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Aligned Magnetic Field and Thermal Radiation effects on Unsteady MHD Flow an Inclined Porous Plate with Chemical Reaction and Heat Source: Finite Difference Technique

Vellanki Nagaraju[1] , Omeshwar Reddy V[2], Srihari Babu V[3]

Abstract.. The purpose of this paper is to perform unsteady hydrodynamic flow over an inclined plate embedded in a porous medium with Soret aligned magnetic field and chemical reaction. Computations were performed to analyze the behavior of fluid velocity, temperature and concentration on the inclined vertical plate with the variation of emerging physical parameters like aligned magnetic field, Rivlin-Ericksen parameter, inclined angle, chemical reaction including soret parameter.

Keywords: *Porous Medium, Soret, Chemical reaction, Rivlin-Ericksen fluid, Finite Difference Method.*

1. Introduction:

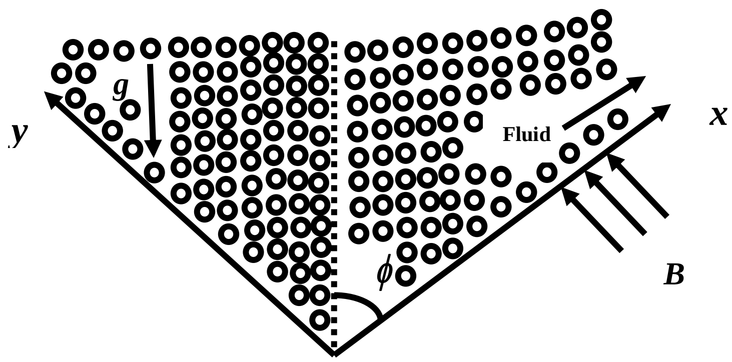
Researchers have been focusing more on improving heat transfer efficiency in recent years as a result of serious energy and environmental issues. Some of the vital applications of heat and mass transfer flow with chemical reaction can be found in catalytic chemical reactors, food processing, and polymer production. On the contrary, flow in porous media has practical applications in heat removal from nuclear fuel, debris, underground disposal of radioactive waste material, storage of food stuffs, paper production, oil exploration, etc. Non-Newtonian fluids have been recognized as one of the most popular research topics not only in the field of fluid mechanics but also in production engineering, chemical engineering, as well as the manufacturing process. The word "viscosity" is one of the major thermo-physical properties of fluid denoting "internal friction" or "thickness". It is concerned with the relationship between fluid's resistance and its rate of deformation resulting from tensile/shear stress. The viscosity of fluid is inversely proportional to its velocity. Viscosity of lubricating oils is used to limit the friction and wear in a mechanical system. Obviously, lubricant's viscosity significantly varies with temperature. This is applied in many areas like drawing of plastic films, glass fiber production, paper production, gluing of labels on hot bodies, wire drawing, and in the process of hot rolling. Sharma et al. [1] discussed Hall effects on thermal instability of Rivlin-Ericksen fluid. Satya Prasad Maddula [2] discussed the Finite element solutions of unsteady free convective flow towards a vertical plate in presence of magnetic field, heat and mass transfer. Pal and Mondal [3] investigated the magnetohydrodynamic convective heat-mass transfer over a vertical stretched sheet by including Soret-Dufour, and temperature-dependent viscosity effects. Prakash et al.[4] investigated the Effects of chemical reaction and radiation absorption on MHD flow of dusty viscoelastic fluid. Tripathy et. al. [5] has been studied chemical reaction effect on MHD free convective surface over a moving vertical plane through porous medium. Chaudhary et. al. [6] motivated study on free convection effects on MHD flow past an infinite vertical accelerated plate embedded in porous media with constant heat flux. D.P.Rao et.al. (7) discussed the effect of heat and mass transfer on unsteady mhd flow of rivlin-ericksen fluid over an inclined channel with two parallel flat plates moving with oscilatory motion while one plate is adiabatic. Niranjan Hari et al. [8] analyzed flow with slip condition. The reactions of chemical processing, Soret-mass transfer, Dufour-heat transfer are verified using non-dimensional parameters at a stagnation point. Seetha mahalakshmi et al.(9) examined the unsteady MHD free convection flow and mass transfer near to a moving vertical plate within the sight of thermal radiation. Several research authors [10-15] explained the effects of Rivlin - Ericksen fluid flow with porous medium. Radiation and Dufour effects on unsteady MHD mixed convective flow in an accelerated vertical wavy plate with varying temperature and mass diffusion discussed by Jagdish Prakash et al. [16]. Reddy et.al. [17] explained the Cross Diffusion Effects on Hydrodynamic Rivlin-Ericksen Fluid Flow Past a Vertically Inclined Plate in Presence of Heat Source, Viscous Dissipation and Heat Transfer by a

Finite Difference Technique. V.Raju et al. [18] discussed the radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate in the presence of chemical reaction. V Sri Hari Babu et al. [19] explained Mass transfer effects on MHD mixed convective flow from a vertical surface with ohmic heating and viscous dissipation. KJ Rami Reddy et al. [20] discussed radiation and chemical reaction effects on unsteady MHD free convection flow past a linearly accelerated vertical porous plate with variable temperature and mass diffusion

Thus the present investigation is concerned with the study of combined effects of thermal diffusion and first-order chemical reaction on an aligned magnetic field in two-dimensional MHD flow, heat and mass transfer of a viscous incompressible fluid past a permeable inclined plate embedded in a porous medium in the presence of Rivlin-Ericksen fluid flow using finite difference technique.

2.MATHEMATICAL ANALYSIS:

Considering 2D unstable MHD free convection to be an incompressible, laminar flow of an electrically conducting, heat absorption fluid through a semi-infinite inclined moving permeable plate at an acute angle to the vertical in a uniform pressure grading and slip flow regime with changing suction, The x-axis is measured along the plate in this chapter, and the fluid is permitted via an aligned magnetic field useful along the y-axis at dissimilar angles. The plate surface is subjected to fluid suction. In Figure 2.1, the flow problem's physical model and coordinate system are depicted. In order to ignore the induced magnetic field, the magnetic Reynolds number is set to a low value in this investigation.The fluid is a grey, absorption-emission, non-scattering medium, and the Rosseland approximation is employed to characterise the radiative heat change in the x-direction, which is deemed minimal in assessment to the y-direction.



Physical model of the problem

Under the above assumptions the boundary layer equations for the problem can be written as.

Equation of Continuity:

$$\frac{\partial v'}{\partial y'} = 0 \qquad (2.1)$$

Momentum Equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} - \left[\frac{\sigma B_0^2}{\rho}\right]u'\sin^2\xi - \left[\frac{\nu}{k'}\right]u' + g\beta_T\left(T' - T'_\infty\right)\left(\cos\varphi\right) + g\beta_C\left(C' - C'_\infty\right)\left(\cos\varphi\right) - \beta_1\left(\frac{\partial^3 u'}{\partial t'\partial y'^2}\right) \tag{2.2}$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{\kappa_T}{\rho C_P}\left(\frac{\partial^2 T'}{\partial y'^2}\right) + \frac{Q'}{\rho C_P}\frac{\partial T}{\partial y} - \frac{1}{\rho C_P}\left(\frac{\partial q'_r}{\partial y'}\right) \tag{2.3}$$

Species Diffusion Equation:

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\left(\frac{\partial^2 C'}{\partial y'^2}\right) - K'_r(C' - C'_\infty) + \frac{D_m k_T}{T_m}\left(\frac{\partial^2 T'}{\partial y'^2}\right) \tag{2.4}$$

The boundary conditions are:

$$\left.\begin{aligned} &u' = L\left(\frac{\partial u'}{\partial y'}\right),\ T' = T_w',\ C' = C_w' \quad at \quad y' = 0 \\ &u' \to 0, \qquad T' \to T_\infty',\ C' \to C_\infty' \quad as \quad y' \to \infty \end{aligned}\right\} \tag{2.5}$$

Surface is a function of time only and we shall take variable suction velocity

$$v' = -V_0(1 + \varepsilon e^{-n't'}) \tag{2.6}$$

Considering the following fluid, which is optically thin, has a low density, and has a radioactive heat flow of:

$$\frac{\partial q_r}{\partial y'} = 4(T' - T_\infty')I' \tag{2.7}$$

The non-dimensional permeability of a porous media is calculated as

$$k'(t) = k_0'(1 + \varepsilon e^{-n't'}) \tag{2.8}$$

Now introduce non-dimensional quantities

$$u = \frac{u'}{V_0},\ y = \frac{y'V_0}{\upsilon},\ n = \frac{4\upsilon n'}{V_0^2}, T = \frac{T' - T_\infty'}{T_w' - T_\infty'}, C = \frac{C' - C_\infty'}{C_w' - C_\infty'}$$

$$Sr = \frac{D_m k_T (T'_w - T'_\infty)}{\nu T_m\left(C'_w - C'_\infty\right)} \tag{2.9}$$

After substituting Eqs. (2.6) - (2.9) in the Eqs. (2.2) - (2.5) then we obtain modified governing PDE's are as follows;

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \varepsilon Ae^{-nt}\right)\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - M\sin^2\xi u - \frac{1}{k\left(1 + \varepsilon Ae^{-nt}\right)}u + Gr_1 T + Gc_1 C - \lambda\left(\frac{\partial^3 u}{\partial t\partial y^2}\right) \tag{2.10}$$

$$\frac{1}{4}\frac{\partial T}{\partial t}-(1+\varepsilon e^{-nt})\frac{\partial T}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-RT+H\frac{\partial T}{\partial y} \tag{2.11}$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{-nt}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-KcC+(Sr)\left(\frac{\partial^2 T}{\partial y^2}\right) \tag{2.12}$$

The related boundary conditions are

$$\left.\begin{array}{l} u=h\left(\dfrac{\partial u}{\partial y}\right), T=1, \quad C=1 \quad at\ y=0 \\ u\to 0, \qquad T\to 0, C\to 0 \quad as\ y\to\infty \end{array}\right\} \tag{2.13}$$

$$\left.\begin{array}{l} Gr=\dfrac{g\beta_T\upsilon(T_w'-T_\infty')}{V_0^3}, Gm=\dfrac{g\beta_c\upsilon(C_w'-C_\infty')}{V_0^3}, K=\dfrac{K_0'V_0^2}{\upsilon^2}, R=\dfrac{4\upsilon I'}{\rho C_p V_0^2} \\ Sc=\dfrac{\upsilon}{D}\ H=\dfrac{Q'\upsilon}{\rho C_p V_0^2(T_w'-T_\infty')},\ K_c=\dfrac{K_c'\upsilon}{V_0^2},\ \Pr=\dfrac{\rho\upsilon C_p}{KT}, M=\dfrac{\sigma B_0^2\upsilon}{V_0^3} \\ M_1=M\sin^2\xi+\dfrac{1}{K},\ M_2=M\ \sin^2\xi+\dfrac{1}{K}-\dfrac{n}{4},\ t=\dfrac{V_0^2 t'}{4\upsilon},\ h=\dfrac{L_1V_0^2}{\upsilon} \\ Gr_1=Gr\cos\phi, Gm_1=Gm\cos\phi \end{array}\right\}$$

(2.14)

2.SOLUTION OF THE PROBLEM:

The non-linear momentum, energy and concentration equations given in equations (2.10), (2.11) and (2.12) are solved under the appropriate initial and boundary conditions (2.13) by the finite difference method. The transport equations (2.10), (2.11) and (2.12) at the grid point (*i*, *j*) are expressed in difference form using Taylor's expansion.

$$\frac{1}{4}\left(\frac{u_i^{j+1}-u_i^j}{\Delta t}\right)-\left(1+\varepsilon Ae^{-nt}\right)\left(\frac{u_{i+1}^j-u_i^j}{\Delta y}\right)=\left(\frac{u_{i+1}^j-2u_i^j+u_{i-1}^j}{(\Delta y)^2}\right)-M\sin^2\xi u_i^j-$$
$$\frac{1}{k\left(1+\varepsilon Ae^{-nt}\right)}u_i^j+Gr_1T_i^j+Gm_1C_i^j-\lambda\left[\left(\frac{u_{i+1}^{j+1}-2u_i^{j+1}+u_{i-1}^{j+1}-u_{i+1}^j+2u_i^j-u_{i-1}^j}{\Delta t(\Delta y)^2}\right)\right] \tag{3.1}$$

$$\frac{1}{4}\left(\frac{T_i^{j+1}-T_i^j}{\Delta t}\right)-\left(1+\varepsilon Ae^{-nt}\right)\left(\frac{T_{i+1}^j-T_i^j}{\Delta y}\right)=\frac{1}{\Pr}\left(\frac{T_{i+1}^j-2T_i^j+T_{i-1}^j}{(\Delta y)^2}\right)-RT_i^j+H\left(\frac{T_{i+1}^j-T_i^j}{\Delta y}\right) \tag{3.2}$$

$$\frac{1}{4}\left(\frac{C_i^{j+1}-C_i^j}{\Delta t}\right)-\left(1+\varepsilon A e^{-nt}\right)\left(\frac{C_{i+1}^j-C_i^j}{\Delta y}\right)=\frac{1}{Sc}\left(\frac{C_{i+1}^j-2C_i^j+C_{i-1}^j}{(\Delta y)^2}\right)$$
$$-K_c C_i^j+(Sr)\left(\frac{C_{i+1}^j-2C_i^j+C_{i-1}^j}{(\Delta y)^2}\right) \tag{3.3}$$

Where the indices i and j refer to y and t correspondingly. The initials and boundary conditions(13) yield.

$$\left.\begin{array}{l} u_i^j=h(\frac{\partial u_i^j}{\partial y}),\ T_i^j=1,\ C_i^j=1\ \ for\ all\ i \\ u_M^j\to 0,\ T_M^j\to 0,\ C_M^j\to 0 \end{array}\right\} \tag{3.4}$$

Thus the values of u, θ and ϕ at grid point t = 0 are known; hence the temperature field has been solved at time $t_{i+1}=t_i+\Delta t$ using the known values of the previous time $t=t_i$ for all $i=1,\ 2,\ ....,\ \ N-1$. Then the velocity field is evaluated using the already known values of temperature and concentration fields obtained at $t_{i+1}=t_i+\Delta t$. These processes are repeated till the required solution of u, θ and ϕ is gained at convergence criteria:

$$abs\left|(u,\ \theta,\ \phi)_{exact}-(u,\ \theta,\ \phi)_{numerical}\right|<10^{-3} \tag{3.5}$$

(3.5)

The non-dimensional form of the Skin-friction at the plate is given by

$$C_f==\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{3.6}$$

The rate of heat transfer coefficient, which in the non-dimensional form in terms of the Nusselt number is given by

$$Nu=-x'\frac{\left(\frac{\partial T'}{\partial y'}\right)_{y'=0}}{T'_w-T'_\infty}\Rightarrow Nu\,\mathrm{Re}_x^{-1}=-\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{3.7}$$

The non-dimensional form rate of mass transfer coefficient in terms of the Sherwood number, is given by

$$Sh=-x'\frac{\left(\frac{\partial C'}{\partial y'}\right)_{y'=0}}{C'_w-C'_\infty}\Rightarrow Sh\,\mathrm{Re}_x^{-1}=-\left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{3.8}$$

Where $\mathrm{Re}_x=\dfrac{U_o x'}{\nu}$.

4 RESULTS AND DISCUSSION:

To measure the physical depth of the problem, the impact of various parameters significant on Velocity, Temperature as well as Concentration were illustrated in the below.

The significance of *M* (M=1,2,3,4)on the velocity is illustrated in above **figure1**. From this figure it is noticed that dissimilar values of *M* leads to decrease in velocity. In view of the fact that, the applied magnetic field acts as Lorentz's force which drags the velocity

Influence of aligned magnetic field parameter ξ is shown in the **figure2**. From the figure the results indicates that velocity declined with the incremental values of ξ.

The impact of inclination of the plate on the velocity is shown in the **figure3**. From the figure it was noticed that diverse incremental values of $\phi(\phi = 0, \frac{\pi}{6}, \frac{\pi}{4}, \frac{\pi}{3})$ leads to decrease in velocity. Causes the fluid has higher velocity when the plate is vertical i.e. ϕ than when inclined because of the fact that the buoyancy effect reductions as a consequence of gravity components *g* Cos ϕ, as the plate is inclined.

Figure4. Depicts the fluid velocity by means of the discrepancies in rarefaction parameter *h(1,3,7)*. From the figure it was ascertained that the velocity is accelerated with the ascending values of rarefaction parameter due to slips at the surface accelerates the fluid motion.

Figure5. Shows the impact of thermal Grashof number (*Gr*=0,5,10,15) on the velocity. 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 commensurate to an accelerated in the thermal Grashof number. It is noticed that strengthen in thermal Grashof number (*Gr*) with the increase velocity.

The impact of modified Grashof number (*Gm*=0,5,10,15) on the velocity is illustrated in **figure6**. *Gm* is defines as the ratio of species buoyancy force to the viscous hydrodynamic force. The results indicate that for dissimilar incremental values of *Gm* leads to rise in velocity.

For dissimilar value of porous medium parameter *(K)* on the velocity of the fluid is plotted in **figure7**. From this figure it was found that the disparate accumulative values of porous parameter *K* lead to rise in velocity. Causes beingness of the porous medium in the flow furnishes confrontation to flow. Consequently, the result resistive force tends to sluggish the motion of the fluid along the surface of the plate.

Figures 8&14. Describes that for assorted progressive values of heat source parameter (*H=1,2,3,4*) leads to weakened in velocity as well as temperature. Owing to electrical energy is transformed resistively into heat. Physically interruption, the existence of heat absorption effects has the propensity to reduce the temperature.

Significance of thermal radiation (*R=1,2,3,4*) on the velocity as well as temperature was illustrated in **Figure** 9 & 13. It was found that dissimilar incremental thermal radiation estimators lead to lessened in velocity as well as temperature.

For various values of the Prandtl number *Pr(0.7,1.0,3.0,5.0)* are shown in the velocity is located in **Figure 12.** From this figure it was observed that for dissimilar values of *Pr* raise then it results, the fluid velocity reduced.

Figures 10 & 16. It shows the behavior of velocity as well as concentration profiles. From the figure the outcomes indicates that for diverse values of chemical reaction parameter (K_c*=1,2,3,4)* leads to decreases in the velocity It is perceived that an escalate in K_c leads to a reduction in the values of velocity. Causes the chemical reaction improves momentum transfer moreover consequently accelerates the flow.

The influence of Schmidt number *Sc* on velocity as well as concentration was shown in **Figures 11 & 15**. From this figure the results indicates that different increment values of *Sc(0.16,0.22,0.68,0.78)* leads to summarized in the velocity as well as at the different increment values of *Sc(0.16,0.22,0.60,1.0) then increases* concentration. This causes the influence of concentration buoyancy to diminished, yielding a decline in the velocity. The depletion in the concentration is accompanied by instantaneous depletion in the concentration boundary layers.

The influence of Rivlin-Ericksen fluid on velocity was shown in **Figure 17.** From this figure when increased Rivlin- Ericksen fluid increased velocity declines.

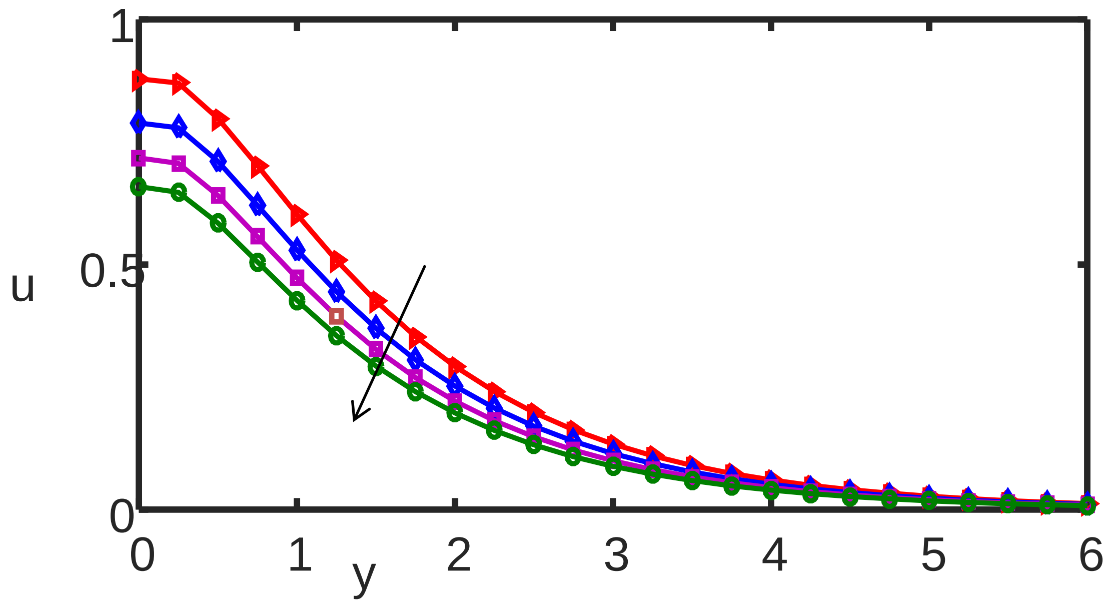


Figure 1: Effect of magnetic field parameter M on Velocity

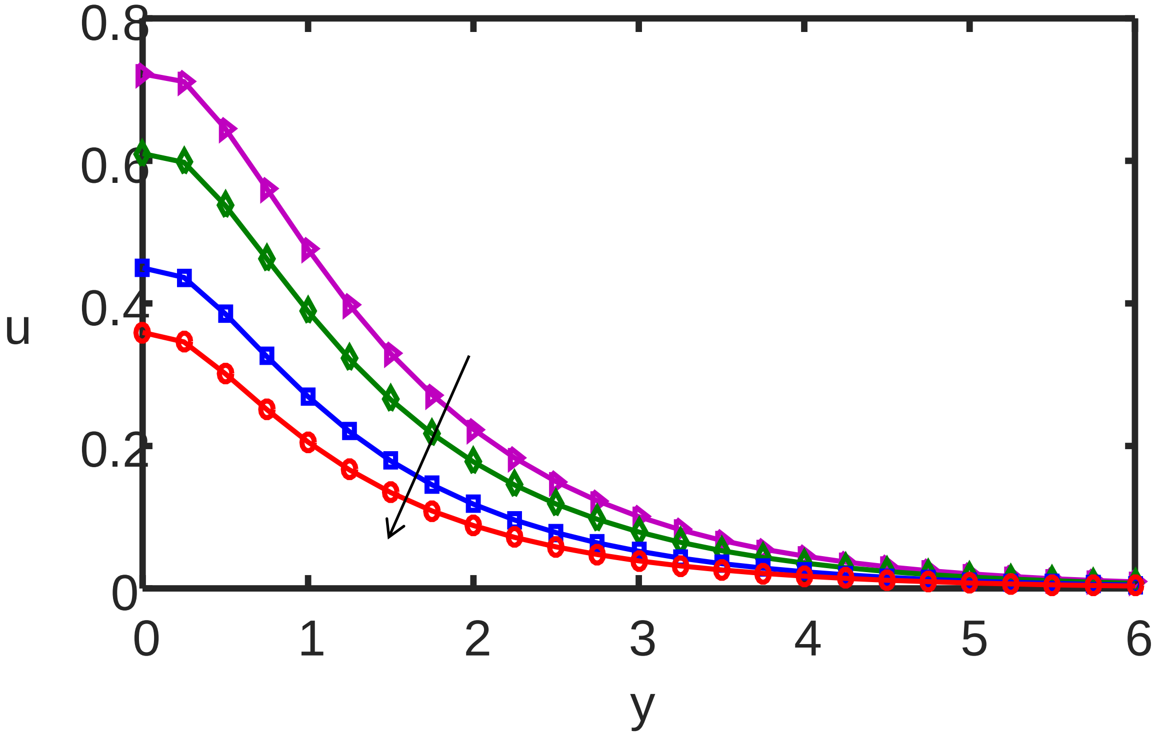


Figure 2: Effect of Aligned magnetic parameter ξ on Velocity

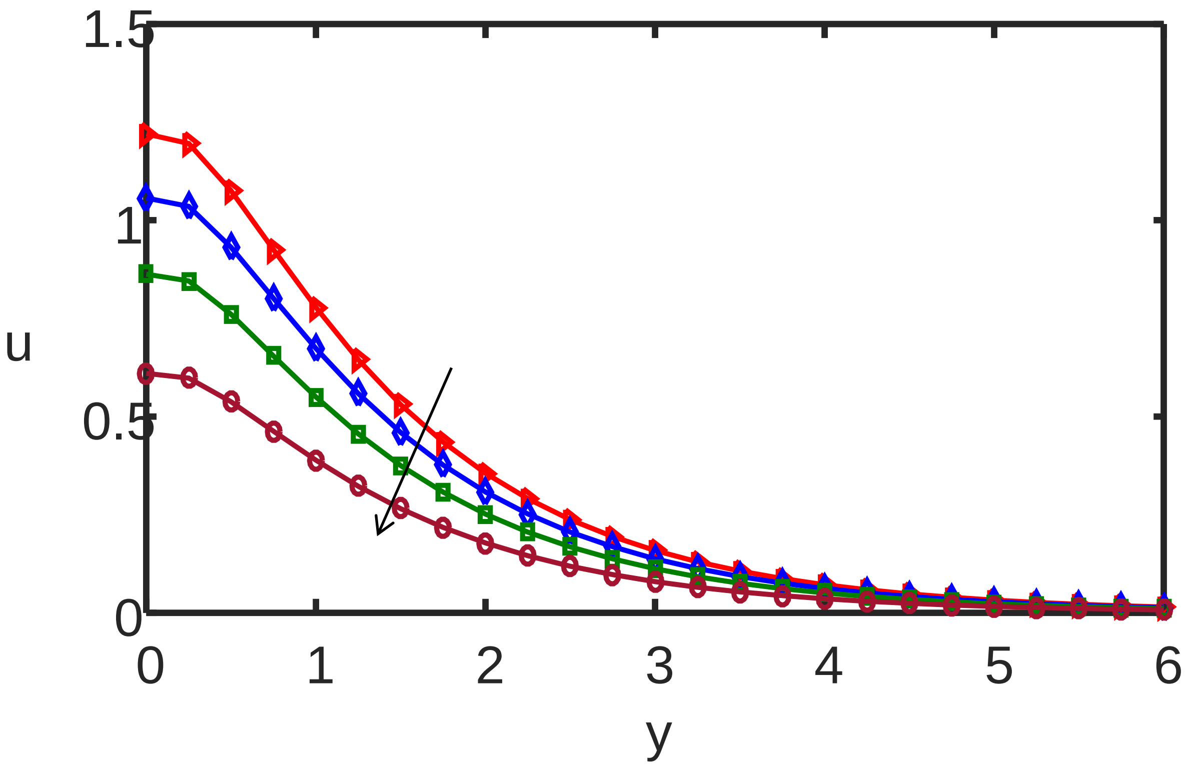


Figure 3: Effect of inclined angle ϕ on Velocity

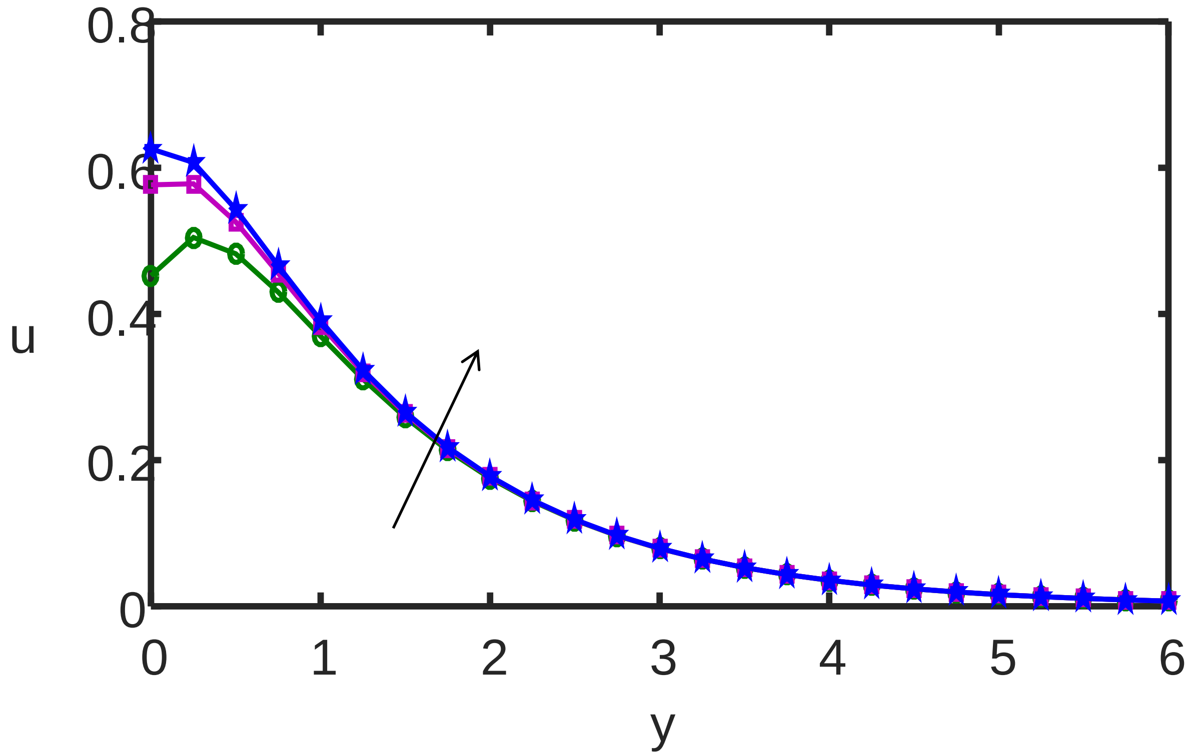


Figure 4: Effect of slip parameter *h* on Velocity profiles

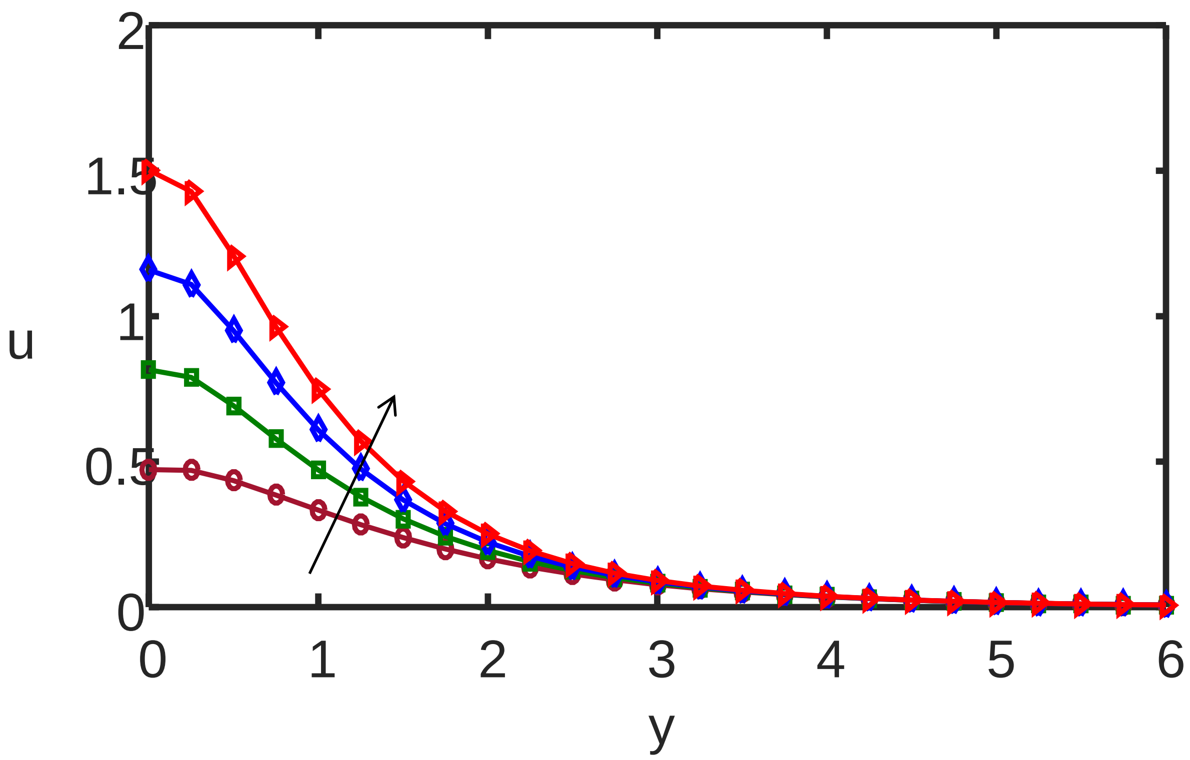


Figure 5: Effect of Grashof number Gr on Velocity

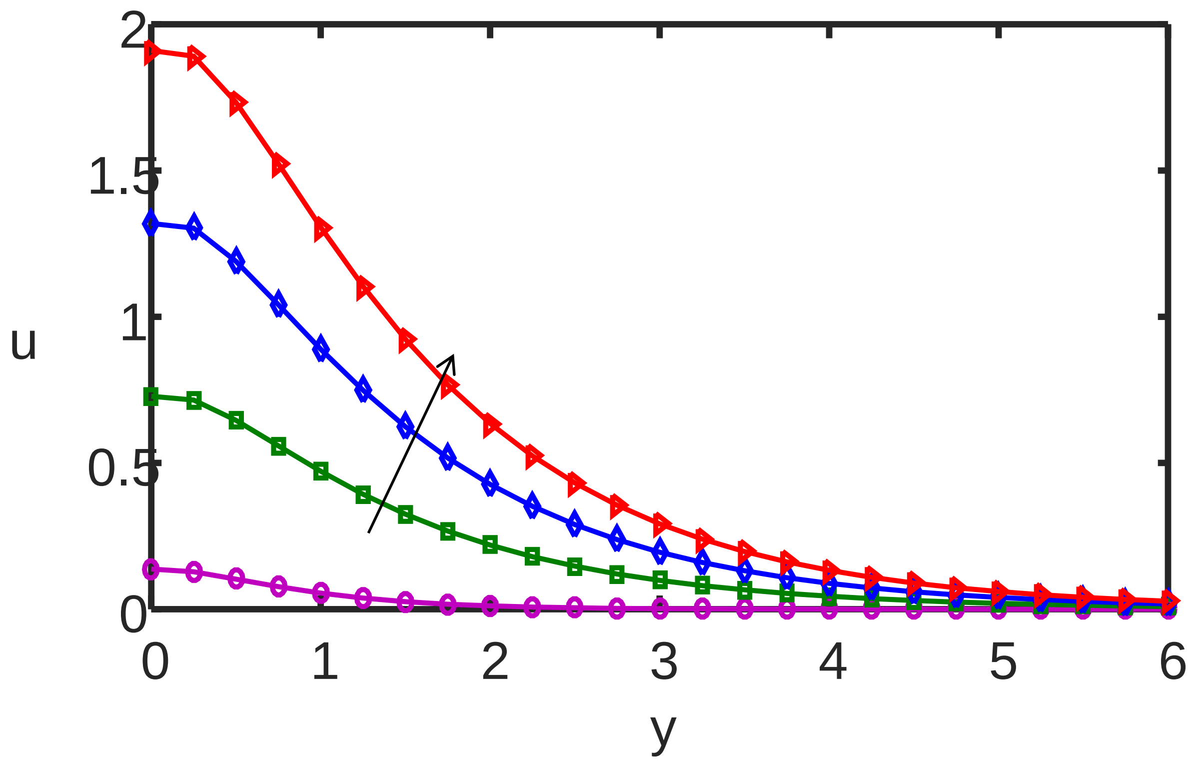


Figure 6: Effect of modified Grashof number *Gm* on Velocity

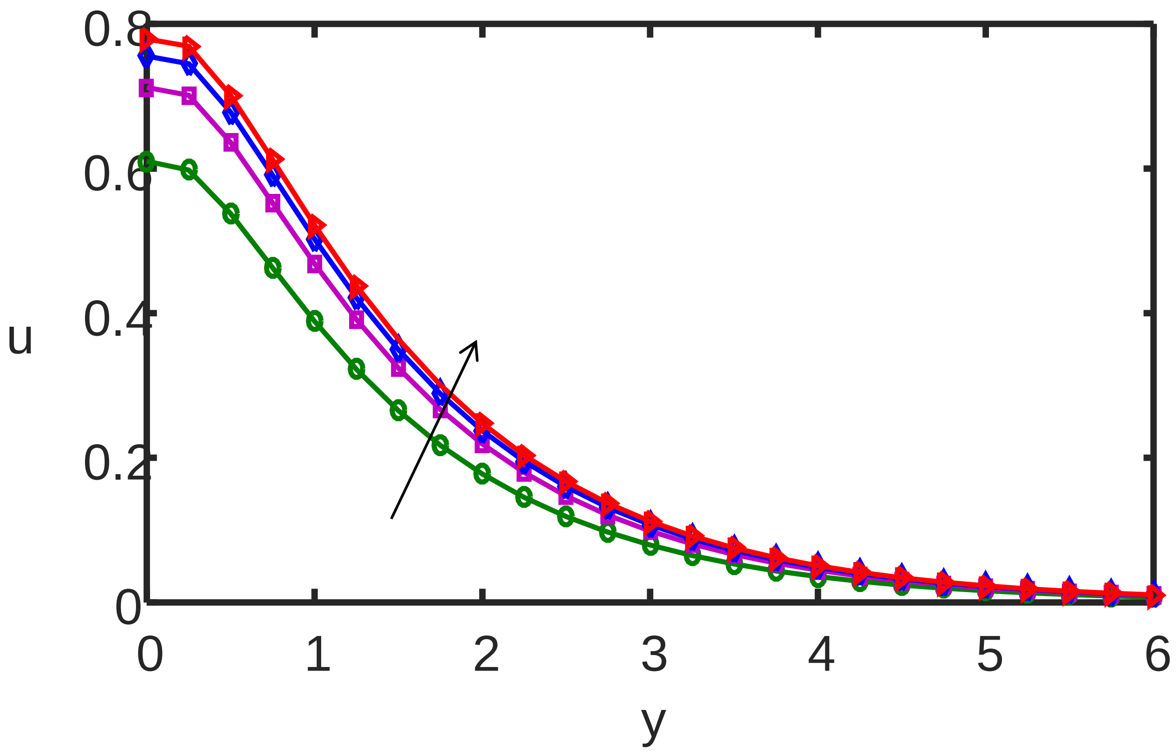


Figure 7: Effect of permeability parameter *K* on Velocity

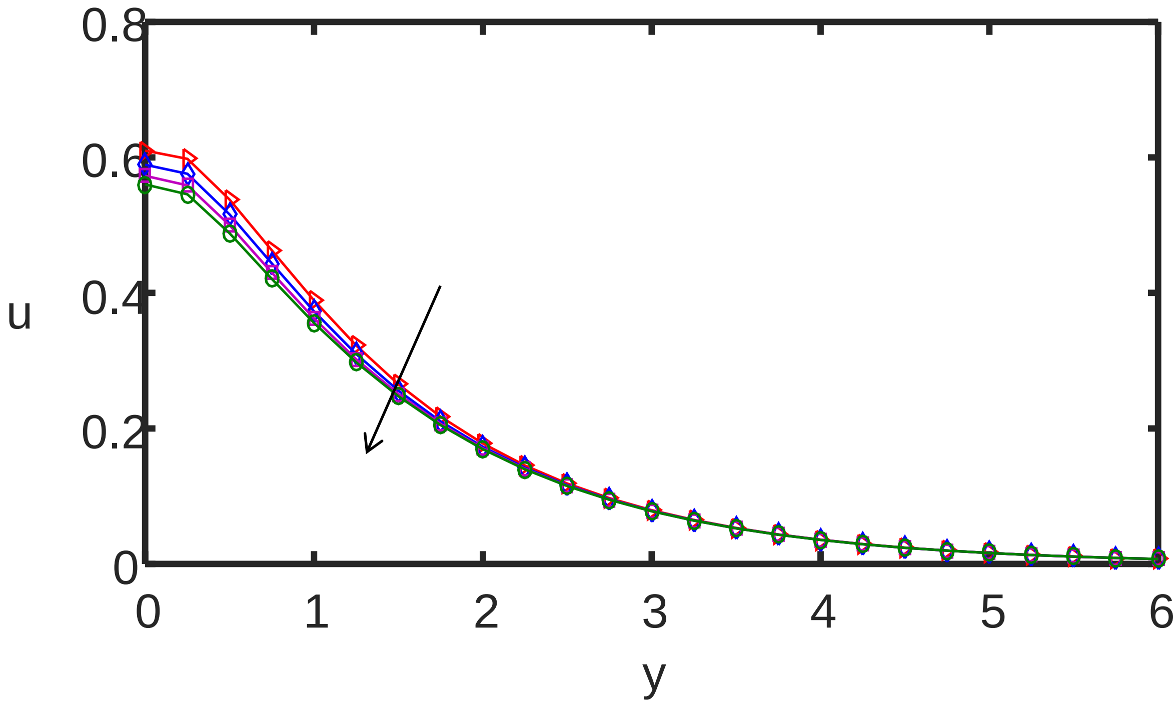


Figure 8: Effect of heat source parameter *H* on Velocity

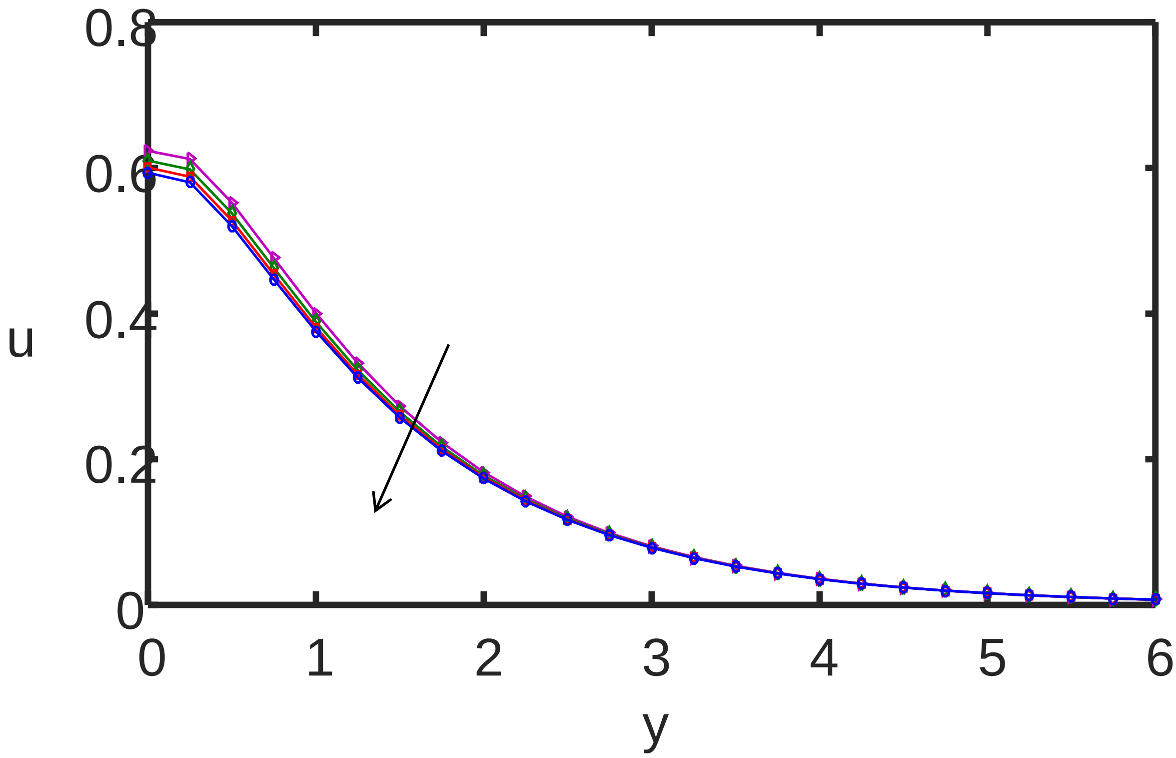


Figure 9: Effect of radiation parameter R on Velocity

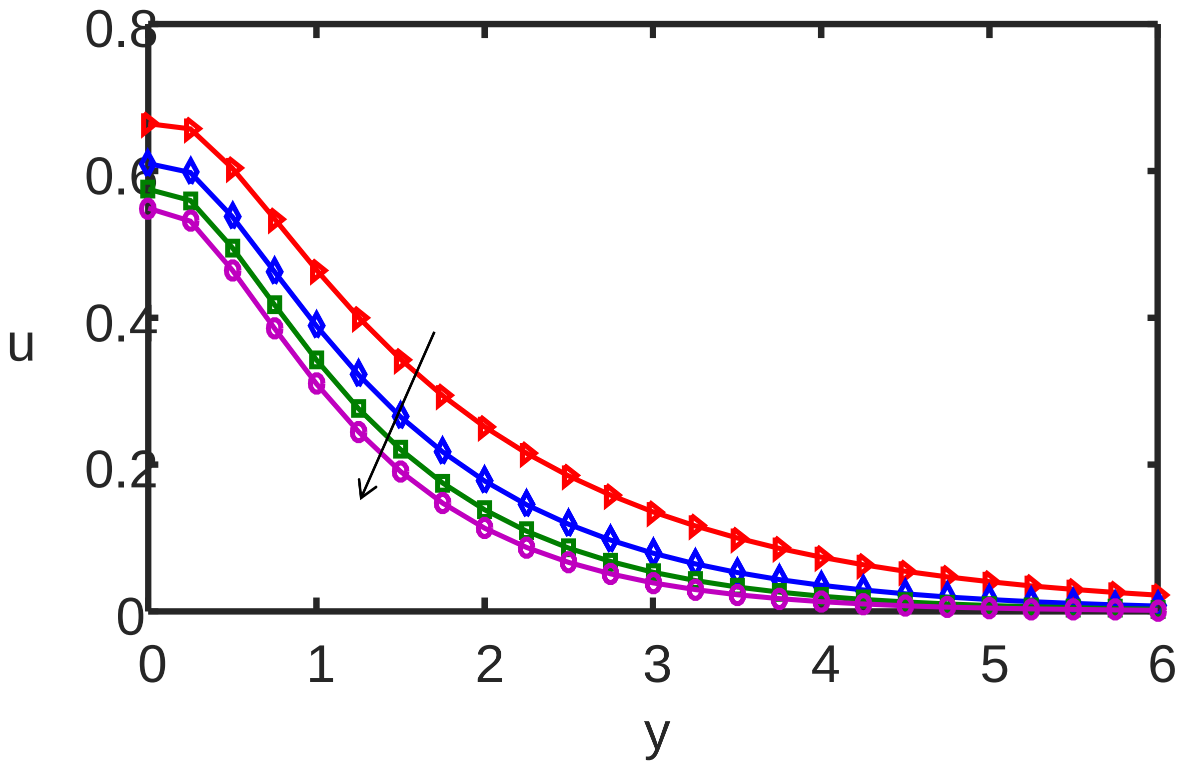


Figure 10: Effect of Chemical reaction parameter K_c on Velocity

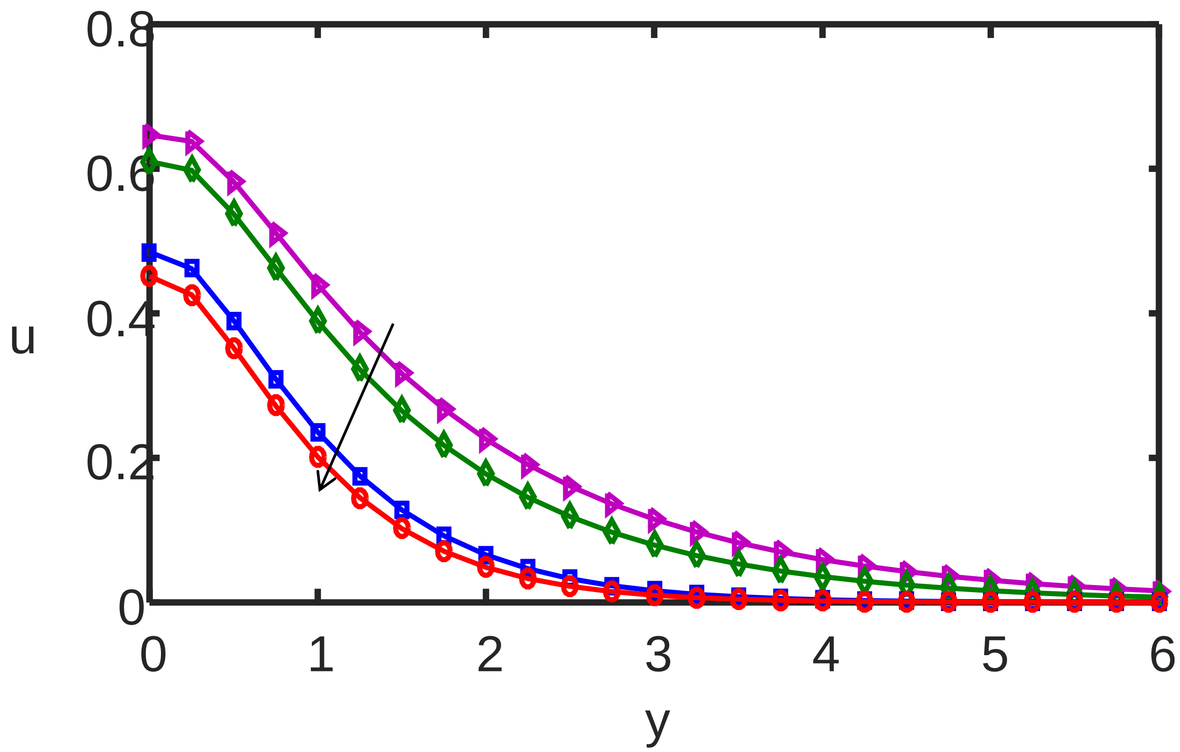


Figure 11: Effect of Schmidt number *Sc* on Velocity

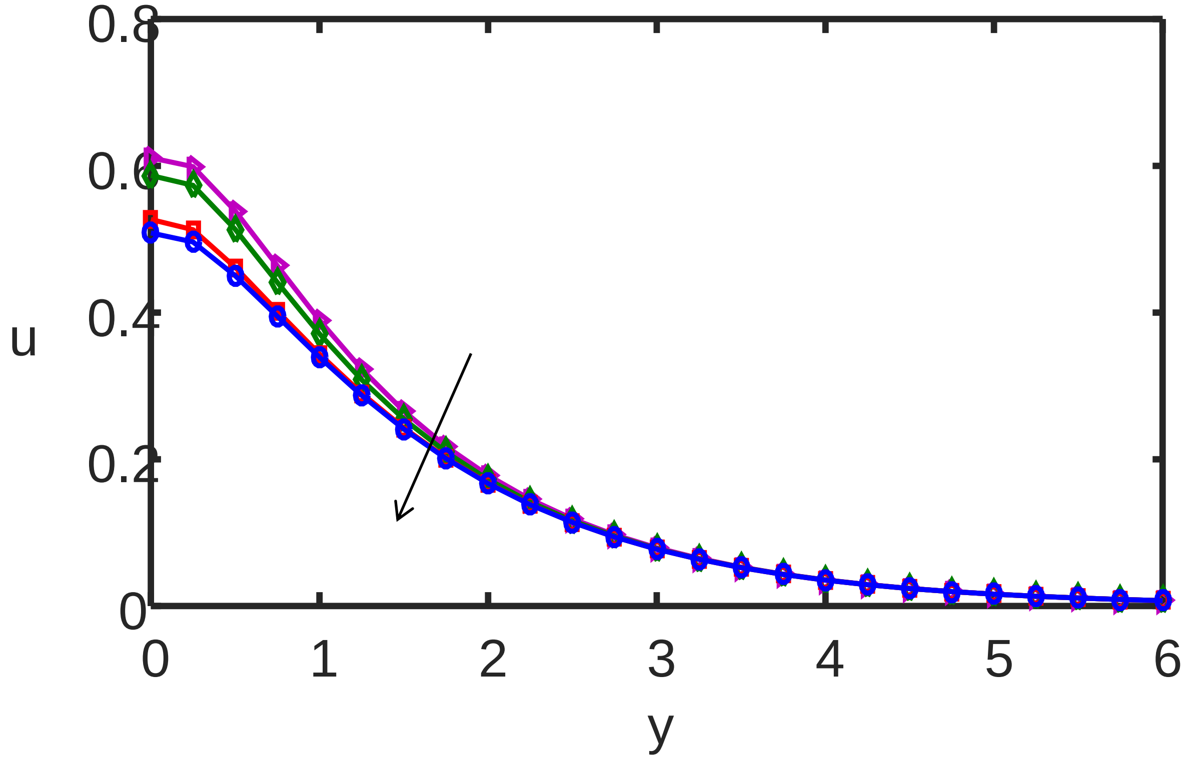


Figure 12: Effect of Prandtl number *Pr* on Velocity

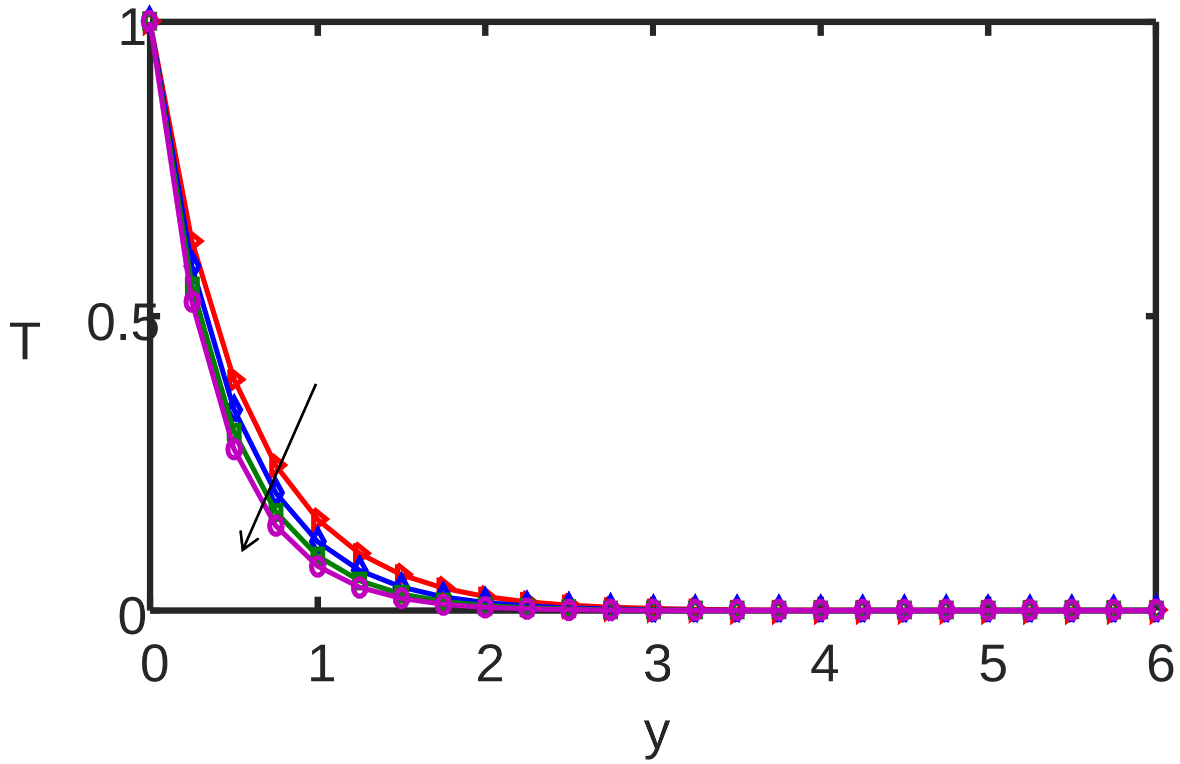


Figure 13: Effect of radiation parameter *R* on Temperature

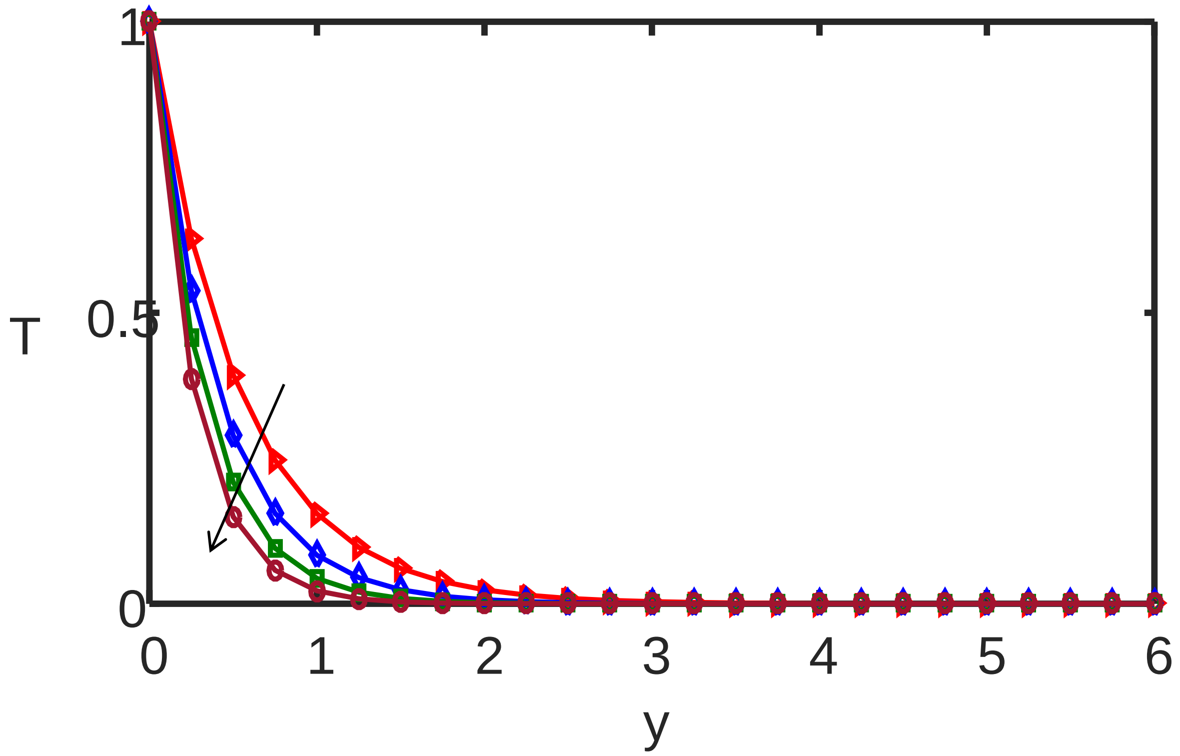


Figure 14: Effect of heat source parameter *H* on Temperature

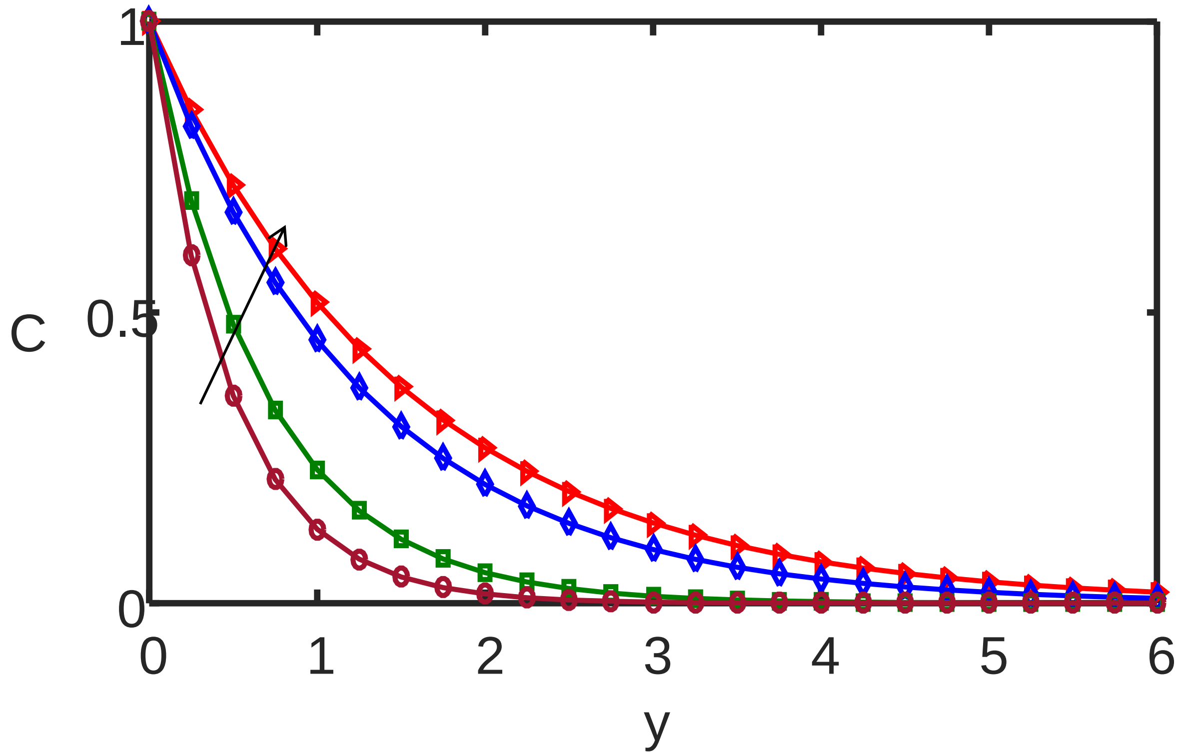


Figure 15: Effect of Schmidt number *Sc* on Concentration

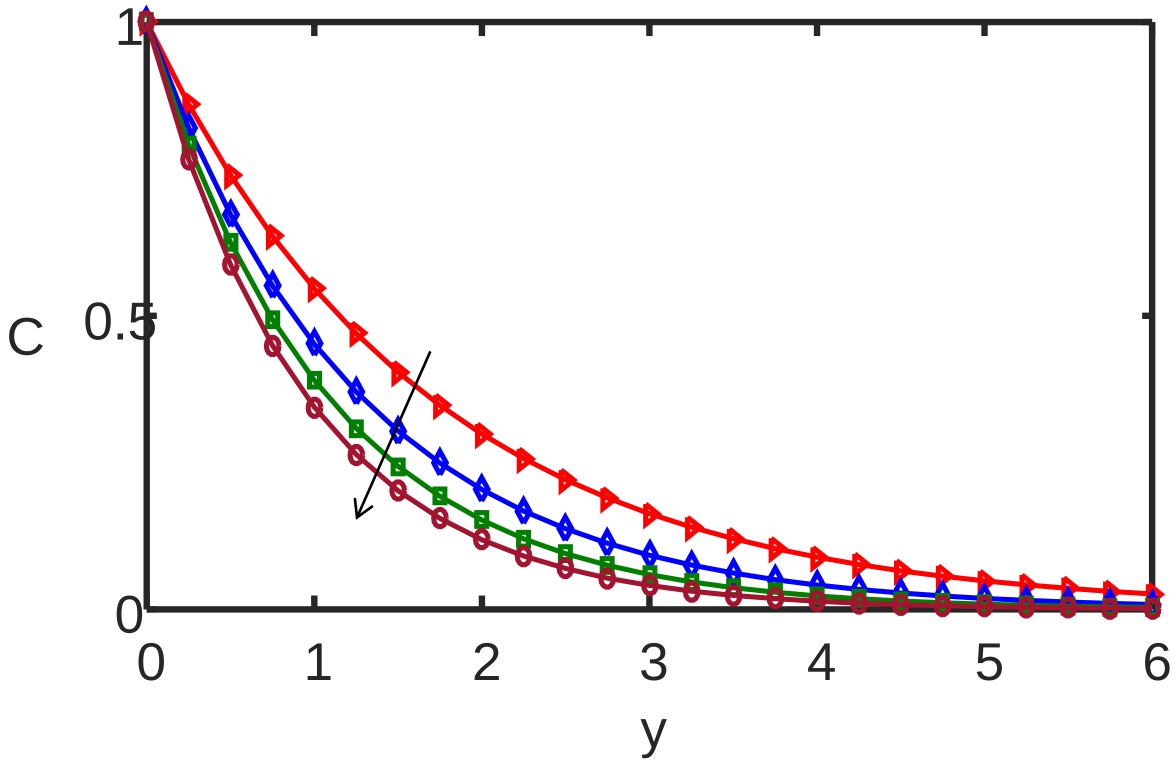


Figure 16: Effect of permeability parameter K on Concentration

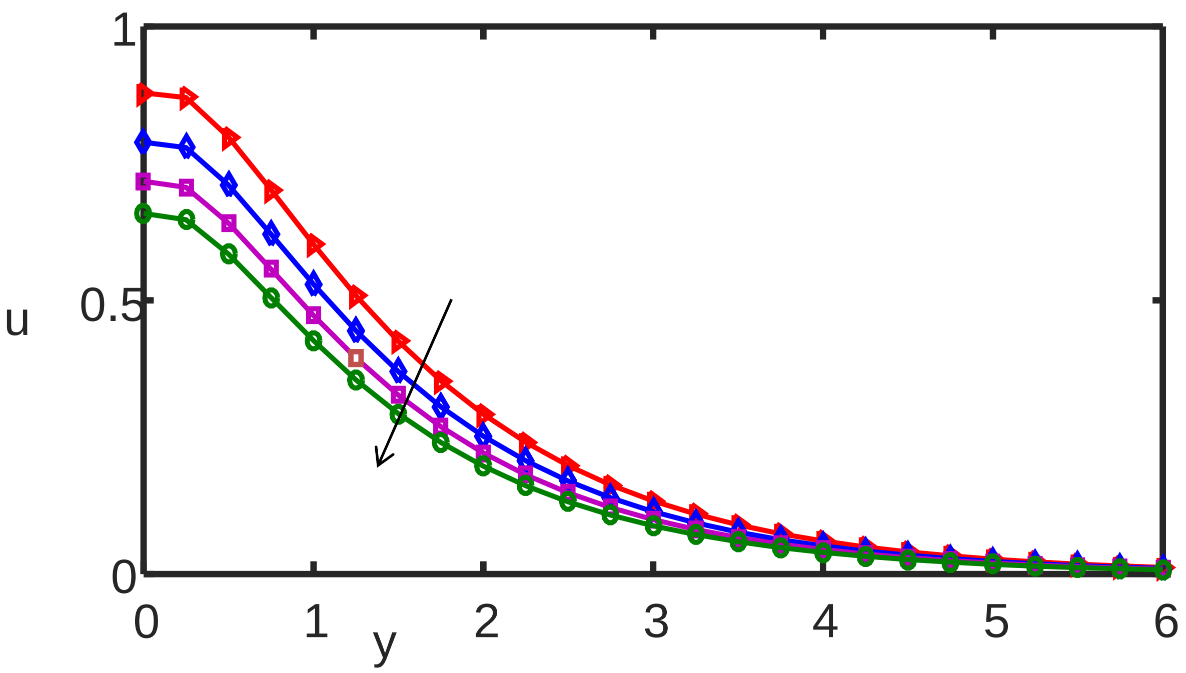


Figure 17: Effect of Rivlin-Ericksen fluid λ on Velocity

5. Conclusions:

We have examined the of combined effects of thermal diffusion and first-order chemical reaction on an aligned magnetic field in two-dimensional MHD flow, heat and mass transfer of a viscous incompressible fluid past a permeable inclined plate embedded in a porous medium in the presence of Rivlin-Ericksen fluid flow using finite difference technique, we can conclude the following:

- Velocity declined by means of increases of magnetic field (M).
- Velocity depreciated with the accumulative values of acute angle α.
- Velocity decreased by means of increasing values of aligned magnetic angle ϕ.
- The increment values of Gr lead to strengthen in Velocity.
- Velocity increased with the increment values of Gm.
- With the increment values of thermal radiation R leads to deletions in velocity.
- Velocity desiccated by means of progressive values of Sc.
- By means of increasing values of Pr leads to decline in velocity.
- Velocity declined by means of increases of Rivlin-Ericksen fluid.

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V.Nagaraju: Department of Mathematics, Assistant Professor, Mallareddy Institute of Technology, Maisammaguda (V), Kompally (M), Medchal, Malkajgiri (Dist)-500100, TS, India.

Email: *vellanki.nagsra@gmail.com*

Omeshwar Reddy V: [1]Department of Mathematics, TKR College of Engineering and Technology, Meerpet, Hyderabad, 500097, Telangana State, India.

Email address:*omesh.reddy1110@gmail.com*

V Sri HariBabu: *Department of Mathematics, Usha Rama College of Engineering& Technology,Telaprolu-521109, A.P, India.*

Email: srihari.veeravalli@gmail.com