

Magnetohydrodynamic Unsteady Natural-Convection Flow of a Newtonian Fluid in the Presence of Consistent Chemical Reaction

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Abstract The effects of variable thermo physical parameters on the natural convective heat and mass transfer of a viscous incompressible, gray absorbing-emitting fluid flowing past an impulsively started moving vertical plate under the action of transversely applied magnetic field in the presence of chemical reaction was considered. The governing boundary-layer equations are formulated with appropriate boundary conditions. The Roseland diffusion approximation is used to analyze the radiative heat flux and it is appropriate for non-Scattering media. The governing boundary layer equations were simplified and non-dimensionalized. The dimensionless equations were discretized and then solved using the Crank-Nicolson's method. The effects of variable thermo physical parameters which are: Magnetic field, dissipation function, Prandtl number, radiation-conduction parameter, thermal Grashof number, species Grashof number, Schmidt number, Reynolds number, chemical reaction parameter and Darcy number are considered on the dimensionless velocity, temperature and concentration profile. It was discovered that Velocity profile decreases with increase in Magnetic field, conduction radiation parameter, Schmidt number, prandtl number, Eckert number and chemical reaction parameter while it decreases with increase in Grashof number. Temperature profile increases with increase in Magnetic field, Schmidt number, Eckert number and chemical reaction parameter while it decreases with increase in conduction radiation parameter, prandtl number, Eckert number, Grashof number and Darcy number. Concentration profile increases with increase in Magnetic field and Conduction Radiation parameter while it decreases with increase in Schmidt number, Grashof number and chemical reaction parameter.

Keywords Natural convection, MHD, Thermal conduction, Viscous dissipation, Chemical reaction

1. Introduction

The study of heat and mass transfer with a chemical reaction is very important to engineers and scientists because of its great importance in many branches of science and engineering.

An unsteady two-dimensional laminar natural convection flow of a viscous, incompressible, electrically conducting, natural-convective heat and mass transfer considering the effects of variable thermo physical parameters in the presence of chemical reaction is considered.

Series of temperature process in the industrial design and combustion and fire science involve thermal radiation heat transfer in combination with conduction convection and mass transfer. For example, radiative convective heat transfer flows arise in industrial furnace systems, astrophysical flows, forest fire dynamics, fire spread in

buildings and so on. Considerable research has therefore appeared studying radiative convective flows in a variety of geometrical configurations with numerical and mathematical models, [1] reported on the effects of thermal radiation in the convection boundary layer-regime of an enclosure. [2] used a radiative flux diffusion approximation to model the interaction of convective and radiative heat transfer in two dimensional complex enclosures. [3] studied numerically the combined influence of radiative flux, gravity field and heat absorption on convection heat transfer in a two-phase flow.

Considerable research work has been published on an impulsively started vertical plate with different boundary conditions. [4] presented analytic solution on the viscous flow past an impulsively started semi-infinite horizontal plate. [5] first presented an exact solution to the Navier-Stokes equation of the flow of a viscous incompressible fluid past an impulsively started infinite horizontal plate moving in its own plane. It is often called Rayleigh's problem in the literature. [6] solved the problem of [4] by finite difference method of a mixed explicit-implicit type which is convergent and stable. [7] obtained the exact solution of the Stokes problem for the case

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of an infinite vertical plate. For the first time, [8] studied the natural convection on flow past an impulsively started vertical plate with variable surface heat flux.

Distribution of temperature in the fabric layers were known to be greatly affected by moisture content and thermal radiation flux. Generally, for low velocity hydromechanics of porous media, a Darcian model is used which relates the bulk matrix impedance in the regime to the pressure drop. This approach is generally accurate for situations where Reynolds number is less than approximately 10. Beyond this value, inertial effects become significant and must be incorporated in mathematical models. [9] studied the influence of solar radiation on free convection in an isotropic, homogeneous porous medium using a computational method. [10] employed a regular two-parameter perturbation analysis in studying radiative flux effects on free convection in a non-Darcian porous medium. They studied four different flow regimes i.e that adjacent to the isothermal surface, flow with a uniform heat flux, plane plume flow and also the flow generated from a horizontal line energy source on a vertical adiabatic surface. Radiation was found to significantly affect all flow cases. [11] used the implicit difference scheme and the Cogley-Vincenti-Giles non-gray model to simulate the radiation-convection gas flow in a non-Darcy porous medium with viscous heating effects.

In all the investigations mentioned above, effects of variable thermo physical parameters in the presence of chemical reaction on an impulsively-started transient radiation-convection heat and mass transfer has not been given great attention. Effects of viscous dissipation are important in geophysical flow and also in certain industrial operations and are usually characterized by the Eckert number. A number of authors have considered viscous heating effects on Newtonian flows. [12] reported on the influence of viscous heating dissipation effects in natural convective flows, showing that the heat transfer rates are reduced by an increase in the dissipation parameter.

Also, effects of magnetic field on viscous incompressible fluid of electrically conducting is of importance in many applications such as extrusion of plastics in the manufacture of Rayon and Nylon, purification of crude oil, textile industries and so on. [13] analyzed the problem of free convection effects on Stokes problem for a vertical plate under the action of transversely applied magnetic field. [14] obtained an exact solution for unsteady MHD free convection flow on an impulsively started vertical plate with constant heat flux. Other studies discussing the effects of radiation on convection flows in porous media have been communicated by [15] who considered transient flow.

The transformed problem is shown to be dictated by the following thermo physical parameters: dimensionless time, thermal Grashof number, species Grashof number, Darcy number, Reynolds number, Magnetic field, Eckert number, Prandtl number, chemical reaction parameter Darcy and Schmidt number. The influence of these parameters on the

velocity profile, temperature function and concentration profiles are discussed graphically.

2. Formulation of Mathematical Problem

An unsteady two-dimensional laminar natural convection flow of a viscous, incompressible, electrically conducting, radiating fluid past an impulsively started semi-infinite vertical plate in the presence of chemical reaction is considered.

We assume that the fluid is grey, absorbing-emitting but non-scattering. The y^* -axis is taken perpendicular to the plate at the leading edge while the x -axis is chosen along the plate in the vertical upward direction.

The origin of x^* -axis is taken to be at the leading edge of the plate. The gravitational acceleration g is acting downward. At time $t^*=0$, it is assumed that the plate and the fluid are at the same ambient temperature T_∞^* and the species concentration C_∞^* . When $t^* > 0$, the temperature of the plate and the species concentration is maintained to be T_w^* (greater than T_∞^*) and C_w^* (greater than C_∞^*) respectively.

Effect of viscous dissipation is considered in the binary mixture and assumed to be very small compared with other chemical species, which are present. A uniformly transverse magnetic field is applied in the direction of flow. It is further assumed that the interaction of the induced magnetic with the flow is considered to be negligible compared to the interaction of the applied magnetic field with the flow. The fluid properties are assumed to be constant except for the body forces terms in the momentum equation which are approximated by Boussinesq relations.

Thermal radiation is assumed to be present in the form of a unidirectional flux in the y^* direction i.e q_r (transverse to the vertical surface).

The Roseland diffusion flux is used and defined following [16] as follows:

$$q_r = \frac{-4\sigma\partial T^{*4}}{3k^1\partial y^*}$$

Where σ is the Stefan-Boltzmann constant and k^1 is the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluid.

Under the Boussinesq approximation, the flow model is governed by these set of equations:

$$\begin{aligned} \frac{\partial u^*}{\partial x^*} + \frac{\partial v^*}{\partial y^*} &= 0 \\ \frac{\partial u^*}{\partial t^*} + u \frac{\partial u^*}{\partial x^*} + v \frac{\partial u^*}{\partial y^*} &= v \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T_\infty^*) + g\beta_*(C^* - C_\infty^*) - \frac{\sigma}{\rho} B_o^2 u^* - \frac{v}{k} u^* \\ \rho c_p \left[\frac{\partial T^*}{\partial t^*} + u \frac{\partial T^*}{\partial x^*} + v \frac{\partial T^*}{\partial y^*} \right] &= k \frac{\partial^2 T^*}{\partial y^{*2}} + \mu \left(\frac{\partial u}{\partial y} \right)^2 - \frac{\partial q_r}{\partial y^*} \end{aligned}$$

$$\frac{\partial C^*}{\partial t^*} + u \frac{\partial C^*}{\partial x^*} + v \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - k_c (C^* - C_\infty^*)$$

With the following boundary conditions

$$\begin{aligned} t^* \leq 0, u^* = 0, v^* = 0, T^* = T_\infty^*, c^* = c_\infty^*, \text{ for all } y \\ t^* > 0, u^* = u_0^*, v^* = 0, T_w^* = T_\infty^*, c_w^* = c_\infty^*, \text{ at } y^* = 0 \\ u^* = 0, T^* = T_\infty^*, c^* = c_\infty^*, \text{ at } x^* = 0 \\ u^* \rightarrow 0, T^* \rightarrow T_\infty^*, c^* \rightarrow c_\infty^* \text{ as } y^* \rightarrow \infty \end{aligned}$$

Where x^* and y^* are coordinates, u^* and v^* are velocity components in the x^* and y^* directions, t^* is the dimensionless time, σ is the Stefan-Boltzmann constant, k_c is the rate of chemical reaction, g is the gravitational acceleration, k^1 is the mean absorption coefficient of thermal expansion, β and β_* represent the thermal and mass transfer coefficient of expansion, μ is the coefficient of dynamic viscosity of the grey fluid, T^* is the temperature of the fluid in the boundary layer, C^* is the species concentration, k is the permeability (hydraulic conductivity of the porous medium with dimensions), D is the species diffusivity, w denotes condition at the wall, (vertical surface) and ∞ denotes condition in the free stream (outside the boundary layer).

Following Raptis and Perdikis [22], we express the quartic temperature function in a linear function of temperature if the temperature differences within the flow are sufficiently small. The Taylor series for T^{*4} , discarding higher order terms can be shown as:

$$T^{*4} \approx 4T_\infty^{*3}T^* - 3T_\infty^{*4}$$

Substituting the above equation into the energy equation, we arrive at this equation:

$$\begin{aligned} \rho c_p \left[\frac{\partial T^*}{\partial t^*} + u \frac{\partial T^*}{\partial x^*} + v \frac{\partial T^*}{\partial y^*} \right] \\ = k \frac{\partial^2 T^*}{\partial y^{*2}} + \mu \left(\frac{\partial u}{\partial y} \right)^2 + \frac{16\sigma T_\infty^{*3}}{3k^1} \frac{\partial^2 T^*}{\partial y^{*2}} \end{aligned}$$

The four equations with their boundary conditions constitutes a two-point boundary value problem which is fairly challenging to solve. We therefore non-dimensionalise the model to facilitate a numerical solution by the Crank Nicolson's method. On introducing the following non dimensional quantities:

$$X = \frac{x^*}{l}, Y = \frac{y^*}{l}, U = \frac{u^*}{u_0}, V = \frac{v^*}{u_0},$$

$$\frac{U_{i,j}^{k+1} - U_{i-1,j}^{k+1} + U_{i,j}^k - U_{i-1,j}^k + U_{i,j}^{k+1} - U_{i-1,j-1}^{k+1} + U_{i,j-1}^k - U_{i-1,j-1}^k}{4\Delta x} + \frac{V_{i,j}^{k+1} - V_{i,j-1}^{k+1} + V_{i,j}^k - V_{i,j-1}^k}{2\Delta y} = 0$$

$$\begin{aligned} \frac{U_{i,j}^{k+1} - U_{i,j}^k}{\Delta t} + U_{i,j}^k \frac{(U_{i,j}^{k+1} - U_{i-1,j}^{k+1} + U_{i,j}^k - U_{i-1,j}^k)}{2\Delta x} + V_{i,j}^k \frac{(U_{i,j}^{k+1} - U_{i,j-1}^{k+1} + U_{i,j+1}^k - U_{i,j-1}^k)}{4\Delta y} \\ = \frac{1}{PrRe} \frac{U_{i,j-1}^{k+1} - 2U_{i,j}^{k+1} + U_{i,j+1}^{k+1} + U_{i,j-1}^k - U_{i,j}^k + U_{i,j+1}^k}{2(\Delta y)^2} + Gr \frac{T_{i,j}^{k+1} + T_{i,j}^k}{2} + Gm \frac{C_{i,j}^{k+1} + C_{i,j}^k}{2} - M \frac{U_{i,j}^{k+1} + U_{i,j}^k}{2} \\ - \frac{1}{DaRe} \frac{U_{i,j}^{k+1} + U_{i,j}^k}{2} \end{aligned}$$

$$T = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, t = \frac{u_0 t^*}{l}$$

Where

$Re = \frac{u_0 l}{\nu}$ is the Reynolds number, $Gr = \frac{g\beta(T_w^* - T_\infty^*)l}{u_0^2}$ is the Grashof number, $Gm = \frac{g\beta_*(C_w^* - C_\infty^*)l}{u_0^2}$ is the modified Grashof number, $M = \frac{\sigma B_0^2 l}{\rho u_0}$ is the magnetic field, $Da = \frac{k}{l^2}$ is the Darcy number, $Re = \frac{\nu}{\alpha}$ is the Prandtl number, $Ec = \frac{u_0 \nu}{c_p(T_w^* - T_\infty^*)l}$ is the Eckert number, $Sc = \frac{\nu}{D}$ is the Schmidt number and $\gamma = \frac{k_c l}{u_0}$ is the chemical reaction parameter.

Substituting the above non-dimensional quantities and parameters into the equations yield the following dimensionless equations:

$$\begin{aligned} \frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} &= 0 \\ \frac{\partial U}{\partial t} + U \frac{\partial U}{\partial X} + V \frac{\partial U}{\partial Y} &= \frac{1}{Re} \frac{\partial^2 U}{\partial Y^2} + GrT + GmC - MU - \frac{U}{ReDa} \\ \frac{\partial T}{\partial t} + U \frac{\partial T}{\partial X} + V \frac{\partial T}{\partial Y} &= \frac{1}{PrRe} \left(1 + \frac{4}{3N} \right) \frac{\partial^2 T}{\partial Y^2} + Ec \left(\frac{\partial U}{\partial Y} \right)^2 \\ \frac{\partial C}{\partial t} + U \frac{\partial C}{\partial X} + V \frac{\partial C}{\partial Y} &= \frac{1}{ScRe} \frac{\partial^2 C}{\partial Y^2} - \gamma C \end{aligned}$$

We define the dimensionless initial and boundary condition in the form:

$$\begin{aligned} T \leq 0, \quad U = V = 0, T = C = 0 \text{ for all } Y \\ T > 0, \quad U = 1, V = 0, T = C = 1, \text{ at } Y = 0 \\ U = T = C = 0, \text{ at } X = 0 \\ U \rightarrow 0, T \rightarrow 0, C \rightarrow 0 \text{ as } Y \rightarrow \infty \end{aligned}$$

3. Numerical Solution and Discussion of Result

To be able to solve the set of unsteady non-linear partial differential equations together with the boundary conditions, we employ an implicit finite difference scheme by Crank-Nicolson which is known to converge faster due to its unconditional stability. The corresponding finite difference equations are given below:

$$\begin{aligned}
& \frac{T_{ij}^{k+1} - T_{ij}^k}{\Delta t} + U_{ij}^k \frac{(T_{ij}^{k+1} - T_{i-1,j}^{k+1} + T_{ij}^k - T_{i-1,j}^k)}{2\Delta x} + V_{ij}^k \frac{(T_{ij+1}^{k+1} - T_{ij-1}^{k+1} + T_{ij+1}^k - T_{ij-1}^k)}{4\Delta y} \\
& = \frac{1}{PrRe} \left(1 + \frac{4}{3N}\right) \frac{T_{ij-1}^{k+1} - 2T_{ij}^{k+1} + T_{ij+1}^{k+1} + T_{ij-1}^k - T_{ij}^k + T_{ij+1}^k}{2(\Delta y)^2} + Ec \left(\frac{\partial U}{\partial Y}\right)^2 \\
& \frac{C_{ij}^{k+1} - C_{ij}^k}{\Delta t} + U_{ij}^k \frac{(C_{ij}^{k+1} - C_{i-1,j}^{k+1} + C_{ij}^k - C_{i-1,j}^k)}{2\Delta x} + V_{ij}^k \frac{(C_{ij+1}^{k+1} - C_{ij-1}^{k+1} + C_{ij+1}^k - C_{ij-1}^k)}{4\Delta y} \\
& = \frac{1}{ScRe} \frac{C_{ij-1}^{k+1} - 2C_{ij}^{k+1} + C_{ij+1}^{k+1} + C_{ij-1}^k - C_{ij}^k + C_{ij+1}^k}{2(\Delta y)^2} - \gamma \frac{C_{ij}^{k+1} + C_{ij}^k}{2}
\end{aligned}$$

In the discretization of the equations, we define the co-ordinate of the mesh points of the solution by $x = i\Delta x, y = j\Delta y, t = k\Delta t$ where i, j, k are positive integers and the value of U at the mesh point is given as U_{ij}^k .

The region of integration is considered to be a rectangle with sides X (MAX)=1 and Y (MAX)=1 whereby regarding Y (MAX) as $Y=\infty$ which lie very well outside the momentum, thermal and concentration boundary layers. The subscript i, j, k relates to grid points along x, y, t directions respectively. We therefore divide X and Y into M and N grid spacing respectively. The mesh sizes are $\Delta x=0.05, \Delta y=0.05$ and $\Delta t=0.01$.

The coefficients U_{ij}^k and V_{ij}^k appearing in the difference equation are treated as constants in any one time step. The values of C, T, U and V are known at all grid point at $t=0$ from the initial conditions. The values of C, T, U and V at time level $(k+1)$ are calculated using the known values at previous time level k .

In view of this, the finite difference equation forms a tridiagonal system of equations at every internal nodal point on a particular i level which is solved with the aid of Matlab package using Thomas Algorithm as discussed in [17].

We therefore calculate the values of C and T at every nodal point for a particular i at $(k+1)th$ time level and the results were used in U at $(k+1)th$ time level. The values of V are also calculated at every nodal point explicitly using equation (79) on a particular i level at $(k+1)th$ time level. Following this step, we were able to determine the values of C, T, U , and V at all grid point at time level $(k+1)th$ in the region. The process is repeated several times for various i we reach the required time. The local truncation error is $O(\Delta t + (\Delta Y)^2 + \Delta X)$ and it tends to zero as $\Delta t, \Delta Y$ and ΔX tends to zero, which indicates that the system is compatible. The compatibility and stability of Crank Nicolson scheme which is unconditionally stable ensures the convergence of the system.

To be able to report on the analysis of the fluid flow, the numerical computations are carried out for various values Prandtl number (Pr), Darcy number (Da), Reynolds number (Re), Schmidt number (Sc), Magnetic field (M), conduction-radiation (n), Grashof number (Gr), modified Grashof number (Gm), Eckert number (Ec) and the chemical reaction parameter γ . We present the contribution of each

parameter by varying parameter and keeping the others fixed. The fixed values are:

$Pr=0.1, Sc=0.5, N=3.0, M=10, Ec=0.001, Gr=10, Gm=10, Da=0.1, Re=1, \gamma=1, t=1.0$

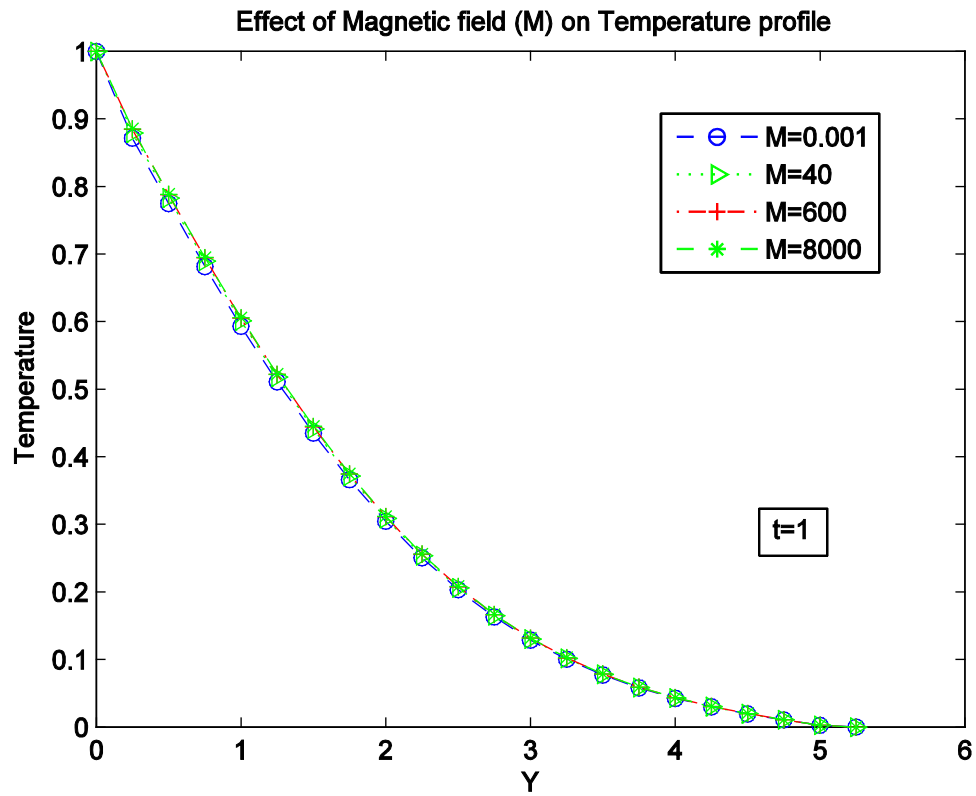
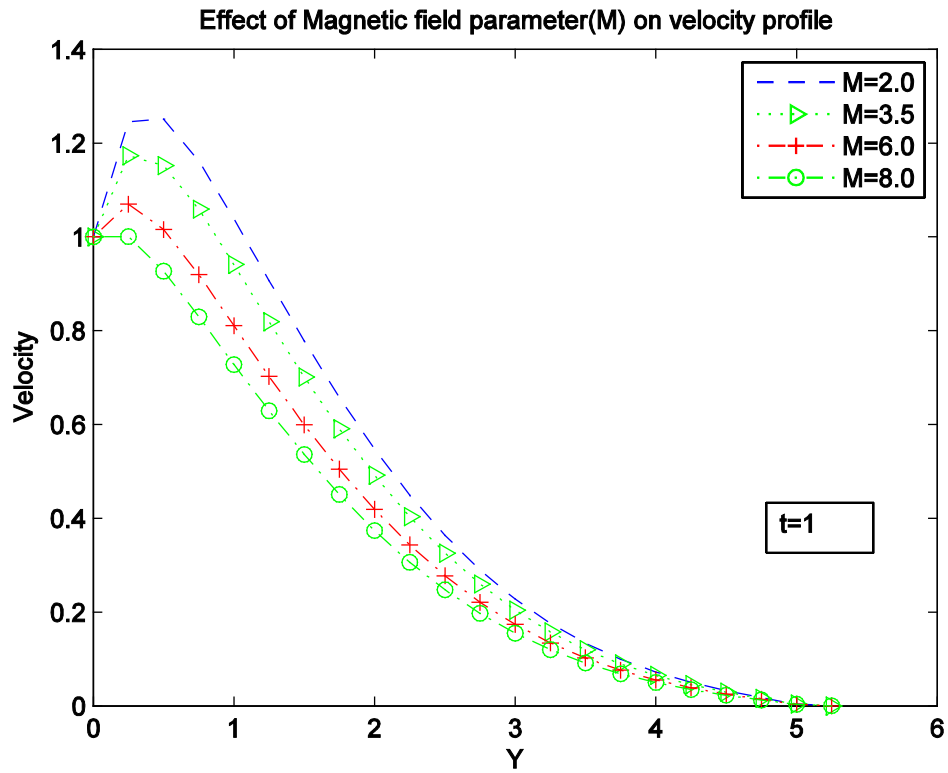
Figure 1, 2 and 3 shows the effects of magnetic field M on the dimensionless velocity, temperature and concentration profiles respectively. Increase in the magnetic field causes reduction in the velocity profile. The application of magnetic field on electrically conducting fluid results to a resistive type of force called Lorentz force which has tendency to slow down the motion of a fluid and increase its temperature.

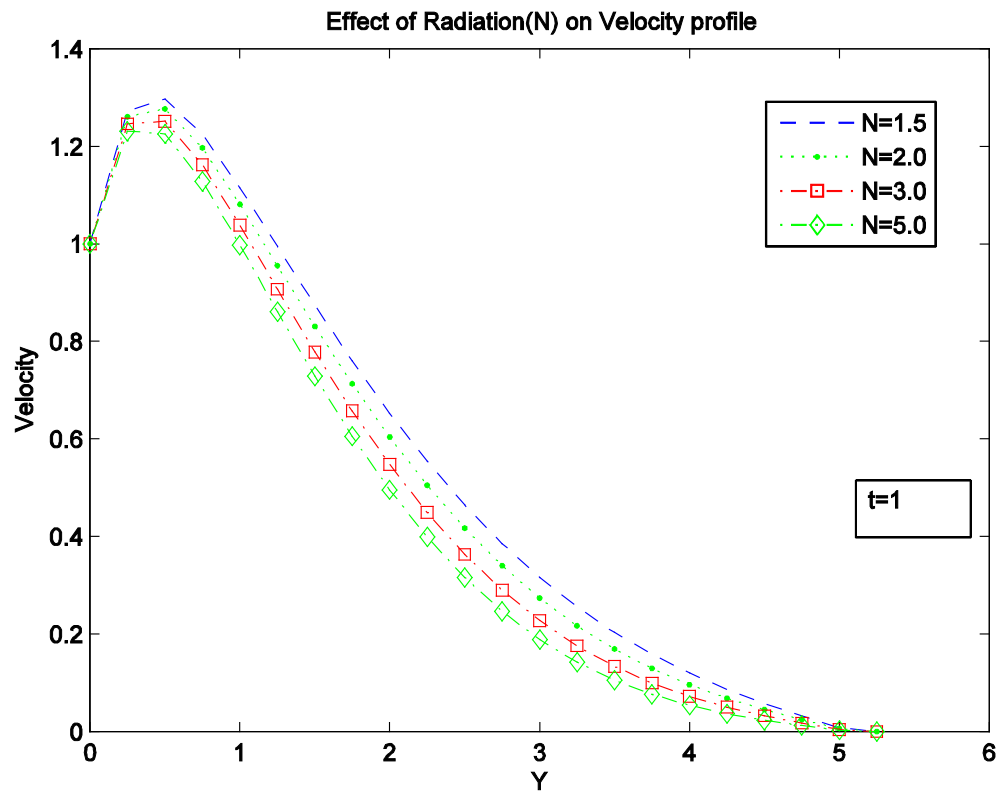
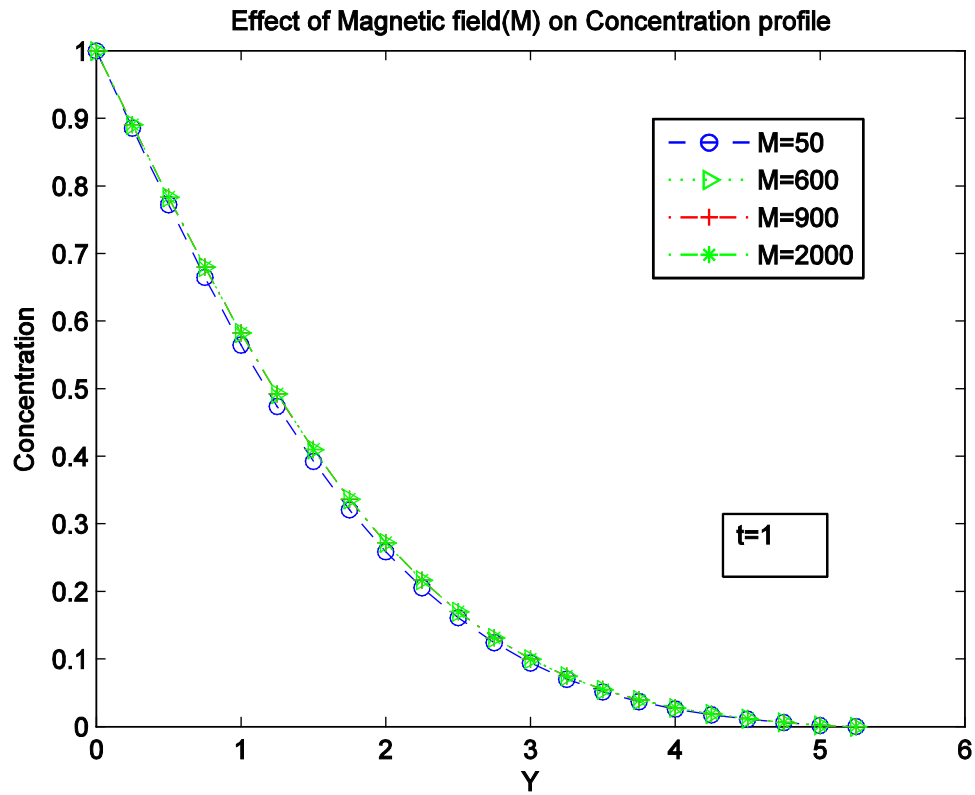
Temperature increases with the increasing value of magnetic field parameter M for both the temperature and species concentration but the increase is so small that it can hardly been seen from the graphs.

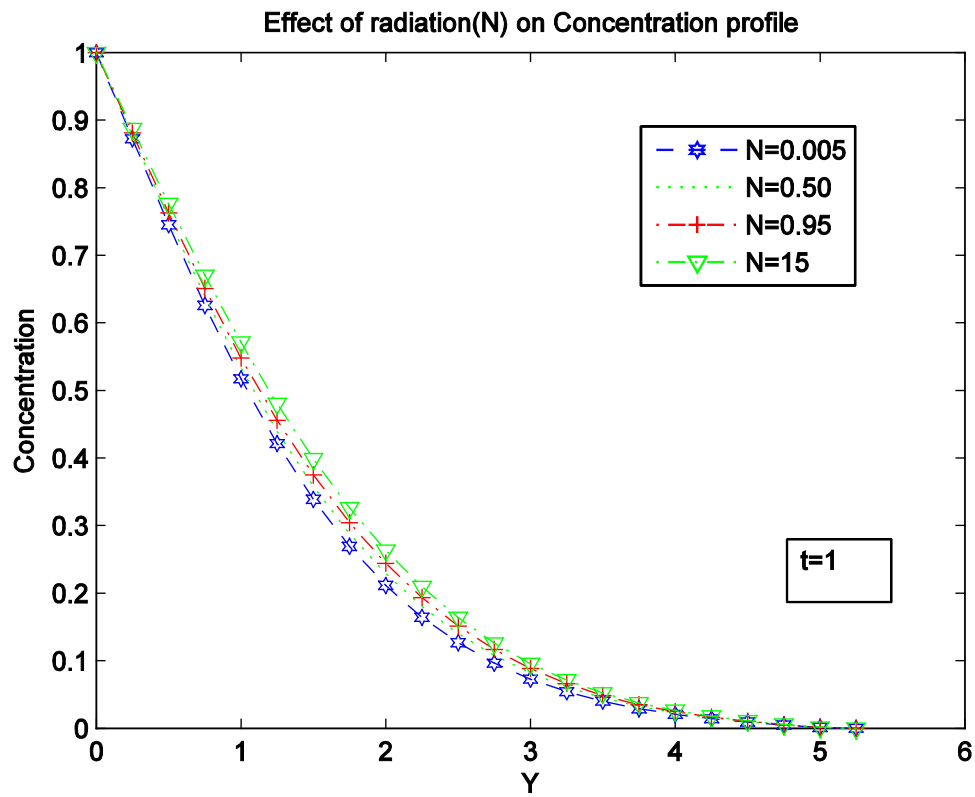
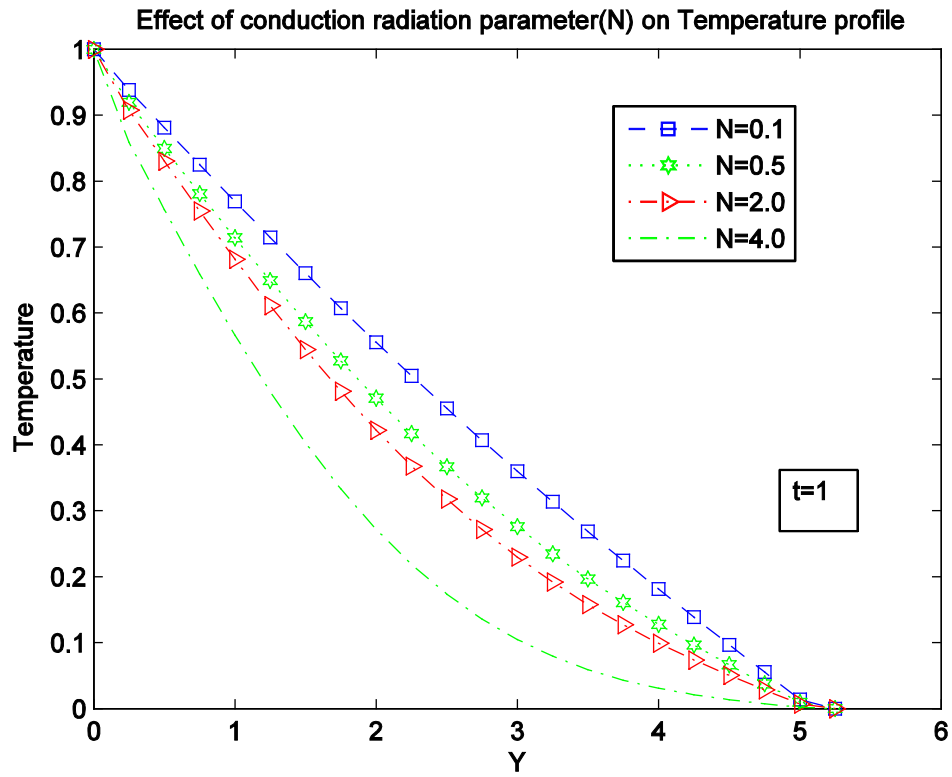
Figure 4, 5 and 6 shows the effect of Conduction-radiation on the velocity, temperature and concentration profile respectively. An increase in N corresponds to an increase in the relative contribution of conduction heat transfer to thermal radiation heat transfer. As N tends to infinity, conduction heat transfer dominates and the contribution of thermal radiative flux disappears. Small value of N corresponds to stronger thermal radiation flux and the maximum temperatures are observed for $N=0.1$. As N increases, considerable reduction is seen in the temperature values from the highest value $N=4.0$ at the wall across the boundary layer to the free stream at which temperature values are negligible for any value of N . All profiles decay to zero in the free stream.

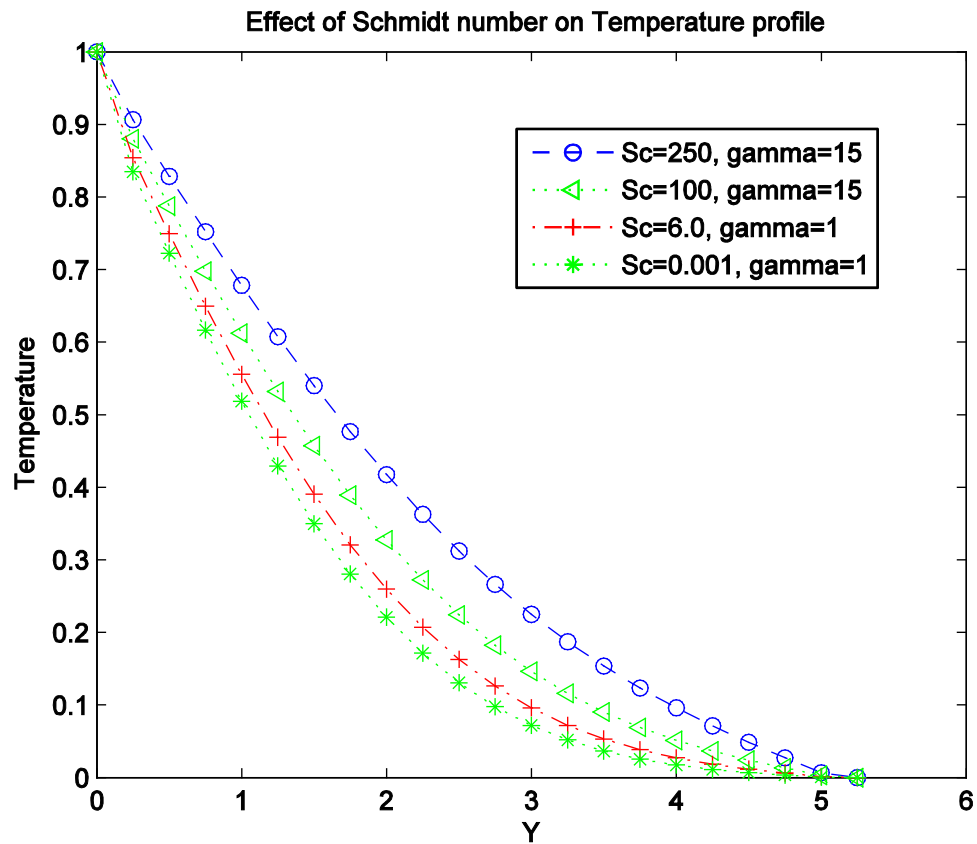
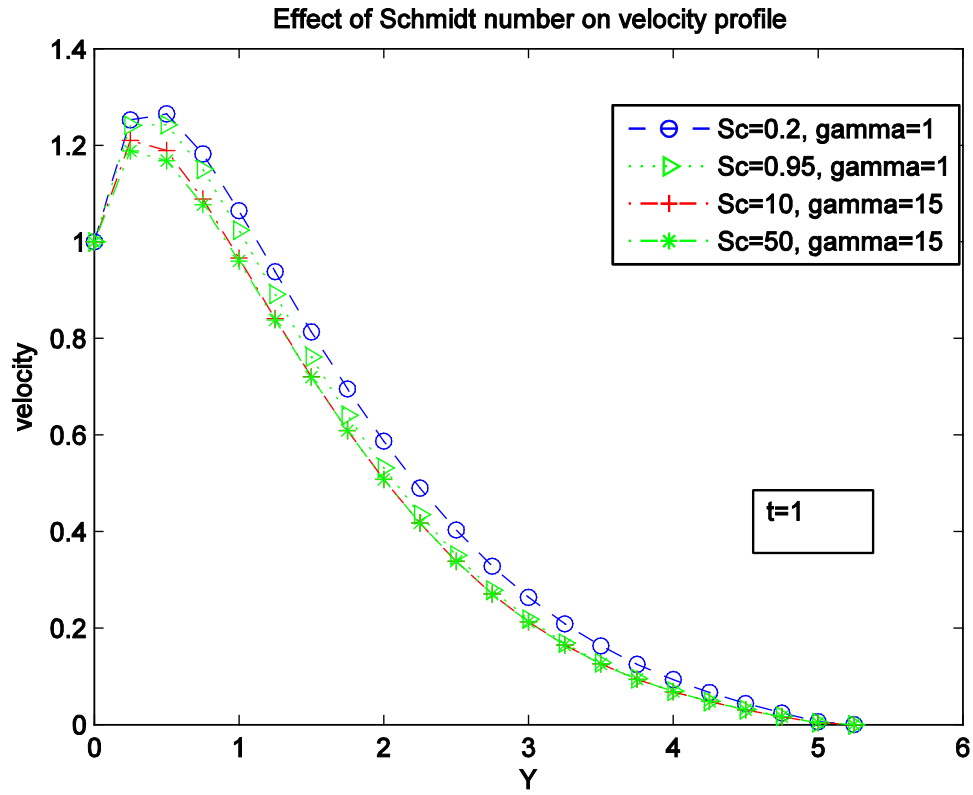
For the concentration profile, increase in Conduction-radiation parameter increases the profile.

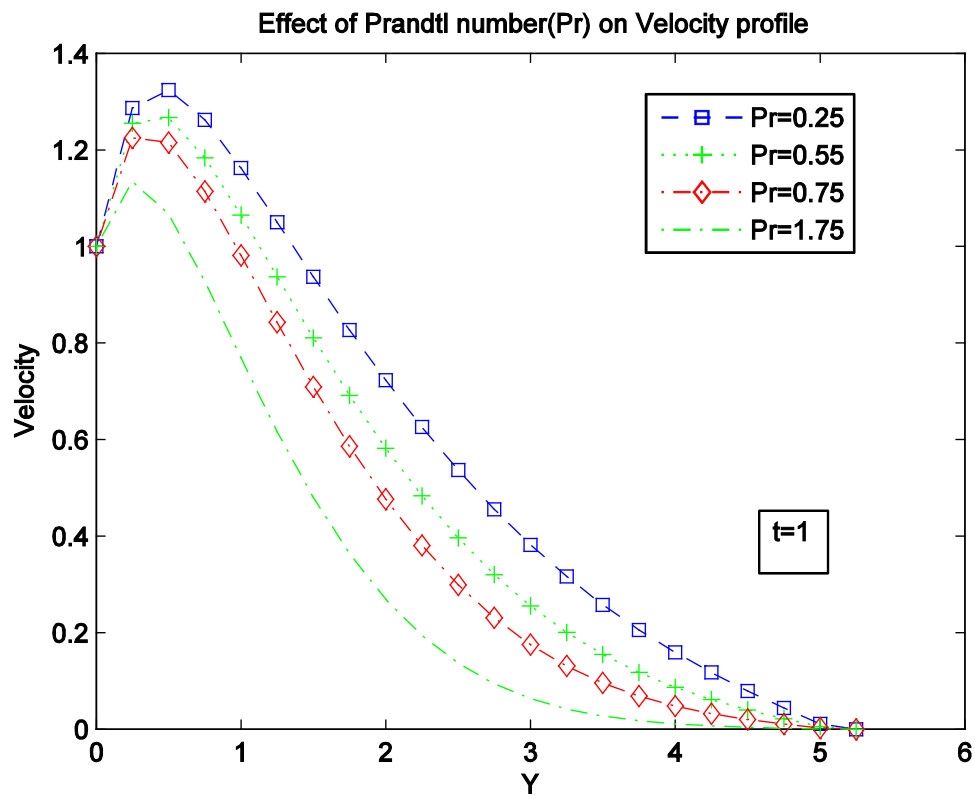
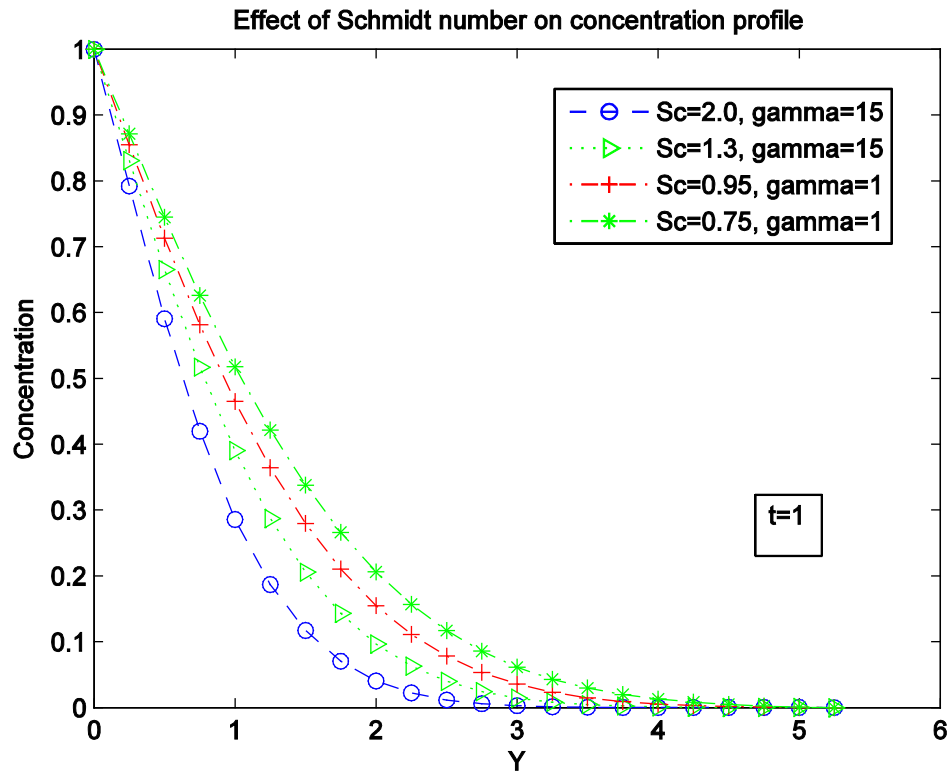
Figure 7, 8 and 9 presented the influence of Schmidt number (Sc) on the velocity, temperature and concentration profiles. We discovered that the velocity and concentration decreases with increase in Sc . Temperature profile increases greatly with an increase in Sc . The dimensionless concentration profile in turns decay from a maximum concentration of 1 at $y=0$ to zero at $y = \infty$. With higher values of Sc , fluid experiences lower diffusion properties and the concentration boundary layer becomes thinner than the velocity boundary layer thickness. A rise in Sc causes a decrease in Temperature.











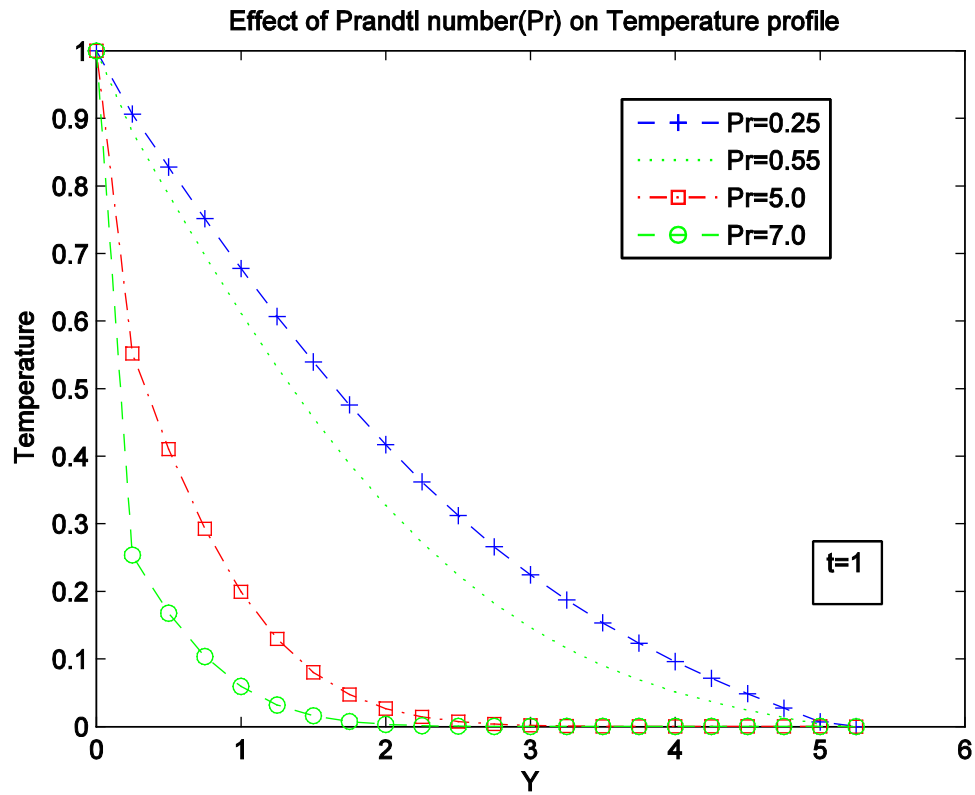


Figure 11. Effect of Prandtl number (Pr) on Temperature Profile

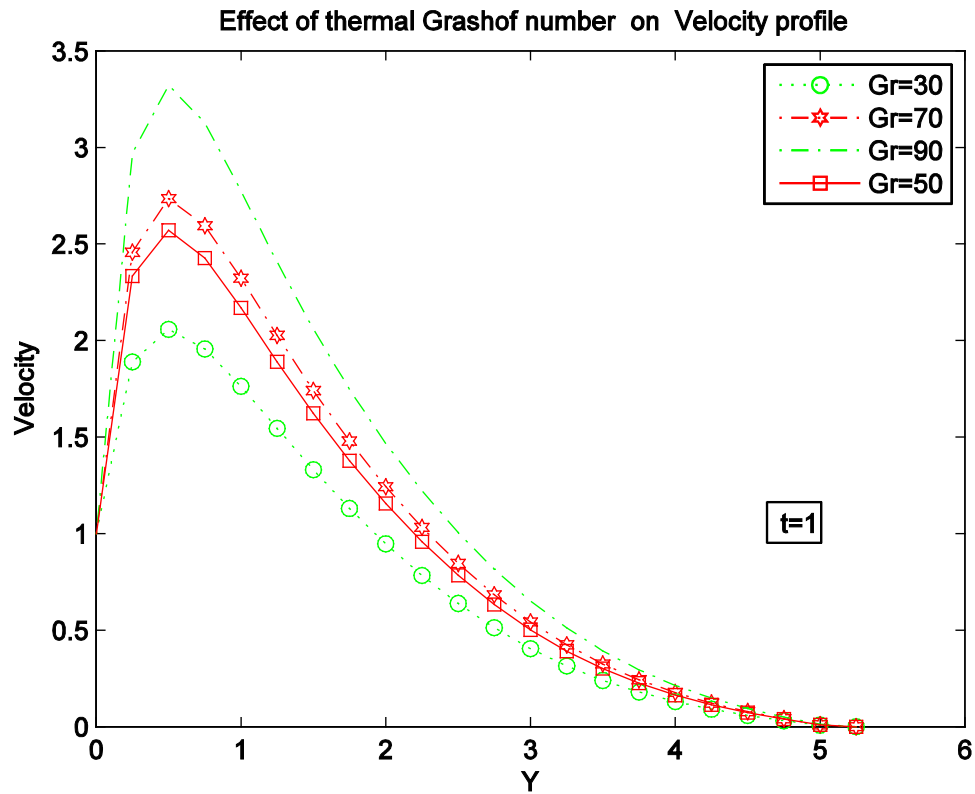
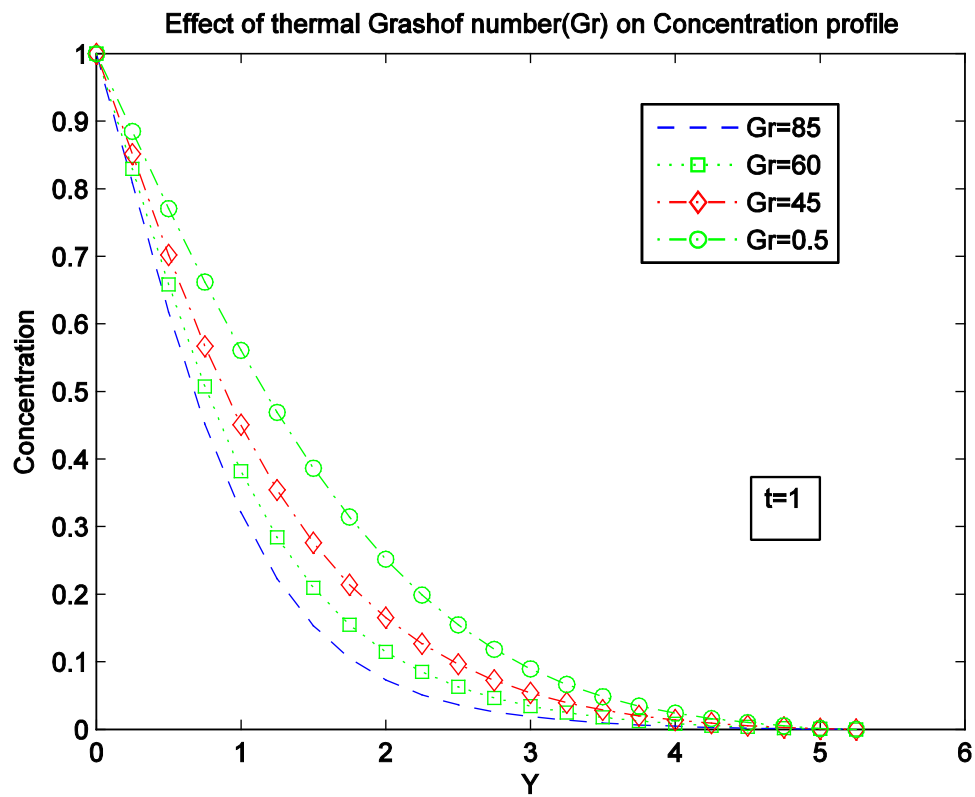
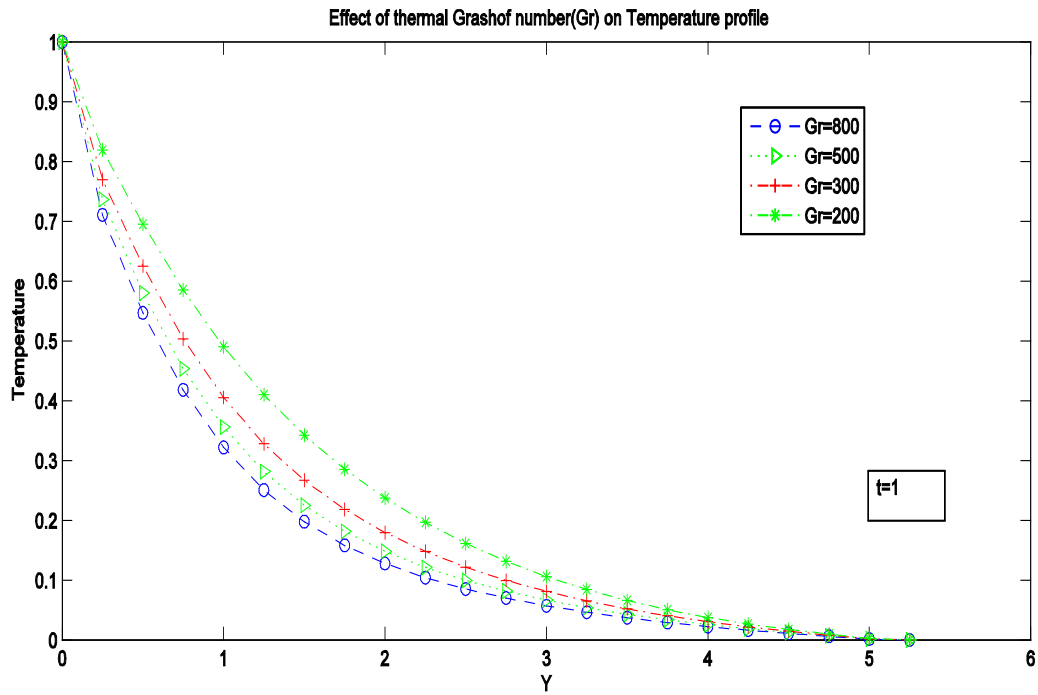
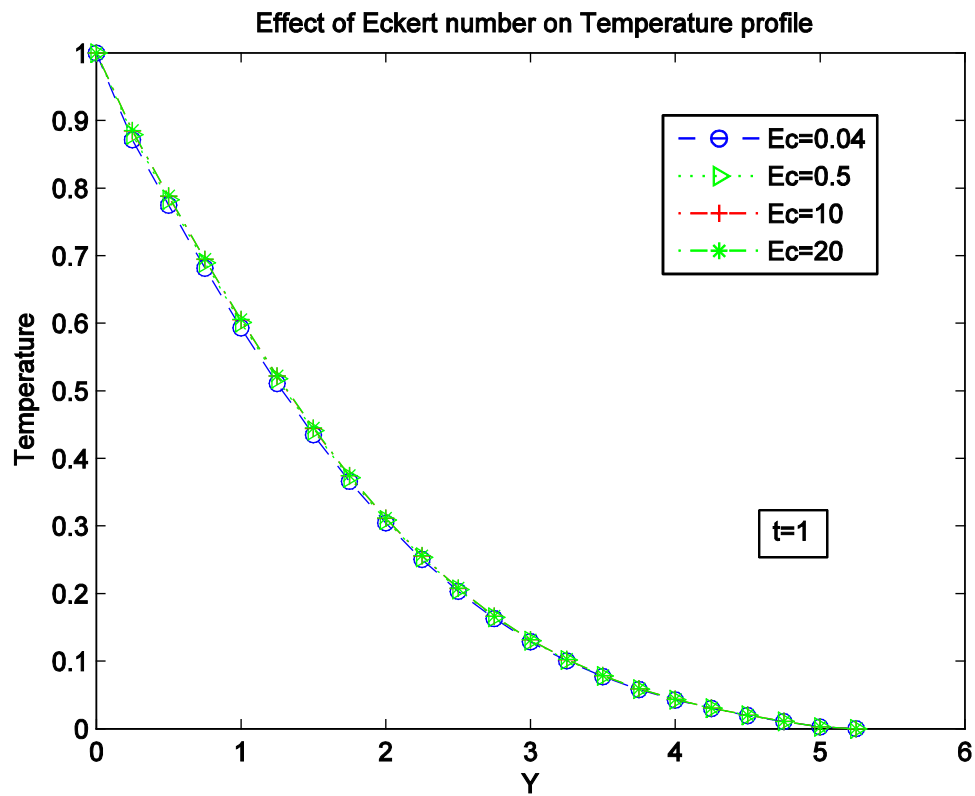
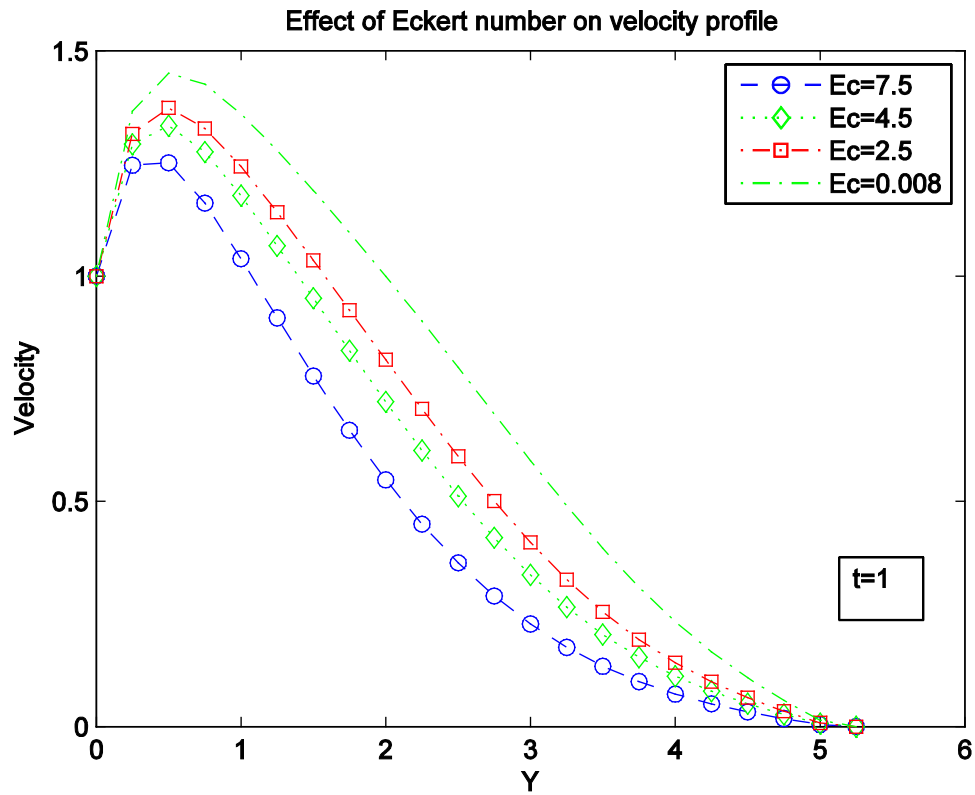


Figure 12. Effect of Grashof number (Gr) on velocity Profile





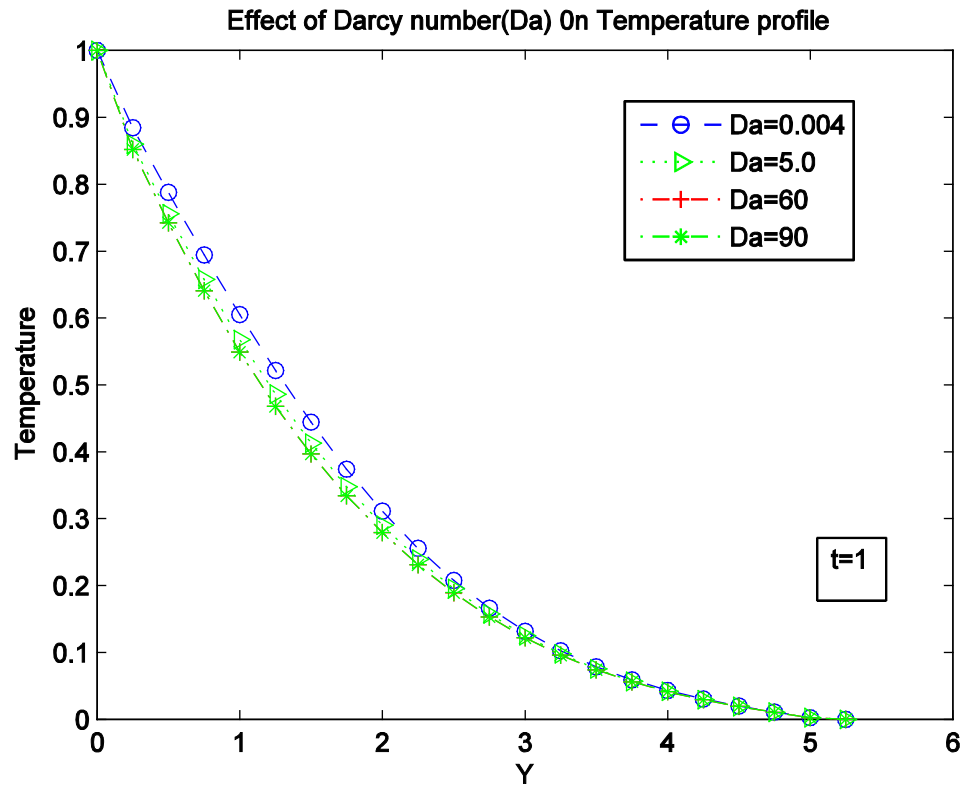
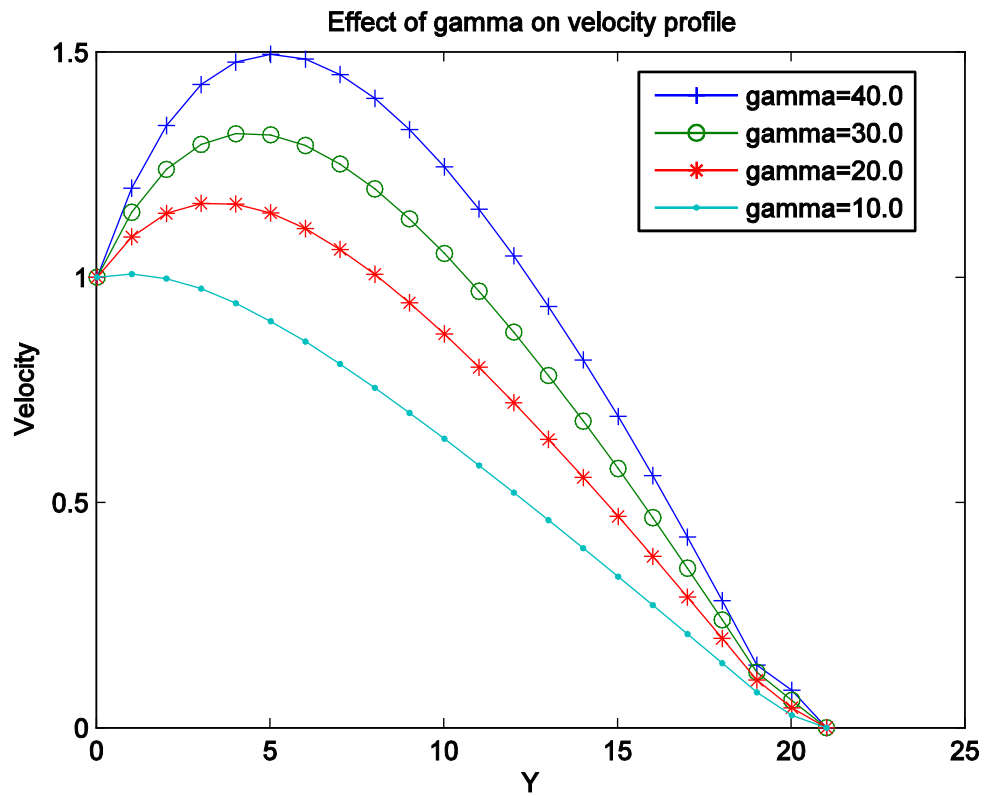


Figure 17. Effect of Darcy number (Da) on Temperature Profile

Figure 18. Effect of chemical reaction parameter (gamma γ) on velocity profile

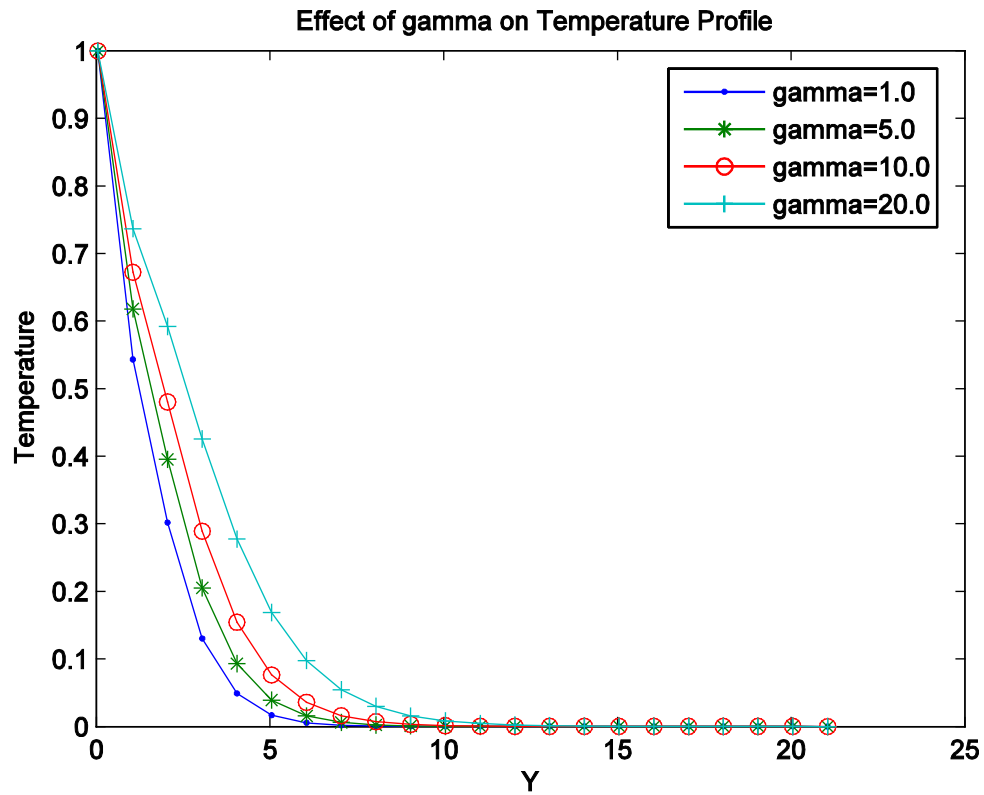
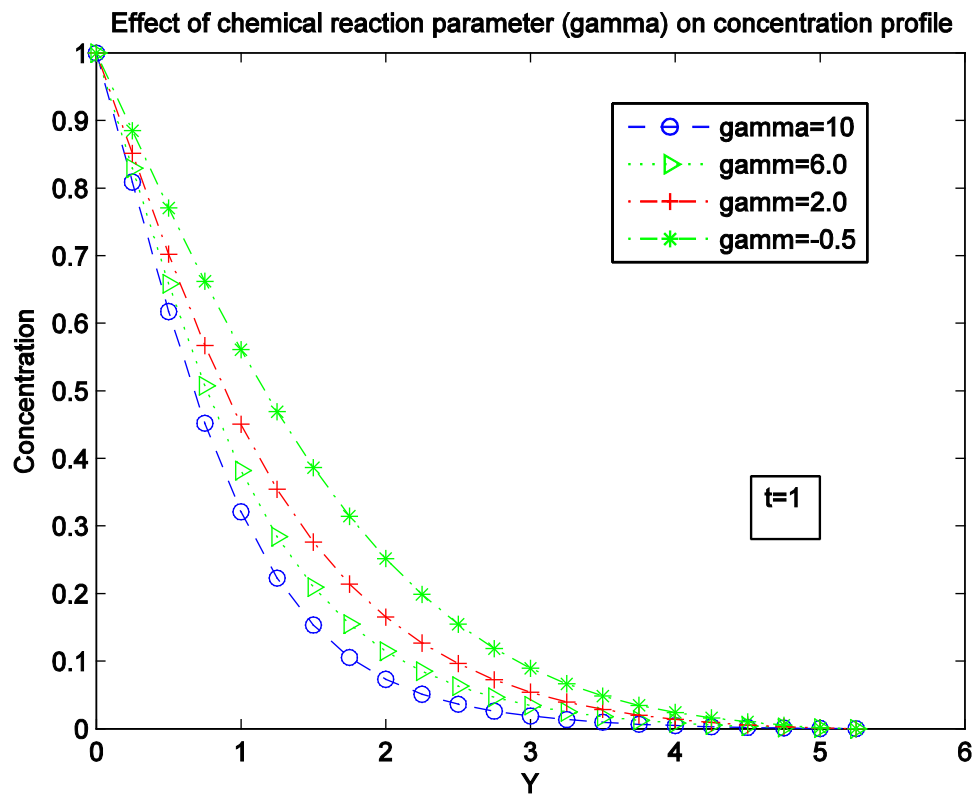
Figure 19. Effect of chemical reaction parameter (gamma γ) on Temperature profileFigure 20. Effect of chemical reaction parameter (gamma γ) on Concentration profile

Figure 10 and 11 gives the effect of Prandtl number (Pr) for velocity and temperature profile.

Prandtl number characterizes the ratio of thickness of the viscous and thermal boundary layers, therefore, from the graph, increase in Prandtl number causes the velocity and temperature profile to decrease.

Figure 12, 13 and 14 present the influence of Grashof number on velocity, temperature and concentration profile. Increase in Gr leads to increase in velocity profile; decrease in temperature and concentration profiles respectively since increasing buoyancy body force has an inhibiting effect on the value of contaminant concentration within the boundary layer regime normal to the barrier.

Figure 15 and 16 show the effect of Eckert number on velocity and temperature profile.

As shown on the graph, considering the values used, increase in Eckert number causes the velocity and temperature profile to reduce without any change in the momentum and boundary layer thickness.

Figure 17 shows the influence of Darcy (Da) number on Temperature profile. Increase in Darcy number results to a rise in temperature profile. The effect of this rise implies that conduction heat transfer becomes less prominent than convection heat transfer and this contributes to the marginal decrease in temperature across the boundary layer from the wall to the free stream.

Figure 18, 19 and 20 display the velocity, temperature and concentration profile for various values of chemical reaction parameter (γ). Increase in the chemical reaction parameter reduces the concentration profile which in turns causes the concentration buoyancy effects to decrease as γ decreases. Increasing chemical reaction parameter causes increase in temperature profile and the velocity profile.

4. Conclusions

We investigate the effects of variable thermo physical parameters on the natural convective heat and mass transfer of a viscous incompressible, gray absorbing-emitting fluid flowing past an impulsively started moving vertical plate under the action of transversely applied magnetic field in the presence of chemical reaction. The governing boundary-layer equations are formulated with appropriate boundary conditions. The usual Roseland diffusion approximation was used to analyze the radiative heat flux and it is appropriate for non-Scattering media. The governing boundary layer equations were simplified and non-dimensionalized. The dimensionless equations were discretized and then solved using the Crank-Nicolsons method. The effects of variable thermo physical parameters which are: Magnetic field (M), Prandtl number (Pr), radiation-conduction parameter (N), thermal Grashof number (Gr), Schmidt number (Sc), chemical reaction parameter (γ), Eckert number (Ec), Darcy number (Da) are considered on the dimensionless velocity, temperature

and species profile. Computations on the variation of local skin friction, Nusselt number and Sherwood number are also recorded. From the graphs plotted, we discover that:

Velocity profile decreases with increase in Magnetic field, conduction radiation parameter, Schmidt number, Prandtl number, Eckert number and chemical reaction parameter while it decreases with increase in Grashof number.

Temperature profile increases with increase in Magnetic field, Schmidt number, Eckert number and chemical reaction parameter while it decreases with increase in conduction radiation parameter, Prandtl number, Eckert number, Grashof number and Darcy number.

Concentration profile increases with increase in Magnetic field and Conduction Radiation parameter while it decreases with increase in Schmidt number, Grashof number and chemical reaction parameter.

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