic convective heat andmass transfer in a boundary layer slip flow past a vertical permeable plate withthermal radiation and chemical reaction were investigated by Pal and Talukdar[10]. Kumar et al. [11] studied the fluctuating flow of elastic-viscous stratifiedfluid through a porous medium past an infinite rigid plane in slip flow regime inthe presence of transverse magnetic field. Muthukumaraswamy [12] studied theheat and mass transfer effects on moving vertical plate in the presence of thermalradiation. Gupta and Sharma [13], Sing et al. [14-16] have studied MHD flowthrough porous medium in slip regime. Recently, Jaiswal and Soundalgekar [17]have discussed the flow past an infinite vertical plate oscillating in its plane inthe presence of a temperature gradient dependent heat source. While Taneja andJain [18] have presented a theoretical analysis for unsteady free convection flowwith radiation in slip flow regime. Yamamoto and yoshidha [19] studied flowwith convective acceleration through a porous medium considering suction andinjection. Flow through a plane porous wall and generalization of this study hasbeen presented by Yamamoto and Iwamura [20].England and Emery [21] have studied the radiation effects of an optically thin gray gas bounded by a stationary plate. Raptis and Massalas [22] investigated the effects of radiation on the oscillatory flow of a gray gas, absorbing-emitting in presence induced magnetic field and analytical solutions were obtained with help of perturbation technique. They found out that the mean velocity decreases with the Hartmann number, while the mean temperature decreases as the radiation increases. The hydrodynamic free convective flow of an optically thin gray gas in the presence of radiation, when the induced magnetic field is taken into account was studied by Raptis et al. [23] using perturbation technique. They concluded that the velocity and induced magnetic field increase as the radiation increases. Hossain et al. [24] determined the effect of radiation on the natural convection flow of an optically dense incompressible fluid along a uniformly heated vertical plate with a uniform suction. The governing non-similar boundary-layer equations are analyzed using (i) a series solution; (ii) an asymptotic solution; and (iii) a full numerical solution. Magnetohydrodynamic mixed free–forced heat and mass convective steady incompressible laminar boundary layer flow of a gray optically thick electrically conducting viscous fluid past a semi-infinite vertical plate for high temperature and concentration differences have studied by Emad and Gamal [25].Orhan and Kaya [26] investigated the mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects using the Keller box scheme, an efficient and accurate finite-difference scheme. They concluded that, an increase in the radiation parameter decreases the local skin friction parameter and increases the local heat transfer parameter. Ghosh et al. [27] considered an exact solution for the hydromagnetic natural convection boundary layer flow past an infinite vertical flat plate under the influence of a transverse magnetic field with magnetic induction effects and the transformed ordinary differential equations are solved exactly. Baby Rani .Ch. et al[29] studied both chemical reaction and radiation effects.The object of the present paper is to study the unsteady MHD freeconvection Aligned magnetic flow of a viscous fluid past a inclined porous plate embedded withporous medium in presence of chemical reaction. In obtaining the solution, theterms regarding radiation effect, temperature gradient dependent heat source aretaken into account of energy equation and chemical reaction parameter is takeninto account of concentration equation. The Permeability of the porous mediumand the suction velocity are considered to be as exponentially decreasingfunction of time.

II. Mathematical Analysis

We consider a two-dimensional unsteady free convection flow of anincompressible viscous fluid past an infinite vertical porous plate. In rectangularCartesian coordinate system, we take x-axis along the plate in the direction offlow and y-axis normal to it. Further the flow is considered in presence oftemperature gradient dependent heat source and effect of radiation and chemicalreaction. In the analysis the magnetic Reynolds number is taken to be small sothat the induced magnetic field is neglected. Likewise for small velocity theviscous dissipation and Darcy's dissipation are neglected. The flow in themedium is entirely due to buoyancy force caused by temperature differencebetween the porous plate and the fluid. Under the above assumptions, theequations governing the conservation of mass (continuity), momentum, energyand concentration can be written as follows.

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

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \upsilon \frac{\partial^2 u'}{\partial y'^2} + g\cos\phi\beta_c\left(C' - C'_\infty\right) - \frac{\sigma}{\rho}B_0^2 u'\sin^2\xi + g\cos\phi\beta_T\left(T' - T'_\infty\right) - \frac{\upsilon}{k'(t)}u' \tag{2}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{K_T}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q'_r}{\partial y'} + \frac{Q'}{\rho C_p}\frac{\partial T}{\partial y} \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_c\left(C' - C'_\infty\right) \tag{4}$$

The boundary conditions are:

$$u' = L\left(\frac{\partial u'}{\partial y'}\right),\ T' = T'_w,\ C' = C'_w \quad at \quad y' = 0$$
$$u' \to 0,\quad T' \to T'_\infty,\ C' \to C'_\infty \quad as \quad y' \to \infty \tag{5}$$

From the continuity equation, it can be seen that v' is either a constant or a function of time. Thus, assuming the suction velocity to be oscillatory about a non-zero constant mean, one can

Write $v' = -V_0(1 + \varepsilon e^{-n't'})$ (6)

where v_0 is the mean suction velocity $(v_0 > 0)$, n is the frequency of oscillation, and ε<<1is a positive constant. The negative sign indicates that the suction velocity is directed towards the plate.

Consider the fluid which is optically thin with a relatively low density and radio-active heat flux is given in the following [28]

$$\frac{\partial q_r}{\partial y'} = 4(T' - T_\infty')I' \tag{7}$$

The permeability of the porous medium in non-dimensional form is considered as

$$k'(t) = k_0'(1 + \varepsilon e^{-n't'}) \tag{8}$$

$$u = \frac{u'}{V_0},\ y = \frac{y'V_0}{\upsilon},\ n = \frac{4\upsilon n'}{V_0^2},\ Gr = \frac{g\beta_T\upsilon(T_w' - T_\infty')}{V_0^3},$$
$$Gm = \frac{g\beta_c\upsilon(C_w' - C_\infty')}{V_0^3},\ T = \frac{T' - T_\infty'}{T_w' - T_\infty'},\ K = \frac{K_0'V_0^2}{\upsilon^2},$$
$$R = \frac{4\upsilon I'}{\rho C_p V_0^2},\ H = \frac{Q'\upsilon}{\rho C_p V_0^2(T_w' - T_\infty')},\ C = \frac{C' - C_\infty'}{C_w' - C_\infty'},$$
$$K_c = \frac{K_c'\upsilon}{V_0^2},\ \Pr = \frac{\rho\upsilon C_p}{KT},\ M = \frac{\sigma B_0^2\upsilon}{V_0^3},\ Sc = \frac{\upsilon}{D},\ t = \frac{V_0^2 t'}{4\upsilon} \tag{9}$$

Introducing the equations (6),(7),(8) and the above stated non-dimensional quantities(9) in the equations (2),(3),(4) we obtain

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1 + \varepsilon e^{-nt})\frac{\partial u}{\partial y} = Gr_1 T + Gm_1 C + \frac{\partial^2 u}{\partial y^2} - \frac{1}{k(1 + \varepsilon e^{-nt})}u - M\sin^2\xi\, u \tag{10}$$

$$\frac{1}{4}\frac{\partial T}{\partial t}-(1+\varepsilon e^{-nt})\frac{\partial T}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-RT+H\frac{\partial T}{\partial y} \quad (11)$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-(1+\varepsilon e^{-nt})\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-K_c C \quad (12)$$

Boundary conditions(5) reduce to

$$u=h\left(\frac{\partial u}{\partial y}\right), T=1, C=1 \quad at\ y=0$$
$$u\to 0, T\to 0, C\to 0 \quad as\ y\to\infty \quad (13)$$

$$h=\frac{L_1 V_0^2}{\upsilon}; Gr_1=Gr\cos\phi, Gm_1=Gm\cos\phi$$

III. Solution Of The Problem

To solve the partial differential equations (10), (11) and (12), we reduce them into ordinary differential equations. To obtain the solution we follow the procedure given by Gersten and Gross. Therefore the expressions for velocity, temperature and concentration are assumed in the following form

$u(y,t) = u_0(y) + \varepsilon e^{-nt} u_1(y) + O(\varepsilon^2) + \cdots$ (14)

$\theta(y,t) = T_0(y) + \varepsilon e^{-nt} T_1(y) + O(\varepsilon^2) + \cdots$ (15)

$C(y,t) = C_0(y) + \varepsilon e^{-nt} C_1(y) + O(\varepsilon^2) + \cdots$ (16)

Substituting (14)-(16) into Eqs.(10)-(12) and equating the harmonic and nonharmonic terms, neglecting the higher order $O(\varepsilon^2)$, and simplifying to get the following pairs of equations for u_0, T_0, C_0 and u_1, T_1, C_1.

$$u_0''(y)+u_0'(y)-M_1u_0(y)=-Gr_1T_0(y)-Gm_1C_0(y) \quad (17)$$

$$u_1''(y)+u_1'(y)-M_2u_1(y)=-Gr_1T_1(y)-Gm_1C_1(y)-\frac{1}{k_0}u_0(y)-u_0'(y) \quad (18)$$

$$T_0''(y)+(1+H)\Pr T_0'(y)-R\Pr T_0(y)=0 \quad (19)$$

$$T_1''(y)+(1+H)\Pr T_1'(y)-\left(R-\frac{n}{4}\right)\Pr T_1(y)=-\Pr T_0'(y) \quad (20)$$

$$C_0''(y)+ScC_0'(y)-K_cScC_0(y)=0 \quad (21)$$

$$C_1''(y)+ScC_1'(y)-\left(K_c-\frac{n}{4}\right)ScC_1(y)=-ScC_0'(y) \quad (22)$$

$$M_1=M\sin^2\xi+\frac{1}{K}, \quad M_2=M\sin^2\xi+\frac{1}{K}-\frac{n}{4}$$

Where the prime denotes ordinary differentiation with respect to y. The corresponding boundary conditions are

$$u_0=hu_0', u_1=hu_1', T_0=1, T_1=0, C_0=1, C_1=0 \quad at\ y=0 \quad (23)$$

$$u_0\to 0, u_1\to 0, T_0\to 0, T_1\to 0, C_0\to 0, C_1\to 0 \quad as\ y\to\infty \quad (24)$$

The equations from (17) – (22) are second order linear differential equations with constant coefficients. The solutions of these paired equations under the corresponding boundary conditions (23) &(24) are:

$$u_1(y)=A_{11}e^{-m_6y}+A_6e^{-m_5y}+A_7e^{-m_3y}+A_8e^{-m_1y}+A_9e^{-m_4y}+A_{10}e^{-m_2y} \quad (25)$$

$$u_0(y)=A_5e^{-m_5y}+A_3e^{-m_3y}+A_4e^{-m_1y} \quad (26)$$

$$T_1(y)=A_2(e^{-m_3y}-e^{-m_4y}) \quad (27)$$

$$T_0(y)=e^{-m_3y} \quad (28)$$

$$C_1(y)=A_2(e^{-m_1y}-e^{-m_2y}) \quad (29)$$

$$C_0(y)=e^{-m_1y} \quad (30)$$

Introducing the equations (25) – (30) in the equations (14) – (16), we obtain the expressions for velocity (u), temperature (T) and concentration (C) as

$$u(y,t) = (A_5 e^{-m_5 y} + A_3 e^{-m_3 y} + A_4 e^{-m_1 y}) + \varepsilon e^{-nt}(A_{11} e^{-m_6 y} + A_6 e^{-m_5 y} + A_7 e^{-m_3 y} + A_8 e^{-m_1 y} + A_9 e^{-m_4 y} + A_{10} e^{-m_2 y}) \quad (31)$$

$$T(y,t) = (e^{-m_3 y}) + \varepsilon e^{-nt} A_2 (e^{-m_3 y} - e^{-m_4 y}) \quad (32)$$

$$C(y,t) = (e^{-m_1 y}) + \varepsilon e^{-nt} A_1 (e^{-m_1 y} - e^{-m_2 y}) \quad (33)$$

The Skin-friction coefficient, the Nusselt number and the Sherwood number are important physical parameters for this type of boundary layer flow which are defined and determined as follows:

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

$$= \left(\left(\frac{\partial u_0}{\partial y}\right)_{y=0} + \varepsilon e^{-nt} \left(\frac{\partial u_1}{\partial y}\right)_{y=0} \right)$$

$$= (-1)((A_5 m_5 + A_3 m_3 + A_4 m_1) + \varepsilon e^{-nt}(A_{11} m_6 + A_6 m_5 + A_7 m_3 + A_8 m_1 + A_9 m_4 + A_{10} m_2)) \quad (34)$$

Nusselt number = Nu = $\left(\frac{\partial T}{\partial y}\right)_{y=0}$

$$= \left(\frac{\partial T_0}{\partial y}\right)_{y=0} + \varepsilon e^{-nt} \left(\frac{\partial T_1}{\partial y}\right)_{y=0} \quad (35)$$

$$= -m_3 + \varepsilon e^{-nt}(A_2 m_4 - A_2 m_3)$$

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

$$= \left(\frac{\partial C_0}{\partial y}\right)_{y=0} + \varepsilon e^{-nt} \left(\frac{\partial C_1}{\partial y}\right)_{y=0} \quad (36)$$

$$= -m_1 + \varepsilon e^{-nt}(A_1 m_2 - A_1 m_1)$$

IV. Results And Discussion

To assess the physical depth of the problem, the effects of various parameters like aligned magnetic parameter ξ, inclined angle ϕ, perturbation parameter ε, slip parameter h, Grashof number Gr, Magnetic parameter M, Permeability of Porous medium K, Heat source parameter H, Radiation parameter R, Chemical reaction parameter Kc, Modified Grashof number Gm and schimidt number Sc on velocity distribution, temperature distribution and concentration distribution are studied in figures (1) to (17), while keeping the other parameters as constants. In figure (1) the effects of M on velocity are shown. From this figure it is noticed that velocity decreases as M increases. Since, the applied magnetic field acts as Lorentz's force which drags the velocity. In figure (2) the effects of ξ on velocity are shown. From this figure it is noticed that velocity decreases as ξ increases. The effect of inclination of the plate on velocity is shown in Fig.3. From Fig.3, we observe that fluid velocity is decreased in increasing angle ϕ. The fluid has higher velocity when the plate is vertical i.e. $\phi = 0$, than when inclined because of the fact that the buoyancy effect decreases due to gravity components g cosϕ, as the plate is inclined. Figure (4) depicts the velocity profiles with the variations in h, it is observed that the significance of the velocity is high near the plate and there after it decreases and reaches to the stationery position at the other side of the plate. As expected velocity increases with an increase in h. Fig. 5 illustrates the effect of the thermal Grashof number (Gr) on the velocity field. The thermal Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. The flow is accelerated due to the enhancement in buoyancy force corresponding to an increase in the thermal Grashof number, i.e., free convection effects. It is noticed that thermal Grashof number (Gr) increases, the velocity field increases. The effect of mass (solutal) Grashof number (Gm) on the velocity illustrated in Fig. 6. The mass (solutal) Grashof number defines the ratio of species buoyancy force to the viscous hydrodynamic force. It is noticed that the velocity increases with increasing values of solutalGrashof number. In figure (7) the velocity increases as K increases. In figure (8) the velocity decreases as H increases. The effect of the thermal radiation conduction (R) on the velocity is illustrated in Fig. 9. It is observed that as the thermal radiation conduction increases, the velocity decreases.Fig.10: It shows the behavior of Velocity for different values of chemical reaction parameter Kc . It is observed that an increase in leads to a decrease in the values of Velocity. The effect of Schmidt number Sc on velocity is shown in fig.11. This figure shows that the velocity decreases with increasing values of Sc. and hence the velocity decreases for large values of Sc. The effect of Schmidt number Pr on velocity is shown in fig.12. This figure shows that the velocity decreases with increasing values of Pr. and hence the velocity decreases for large values of Pr. In the figures (13) & (14) the temperature distribution decreases as R and H increase respectively. Fig. 15 shows the variation of the thermal boundary-layer with the perturbation parameter (ε). It is observed that the thermal boundary layer thickness decreases with an increase in the perturbation parameter.Fig.16 shows the behavior of concentration for different values of schmidit number Sc. It is observed that an increase in leads to a decrease in the values of concentration.Fig.17shows the behavior of concentration for different values of chemical reaction parameter Kc. It is observed that an increase in leads to a decrease in the values of concentration. The variations in skin friction, nusselt number and Sherwood number are studied at n = 0.5, t =1 and ε = 0.1 through the tables (1) to (3). From Table 1,we have Increasing values of Gr, Gm and K, Skin friction coefficient is increasing and Increasing values of Sc, ξ, ϕ, M, H and h, Skin friction coefficient is decreasing. From Table 2, Increasing values of Pr, H, R, Nusselt number coefficient is decreasing. From Table 3, Increasing values of Sc and Kc, Nusselt number coefficient is decreasing.

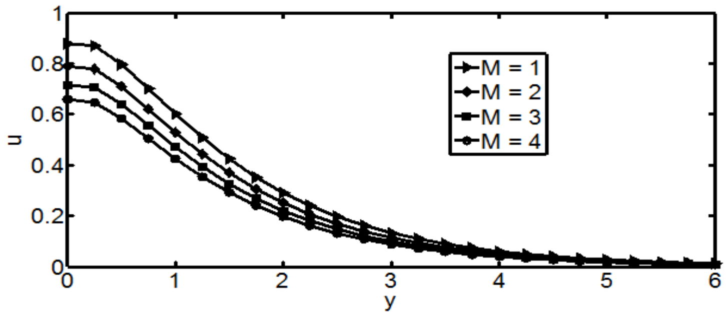

Fig.1: Velocity profiles for different values of magnetic parameter M with Sc = 0.22, n = 0.1, t = 1, ∈ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, h = 5, ϕ = π/3, ξ = π/6.

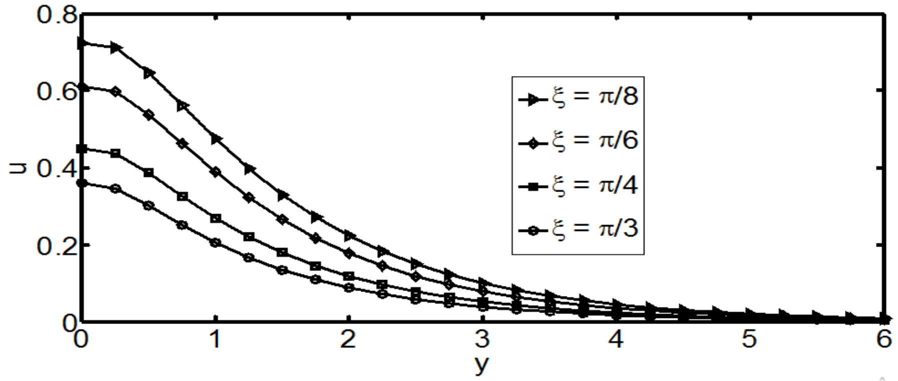

Fig.2: Velocity profiles for different values of Aligned magnetic parameter ξwith Sc = 0.22, n = 0.1, t = 1, ∈ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, ϕ = π/3.

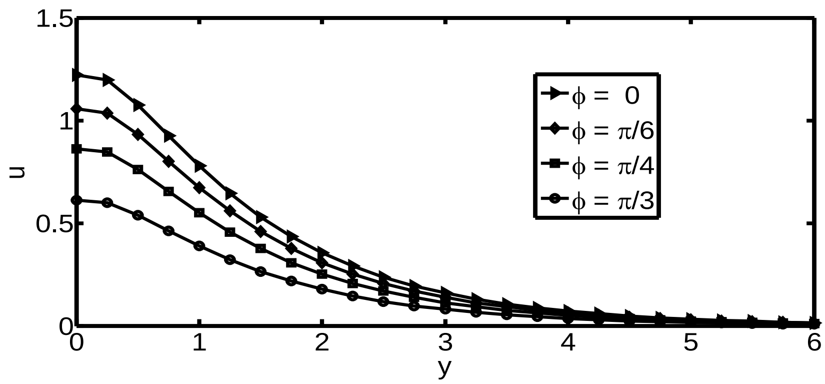

Fig.3: Velocity profiles for different values of inclined angle $\phi$with Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, $\xi = \pi/6$.

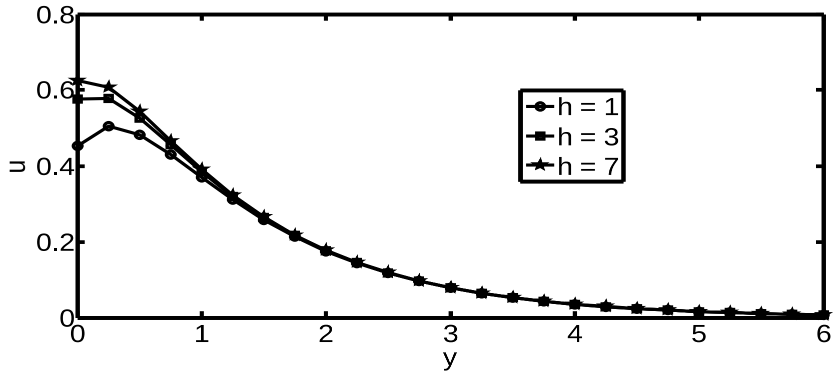

Fig.4: Velocity profiles for different values of slip parameter hwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, $\phi = \pi/3$, $\xi = \pi/6$.

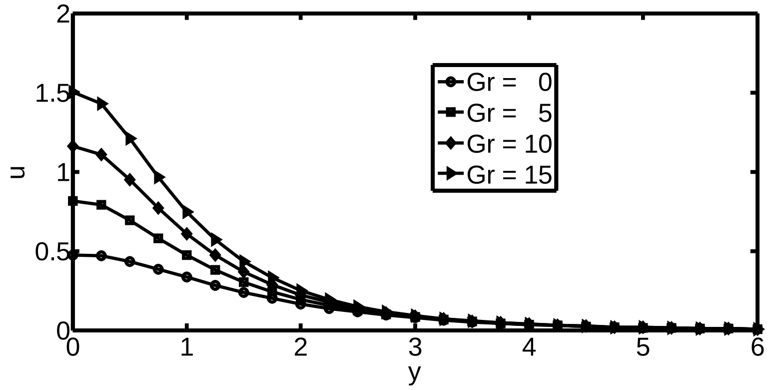

Fig.5: Velocity profiles for different values of Grashof number Grwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gm = 4, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

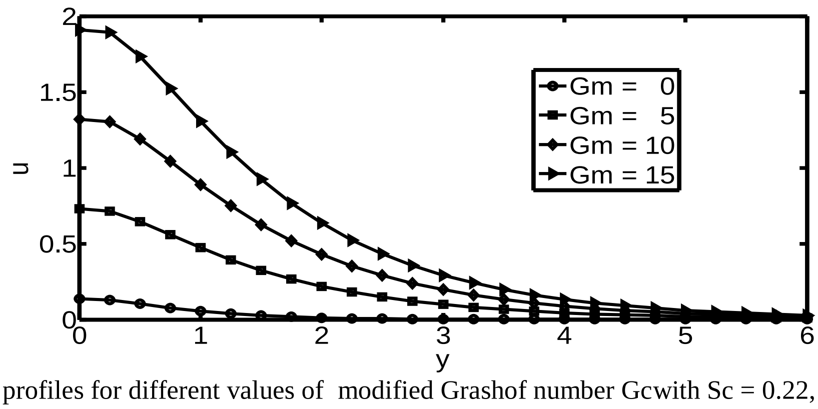

Fig.6: Velocity profiles for different values of modified Grashof number Gcwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

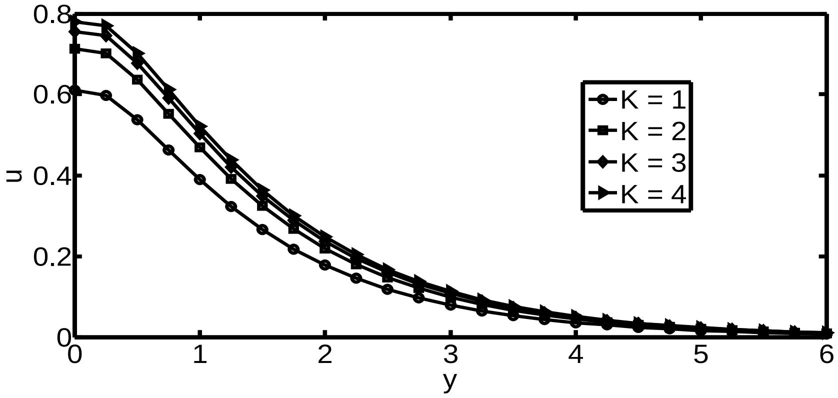

Fig.7: Velocity profiles for different values of permeability parameter Kwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

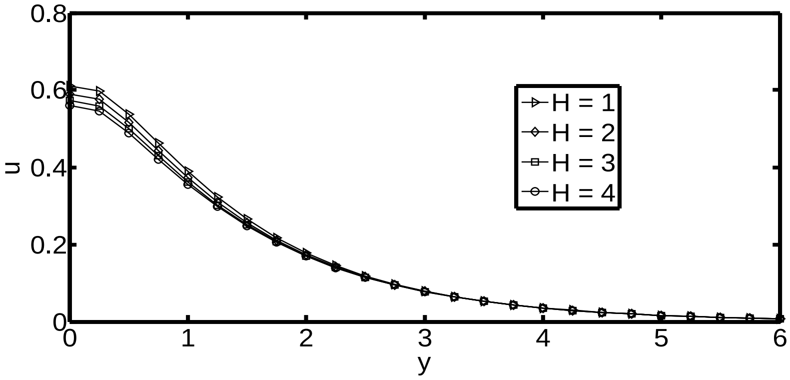

Fig.8: Velocity profiles for different values of heat source parameter Hwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

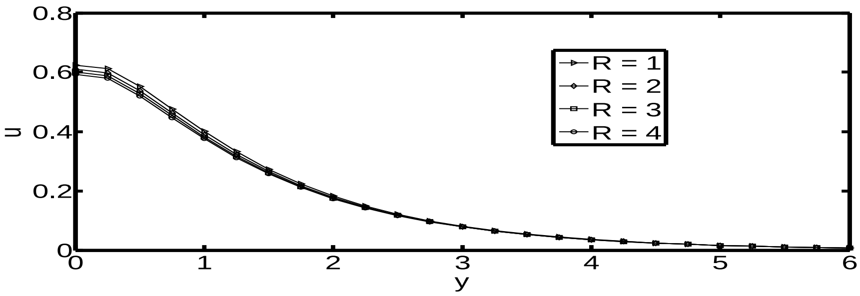

Fig.9: Velocity profiles for different values of radiation parameter R with Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

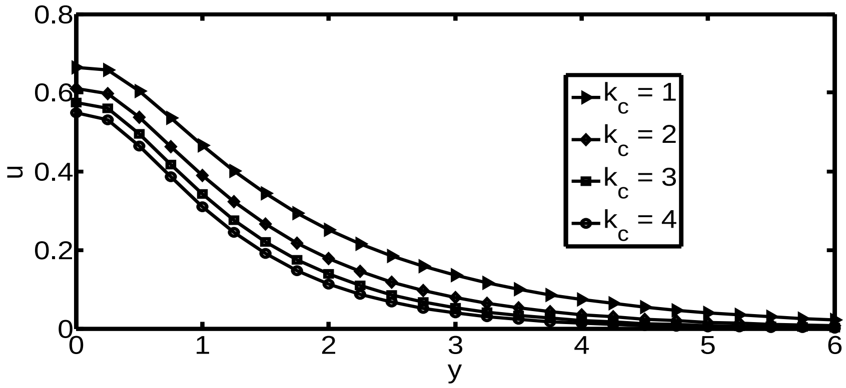

Fig.10: Velocity profiles for different values of chemical reaction parameter Kcwith Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

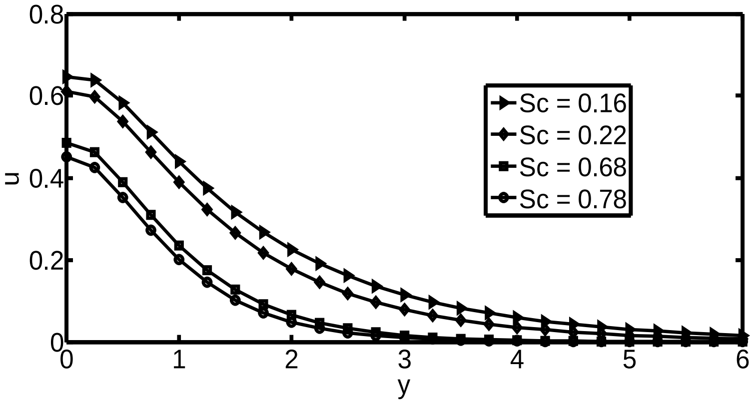

Fig.11: Velocity profiles for different values of Schmidt number Scwith n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, $\phi = \pi/3$, $\xi = \pi/6$.

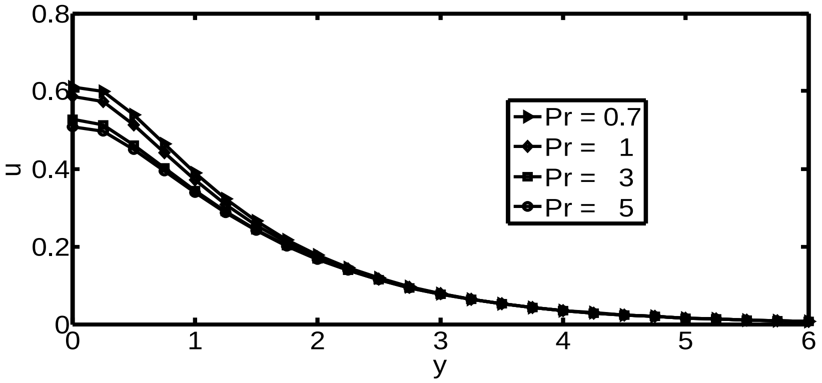

Fig.12: Velocity profiles for different values of prandtl number Prwith Sc = 0.22, n = 0.1, t = 1, ∊ = 0.1, Kc = 2, R = 2, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, ϕ = π/3, ξ = π/6.

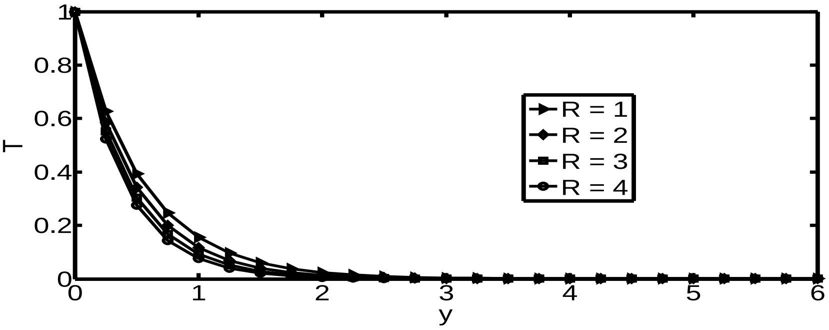

Fig.13: Temperature profiles for different values of radiation parameter R with Sc = 0.22, n = 0.1, t = 1, ∊ = 0.1, Kc = 2, Pr = 0.71, H = 1.

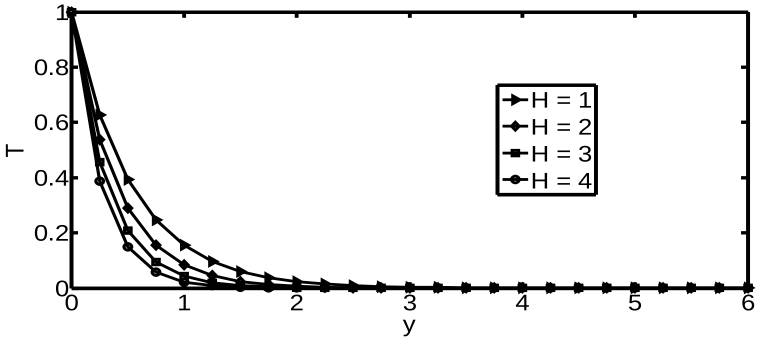

Fig.14: Temperature profiles for different values of heat source parameter Hwith Sc = 0.22, n = 0.1, t = 1, ∊ = 0.1, Kc = 2, R = 2, Pr = 0.71.

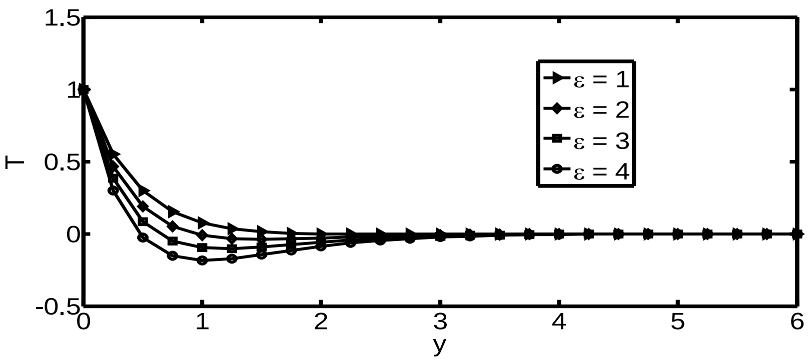

Fig.15: Temperature profiles for different values of perturbation parameter εwith Sc = 0.22, n = 0.1, t = 1, Kc = 2, R = 2, Pr = 0.71, H = 1.

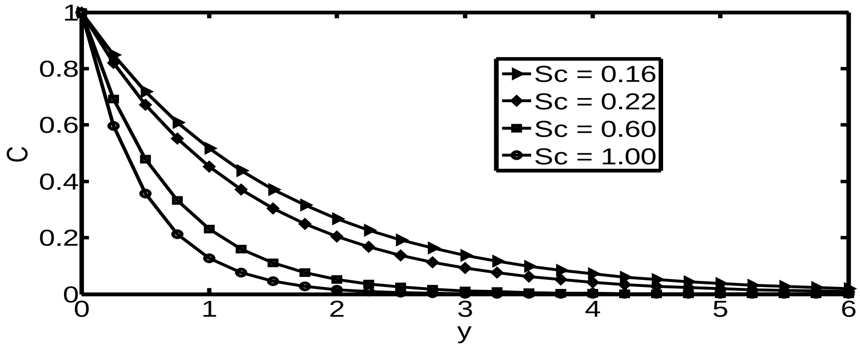

Fig.16: Concentration profiles for different values of schimidt number Scwith n = 0.1, t = 1, ∈ = 0.1, Kc = 2.

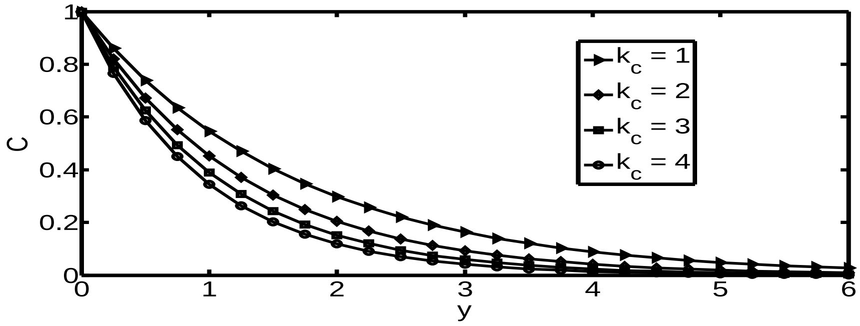

Fig.17: Concentration profiles for different values of permeability parameter Kwith Sc = 0.22, n = 0.1, t = 1, ∈ = 0.1.

TABLE: 1SKIN-FRICTION COEFFICIENT / LOCAL WALL SHEAR STRESS

With Sc = 0.22, n = 0.1, t = 1, ∈ = 0.1, Kc = 2, R = 2, Pr = 0.71, H = 1, Gr = 2, Gm = 4, K = 1, M = 5, h = 5, ϕ = π/3, ξ = π/6.

Sc	Gr	Gm	ϕ	M	ξ	K	H	h	Cf
0.16	2	4	π/3	5	π/6	1	1	5	0.1894
0.60	2	4	π/3	5	π/6	1	1	5	0.1327
0.78	2	4	π/3	5	π/6	1	1	5	0.1221
0.22	**5**	4	π/3	5	π/6	1	1	5	0.1632
0.22	**10**	4	π/3	5	π/6	1	1	5	0.2318
0.22	**15**	4	π/3	5	π/6	1	1	5	0.3004
0.22	**20**	4	π/3	5	π/6	1	1	5	0.3691
0.22	2	**5**	π/3	5	π/6	1	1	5	0.1457
0.22	2	**10**	π/3	5	π/6	1	1	5	0.2639
0.22	2	**15**	π/3	5	π/6	1	1	5	0.3821
0.22	2	**20**	π/3	5	π/6	1	1	5	0.5003
0.22	2	4	**0**	5	π/6	1	1	5	0.2440
0.22	2	4	**π/6**	5	π/6	1	1	5	0.2113
0.22	2	4	**π/4**	5	π/6	1	1	5	0.1716
0.22	2	4	**π/3**	5	π/6	1	1	5	0.1220
0.22	2	4	π/3	**1**	π/6	1	1	5	0.1758
0.22	2	4	π/3	**2**	π/6	1	1	5	0.1578
0.22	2	4	π/3	**3**	π/6	1	1	5	0.1435
0.22	2	4	π/3	**4**	π/6	1	1	5	0.1318
0.22	2	4	π/3	5	**π/8**	1	1	5	0.1444
0.22	2	4	π/3	5	**π/6**	1	1	5	0.1220
0.22	2	4	π/3	5	**π/4**	1	1	5	0.0899
0.22	2	4	π/3	5	**π/3**	1	1	5	0.0719
0.22	2	4	π/3	5	π/6	**2**	1	5	0.2278
0.22	2	4	π/3	5	π/6	**3**	1	5	0.2541
0.22	2	4	π/3	5	π/6	**4**	1	5	0.2701
0.22	2	4	π/3	5	π/6	1	**2**	5	0.1696
0.22	2	4	π/3	5	π/6	1	**3**	5	0.1649
0.22	2	4	π/3	5	π/6	1	**4**	5	0.1614
0.22	2	4	π/3	5	π/6	1	1	**0.2**	1.2627
0.22	2	4	π/3	5	π/6	1	1	**0.3**	1.1186
0.22	2	4	π/3	5	π/6	1	1	**0.4**	1.0040

TABLE: 2NUSSLET NUMBER / LOCAL SURFACE HEAT FLUX

With Sc = 0.22, n = 0.1, t = 1, $\in$ = 0.1, Kc = 2, R = 1, Pr = 0.71, H = 1.

Pr	H	R	Nu
0.70	1	1	-1.8431
1.00	1	1	-2.4917
2.00	1	1	-4.6142
3.00	1	1	-6.7178
0.71	**2**	1	-2.4805
0.71	**3**	1	-3.1310
0.71	**4**	1	-3.8011
0.71	1	**2**	-2.1458
0.71	1	**3**	-2.3792
0.71	1	**4**	-2.5833

TABLE: 3SHERWOOD NUMBER / RATE OF MASS / LOCAL MASS FLUX

With n=0.1, t= 1, $\in$ = 0.1.

Sc	Kc	Sh
0.16	2.0	-2.1281
0.22	2.0	-2.9275
0.60	2.0	-8.7676
0.78	2.0	-11.9866
0.22	**1**	-1.8062
0.22	**3**	-3.9751
0.22	**4**	-4.9840

V. Conclusions

In this paper, chemical reaction effect and aligned magnetic on steady two-dimensional free convection flow of a viscous incompressible electrically conducting fluid through a porous medium bounded by an inclined surface with constant suction velocity, constant heat and mass flux in the presence of uniform magnetic field has been studied. The dimensionless governing equations are solved using perturbation technique.

The following observations are made:

- Velocity decreases as M increases.
- Velocity decreases as ξ increases.
- Velocity is decreased in increasing angle ϕ.
- As expected velocity increases with an increase in h.
- Thermal Grashof number (Gr) increases, the velocity field increases.
- The velocity increases with increasing values of solutalGrashof number.
- As the thermal radiation conduction increases, the velocity decreases.
- An increase in leads to a decrease in the values of Velocity.
- The velocity decreases with increasing values of Sc.
- The velocity decreases with increasing values of Pr.
- The temperature distribution decreases as R and H increase respectively.
- The thermal boundary layer thickness decreases with an increase in the perturbation parameter.
- An increase in leads to a decrease in the values of concentration.
- An increase in leads to a decrease in the values of concentration.

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