Diffusion-Thermo Effects on Hydromagnetic Free Convection Heat and Mass Transfer Flow through High Porous Medium Bounded by a Vertical Surface

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Abstract
The objective of this work is to study the Diffusion-thermo effect (Dufour effect) on unsteady MHD free convective heat and mass transfer flow of a viscous incompressible electrically conducting, radiating and chemically reacting fluid past a semi-infinite vertical permeable plate embedded in high porous medium with time dependent suction. A uniform magnetic field of strength B_0 is applied in the transverse direction to the fluid flow. The dimensionless governing equations are solved by a regular perturbation technique. The effect of flow parameters on velocity, temperature, concentration, the rate of heat transfer, the rate of mass transfer and the skin friction coefficients are shown in graphical and tabular forms. It is observed that the effect of Dufour number on temperature and velocity field is significant near the plate.
Keywords: chemical reaction, MHD, porous medium, radiation and Dufour number.

1 Introduction

Magneto hydrodynamics (MHD) (magneto fluid dynamics or hydromagnetic) is the study of the dynamics of electrically conducting fluids. Examples of such fluids include plasmas, liquid metals, and salt water or electrolytes. The word magneto hydrodynamics (MHD) is derived from magneto- meaning magnetic field, hydro- meaning liquid, and *-dynamics* meaning movement. The field of MHD was initiated by Hannes Alfvén, for which he received the Nobel Prize in Physics in 1970.

In recent years, the problems of free convective and heat transfer flows through a porous medium under the influence of a magnetic field have been attracted the attention of a number of researchers because of their possible applications in many branches of science and technology, such as its applications in transportation cooling of re-entry vehicles and rocket boosters, cross-hatching on ablative surfaces and film vaporization in combustion chambers. On the other hand, flow through a porous medium have numerous engineering and geophysical applications, for example, in chemical engineering for filtration and purification process; in agriculture engineering to study the underground water resources in petroleum technology to study the movement of natural gas, oil and water through the oil reservoirs. In the view of these applications many researchers have studied MHD free convective heat and mass transfer flow in a porous medium: some of them are Raptis and Kafoussias [1982] ,Sattar[1993] and Kim[2004].

The Study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost Universal occurrence in many branches of science and engineering. The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions.

Combined heat and mass transfer problems with chemical reactions are of importance in many processes and have therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and the mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries, for example, in the power industry among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid.

In most of the studies related to heat and mass transfer process, Soret and Dufour effects are neglected on the basis that they are of a smaller order of magnitude than the effects described by fouriers and ficks laws .But these effects are considered as second order phenomena and may become significant in areas such as hydrology, petrology, geoscienceces, etc. The Dufour effect was found to be of order of considerable magnitude so that it cannot be neglected ,Eckert and Drake[1972].Dursunkaya and Worek[1992] studied diffusion-thermo and thermal-diffusion effects in Transient and steady natural convection from a vertical surface, Where as Kasfoussias and Williams [1995] presented the same effect on mixed convective and mass transfer steady laminar boundary layer flow over a vertical flat plate with temperature dependent viscosity.El-Aziz[2008] investigated the combined effects of thermal-diffusion and diffusion-thermo on MHD heat and mass transfer over a permeable stretching surface with thermal radiation.Ahmed [2009] discussed free convective heat and mass transfer of an incompressible, electrically conducting fluid over a stretching sheet in the presence of suction and injection with thermal-diffusion and diffusion-thermo effects.

The study of heat and mass transfer is necessary for determining the quality of the final product, samad and Mohebujjaman [2009] .Sparrow [1978] explained a parameter named Rosseland approximation to describe the radiation heat flux in the energy equation in his book. By using the Rosseland diffusion approximation in 1978, a steady of the unsteady mixed convection flow of an optically dense viscous incompressible fluid past a heated vertical plate with a free uniform stream velocity and surface temperature was made by Hossain and Takhar[1996].Poornima[2013]studied the effects of thermal radiation and chemical reaction on MHD free convective flow past a semi-infinite vertical porous moving plate.

A comprehensive review of the studies of convective heat transfer mechanism through porous medium has been made by Nield and Bejan[1998].Hiemath and patil [1993] studied the effects on free convection currents on the oscillatory flow through a porous medium, which is bounded by vertical plane surface of constant temperature.Fluctuating heat and mass transfer on three-dimensional flow through a porous medium with variable permeability has been discussed by sharma et al [2007].Magneto hydrodynamics is currently undergoing a period of great enlargement and differentiation of subject matter. The interest in these new problems generates from their importance in liquid metals, electrolytes and ionized gases. Unsteady hydromagnetic free convection flow of Newtonian fluid has been investigated by Helmy[1998].Chaudhary and Sharma[2006] considered combined heat and mass transfer by laminar mixed convection flow from a vertical surface with induced magnetic field.

The Diffusion-thermo(Dufour) effect was found to be of a considerable magnitude such that it cannot be ignored described by Eckert and Drake in their book.Postelnicu [2004] studied numerically the influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Alam and Rahman [2006] discovered the Dufour and Soret effect on Unsteady MHD flow in a porous medium.

In the above stated papers, the diffusion-thermo and thermal-diffusion term were neglected from the energy and concentration equations respectively. But when heat and mass transfer occurs simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of intricate nature .It has been found that an energy flux can be generated not only by temperature gradient but by composition gradients as well. The energy flux caused by composition gradient is called the Dufour or diffusion-thermal effect. The diffusion-thermo(Dufour) effect was found to be of considerable magnitude such that it cannot be ignored Eckert and Darke[1972].In view of the importance of this diffusion-thermo effect, Jha and Singh[1990] studied the free convection and mass transfer flow about an infinite vertical flat plate moving impulsively in its own plane, Ibrahim[2008] et.al. Very recently reported computational solutions for transient reactive magnetohydrodynamic heat transfer with heat source and wall flux effects.

The main object of the present investigation is to study the effects of diffusion-thermo, radiation absorption, Chemical reaction and heat absorption parameter of heat absorbing fluid with suction velocity varying with time .It is assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the fluid flow direction in the presence of a uniform transverse magnetic field. It is also assumed that the temperature and concentration at the plate and exponentially varying with time.

2 .Formulation of the Problem

An unsteady, laminar, two dimensional free convection flow of a viscous, incompressible electrically conducting and radiating fluid past a semi-infinite vertical porous moving plate embedded in a porous medium is considered. The fluid is considered to be a gray, absorbing emitting radiation but non-scattering medium .The x^*- axis is taken in the upward direction along the plate and y^*- axis normal to it .The plate is maintained at a constant temperature T_w and concentration C_w which are higher than the ambient temperature T_∞ and ambient concentration C_∞ respectively. A uniform magnetic field is applied in the transverse direction to the flow. The fluid is assumed to be slightly conducting, so that the magnetic Reynolds number is much less than unity and hence the induced magnetic field is negligible in comparison with the applied magnetic field. The level of concentration of foreign mass is assumed to be low. Since the plate is of infinite length, all the physical variables are functions of y^* and time t^*only. It is also assumed that all the fluid properties are constant except that the influence of the density variation with temperature and concentration in the body force term (Boussinesq's approximation).Then, under the above assumptions, in the absence of input electric field, the governing equations are

$$\frac{\partial v^*}{\partial y^*}=0 \qquad (1)$$

$$\frac{\partial u^*}{\partial t^*} + \vartheta^* \frac{\partial u^*}{\partial y^*} = g\beta(T^* - T_\infty) + g\beta^* (C^* - C_\infty) + v\frac{\partial^2 u^*}{\partial y^{*2}} - \sigma \frac{B_0^2 u^*}{\rho} - u^* \frac{v}{k^*} \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + \vartheta^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T^* - T_\infty) + Q_1^*(C^* - C_\infty) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} + \frac{D_m K_t}{\rho C_p c_s}\frac{\partial^2 C^*}{\partial y^{*2}} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + \vartheta^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - k_1(C^* - C_\infty) \tag{4}$$

The boundary conditions for the velocity, temperature and concentration fields are

$$\begin{aligned} &u^* = u_p^*, T^* = T_w, C^* = C_w \quad at\ y^*=0 \\ &u^* \to U^*(t^*),\ T^* \to T_\infty, C^* \to C_\infty, \text{as } y^* \to \infty \end{aligned} \tag{5}$$

where u_p^* the wall dimensional velocity, T^* , C^*- dimensional temperature and concentration, u^*, v^* Velocity component in $x^*$and y^* direction, respectively, K^*- permeability parameter, T_∞ , C_∞-free stream temperature and concentration respectively, g- acceleration due to gravity,ϑ-kinematics viscosity, ρ -density, σ -the electric conductivity of the fluid, β, β^* - the coefficients of thermal and concentration expansions respectively, k^*, thermal conductivity, C_p- the specific heat at constant pressure, B_0 - magnetic induction, Q_0- the heat absorption coefficient , Q_1^* the radiation absorption parameter, D - the mass diffusivity coefficient , K_1- chemical reaction parameter and q_r- the radiative heat flux.

The first and second terms on the right hand side of the momentum equation (2) denote the thermal and concentration buoyancy effects, respectively. Also the second, third and fourth terms on the right hand side of the energy equation (3) represent the heat absorption, radiation absorption and thermal radiation respectively. The last term of the concentration equation (4) represents the chemical concentration buoyancy effects. It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and concentration at the wall as well as the suction velocity are exponentially varying with time.

By using the Rosseland approximation (Brewster1992), the radiative heat flux q_r is given by

$$q_r = -\frac{4\sigma_s}{3k_e}\frac{\partial T^4}{\partial y} \tag{6}$$

where σ_s is the Stephen Boltzmann constant and k_e the mean absorption coefficient.

It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids .If the temperature differences within the flow are sufficiently small, then equation (5) can be linearized by expanding T^4 into the Taylor series about T_∞, which after neglecting higher order terms takes the form

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \tag{7}$$

In view of equations (5) and (6) ,equation (3) reduces to

$$\frac{\partial T^*}{\partial t^*} + \vartheta^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T^* - T_\infty) + Q_1^*(C^* - C_\infty) + \frac{16\sigma_s T_\infty^3}{3k_e \rho C_p}\frac{\partial^2 T}{\partial y^2} \tag{8}$$

From the continuity equation (1), it is obvious that the suction velocity is a constant or function of time. Hence it is assumed that

$$\vartheta^* = -V_0(1+\in e^{wt}) \tag{9}$$

Where V_0 is the mean suction velocity and $\in$ is a small quantity less than unity. The negative sign indicates that the suction velocity is directed towards the plate.

In order to write the governing equations and the boundary conditions in the dimensionless form, the following dimensionless quantities are introduced.

$$u = \frac{u^*}{V_0}, v = \frac{v^*}{V_0}, y = \frac{y^* V_0}{v}, u_p = \frac{u_p^*}{V_0}, \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, U(t) = \frac{U^*(t^*)}{V_0}, t = \frac{V_0^2 t^*}{v},$$

$$Gr = \frac{vg\beta(T_w - T_\infty)}{V_0^3}, Gc = \frac{vg\beta(C_w - C_\infty)}{V_0^3}, M = \frac{\sigma B_0^2 v}{\rho V_0^2}, K = \frac{V_0^2 K^*}{v^2}, \gamma = \frac{K_1 v}{V_0^2}, Sc = \frac{v}{D}, \emptyset = \frac{Q_0 v^2}{kV_0^2}$$

$$Pr = \frac{\mu C_p}{k}, Q_1 = \frac{v^2 Q_1^*(C_w - C_\infty)}{kV_0^2(T_w - T_\infty)}, N = \frac{k_e k}{4\sigma_s T_\infty^3}, \ Du = \frac{DmK_T(C_w - C_\infty)}{kC_s(T_w - T_\infty)} \tag{10}$$

In view of the above, the governing equations (2), (4) and (8) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1+\in e^{wt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u + Gr\theta + GcC \tag{11}$$

$$\frac{\partial \theta}{\partial t} - (1+\in e^{wt})\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\left(1 + \frac{4}{3N}\right)\frac{\partial^2 \theta}{\partial y^2} - \frac{\emptyset\theta}{P_r} + \frac{Q_1 C}{P_r} + \frac{Du}{P_r}\frac{\partial^2 C}{\partial y^2} \tag{12}$$

$$\frac{\partial C}{\partial t} - (1+\in e^{wt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - \gamma C \tag{13}$$

The corresponding boundary conditions are

$$\begin{aligned} &u = u_p, \quad \theta = 1, \quad C = 1 \quad at\ y = 0 \\ &u \to U(t), \ \theta \to 0, C \to 0 \quad as\ y \to \infty \end{aligned} \tag{14}$$

3. Method Of Solution

In order to reduce the above system of partial differential equations to a system of ordinary differential equations, the velocity, temperature and concentration in the neighborhood of the porous plate are assumed as

$$U(y,t) = u_0(y) + \in e^{wt}u_1(y), \theta(y,t) = \theta_0(y) + \in e^{wt}\theta_1(y), C(y,t) = C_0(y) + \in e^{wt}C_1(y)$$

$$\text{Also} \quad U(t) = 1 + \in e^{wt} \tag{15}$$

Substituting equation (15) in equations (11)-(14) and equating the harmonic and non-harmonic terms, neglecting the higher order terms in ε, we get

$$u_0'' + u_0' - h3u_0 = -Gr\theta_0 - GcC_0 \tag{16}$$

$$u_1'' + u_1' - h4u_1 = -u_0' - Gr\theta_1 - GcC_1 \tag{17}$$

$$\left(1 + \frac{4}{3N}\right)\theta_0'' + Pr\theta_0' - \theta_0 = -Q_1C_0 - DuC_0'' \tag{18}$$

$$\left(1 + \frac{4}{3N}\right)\theta_1'' + Pr\theta_1' - h2\theta_1 = -Pr\theta_0' - Q_1C_1 - DuC_1'' \tag{19}$$

$$\frac{1}{Sc}C_0'' + C_0' - \gamma C_0 = 0 \tag{20}$$

$$\frac{1}{Sc}C_1'' + C_1' - hC_1 = -C_0' \tag{21}$$

The corresponding boundary conditions are

$$\begin{aligned} &u_0 = u_p, u_1 = 0, \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0\ at\ \ y = 0 \\ &u_0 = 1, u_1 = 1, \theta_0 \to 0, \theta_1 \to 0, C_1 \to 0, C_0 \to 0\ as\ y \to \infty \end{aligned} \tag{22}$$

Solving the equations (16)-(21) subject to the boundary conditions (22), we get

$$u_0(y) = 1 + A_5e^{-m5y} + B_4e^{-m1y} + B_5e^{-m3y} \tag{23}$$

$$u_1(y) = 1 + A_6e^{-m6y} + D_1e^{-m1y} + D_2e^{-m2y} + D_3e^{-m3y} + D_4e^{-m4y} + D_5e^{-m5y} \tag{24}$$

$$\theta_0(y) = A_2 e^{-m_1 y} + A_3 e^{-m_3 y} \tag{25}$$

$$\theta_1(y) = B_1 e^{-m_1 y} + B_2 e^{-m_2 y} + B_3 e^{-m_3 y} + A_4 e^{-m_4 y} \tag{26}$$

$$C_0(y) = e^{-m_1 y} \tag{27}$$

$$C_1(y) = A_1(e^{-m_1 y} - e^{-m_2 y}) \tag{28}$$

Where the expressions for the constants are given in the appendix.
From the technological point of view, the skin friction, rate of heat transfer coefficient and rate of mass transfer coefficient at the plate are important physical parameters for this type of boundary layer flow.

Knowing the velocity field, the skin-friction at the plate can be obtained, which in non-dimensional form is given by

$$C_f = \frac{\tau_w}{\rho U_0 V_0} = (\frac{\partial u}{\partial y})_{at\ y=0} = (-A_5 m_5 - B_4 m_1 - B_5 m_3) + \in e^{wt}(-A_6 m_6 - D_1 m_1 - D_2 m_2 - D_3 m_3 - D_4 m_4 - D_5 m_5) \tag{29}$$

Knowing the temperature field, the rate of heat transfer coefficient at the plate can be obtained, which in non-dimensional form, in terms of Nusselt number, is given by

$$N_u = -\frac{q_w \delta}{k(T_w - T_\infty)} = -(\frac{\partial \theta}{\partial y})_{at\ y=0} = (A_2 m_1 + A_3 m_3) + \in e^{wt}(B_1 m_1 + B_2 m_2 + B_3 m_3 + A_4 m_4) \tag{30}$$

Knowing the concentration field. The rate of mass transfer coeffient the plate can be obtained, which is non-dimensional form, in terms of Sherwood number, is given by

$$Sh = M_u = -\frac{M_w \delta}{D_m(C_w - c_\infty)} = -(\frac{\partial C}{\partial y})_{at\ y=0} = m_1 + \in e^{wt}(A_1 m_1 - A_1 m_2). \tag{31}$$

4. Results and Discussion
In order to get a physical insight of the problem, the numerical calculations are carried out to illustrate the influence of various physical parameters viz., thermal radiation, magnetic parameter, chemical reaction parameter and permeability parameter on the velocity, temperature, concentration, skin-friction, Nusselt number and Sherwood number and presented graphically in Figures (1)-(19). Throughout the calculations, the parametric values are chosen as, ∈=0.2, ω=0.1 up =0.5, Pr =0.71,t =1, Gr= 4,Gc = 2, Q_1 = 2, K = 2, M = 2, $\emptyset$ = 2, γ = 0.2 and Sc = 0.2.All the graphs therefore correspond to these values unless specifically indicated on the appropriate graph.
Fig.1 displays the concentration profiles for different values of Schmidt number Sc.From this figure it is clear that the concentration decreases rapidly with increasing values of Sc.Also observe that for low Schmidt value gases the concentration is very high ,in this figure for hydrogen gas the concentration is very high comparing with ammonia.

Fig.2 shows the influence of Chemical reaction parameter γ on concentration profiles for different values of.From this it is clear that the concentration is increases with negatively increasing values of γ(i.e. generative reaction) and concentration decreases with increasing values of γ (i.e. destructive reaction).

The temperature profiles for different values of radiation parameter N are shown in Fig. 3. From this figure it is clear that the temperature decreases with increasing values of N.

Fig.4 depicts the variation of temperature profiles for different values of Radiation absorption parameter Q_1.It is clear that the temperature increases rapidly with increasing values of radiation absorption parameter Q_1.It is clear that the temperature reaches maximum value near the boundary layer .

Fig.5 has been plotted to depict the variation of temperature profiles for different values of Schmidt number Sc.It is clear that the temperature is increases rapidly with increasing values of Sc.

Fig.6 displays the temperature profiles for different values of heat absorption parameter $\emptyset$.It is clear that the temperature decreases with increasing values of $\emptyset$,also we observe that in the presence of heat absorption parameter $\emptyset$,the temperature is decreases rapidly.

Fig.7 illustrates the variation of the temperature profiles for different values of Dufour number Df.It is clear that temperature increases with increasing values of Dufour number.It is noticed that there is a considerable effect of Df on temperature.

Fig.8 displays the velocity profiles for different values of Permeability parameter K .it is clear that the temperature increases with increasing values of K and reaches the maximum value near the boundary layer.

The velocity profiles for different values of Magnetic field parameter M are shown in fig.9.It is noticed that the velocity decreases rapidly with the increasing values of M.Also we observe that before applying the magnetic field to the plate the velocity is very high,while it is suddenly decreases when the magnetic field is introduced.

For different values of the thermal buoyancy force parameter Gr and solutal buoyancy force parameter Gc are plotted in fig.10 and fig.13. As seen from this figures that maximum peak value is attained and minimum peak value is observed for small values fo buoyancy forces, this is due to fact that buoyancy force enhances fluid velocity and increase the buoyancy layer thickness with increase in the value of $Gr\ or\ Gc$.

Fig.11 represents the decrease in fluid velocity when the heat absorption parameter $\emptyset$ is increased it is also observed that the hydromagnetic boundary layer decrease as the heat absorption effect increase.

Fig.12 depicts the velocity profiles for different values of Radiation absorption parameter Q_1.From this figure it is clear that the velocity decreases within the boundary layer with Q_1.

The influence of Schmidt number Sc on the velocity fields are shown in fig.14, we observe from fig.14 that at a very low values of Schmidt number (e.g., $Sc = 0.2$), here is increase in the peak velocity near the plate($y \simeq 1$). Whereas for higher values of Schmidt number, the peak shifts closer to the plate, further it is observed that the momentum boundary layer decrease with increase in the value of Sc.

Fig.15 has been plotted to depict the variation of velocity profiles against y for different values of Df and hence the buoyancy layer thickness can be decreases with Df. It is observed that the fluid velocity decreases with increasing the diffusion thermo parameterDf.

Graphs:

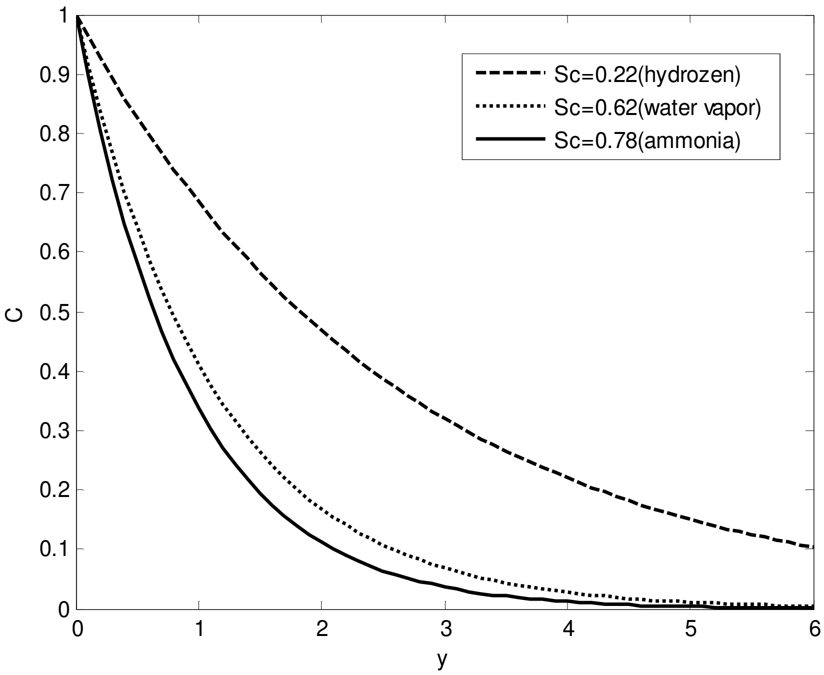

Fig.1 Concentration profiles against span wise coordinate y for different values of Schmidt number (Sc) with $\gamma = 0.2, w = 0.1, t = 1, \epsilon = 0.2$

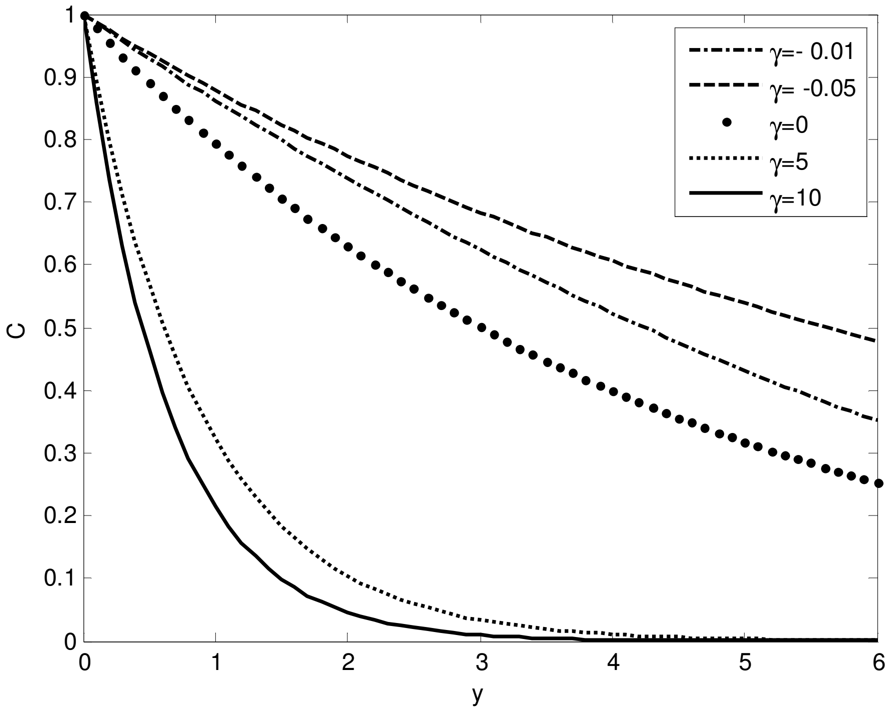

Fig.2: Concentration profiles against span wise coordinate y for different values of Chemical reaction parameter(γ) with $Sc = 0.2, w = 0.1, t = 1, \epsilon = 0.2$

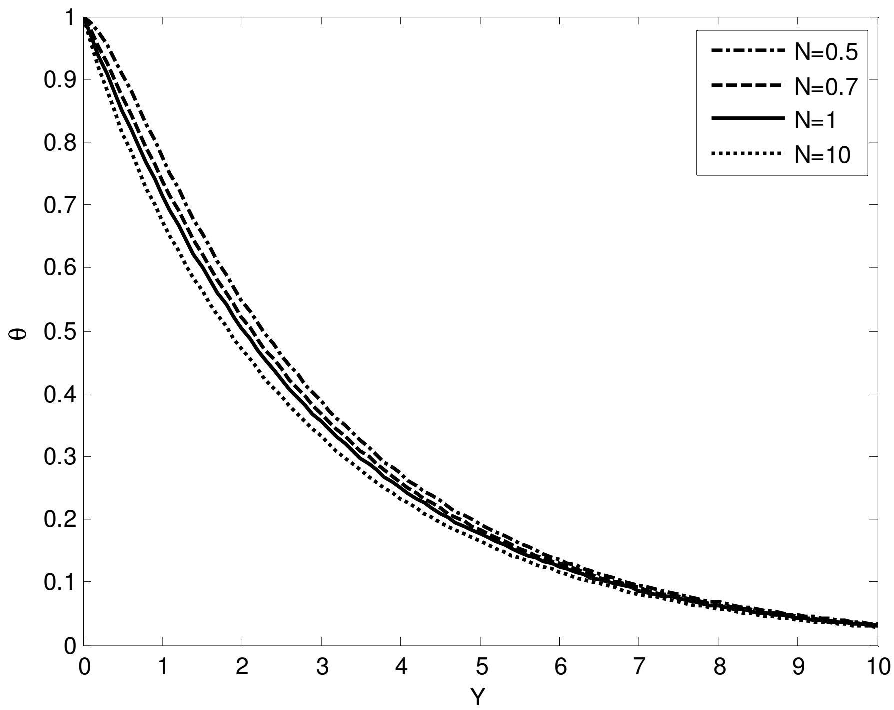

Fig.3: Temperature profiles against span wise coordinate y for different values of Radiation parameter (N) with $Df = 0.5, K = 2, M = 2, \emptyset = 2, Q_1 = 2.$

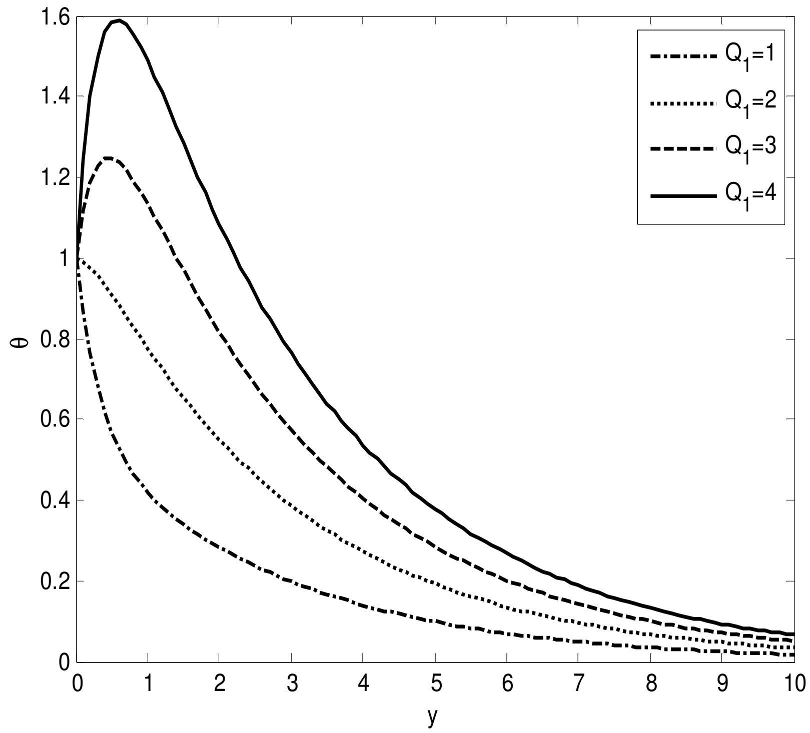

Fig.4: Temperature profiles against span wise coordinate y for different values of Radiation absorption coefficient (Q_1) with $N = 0.5, Df = 0.5, K = 2, M = 2, \emptyset = 2$

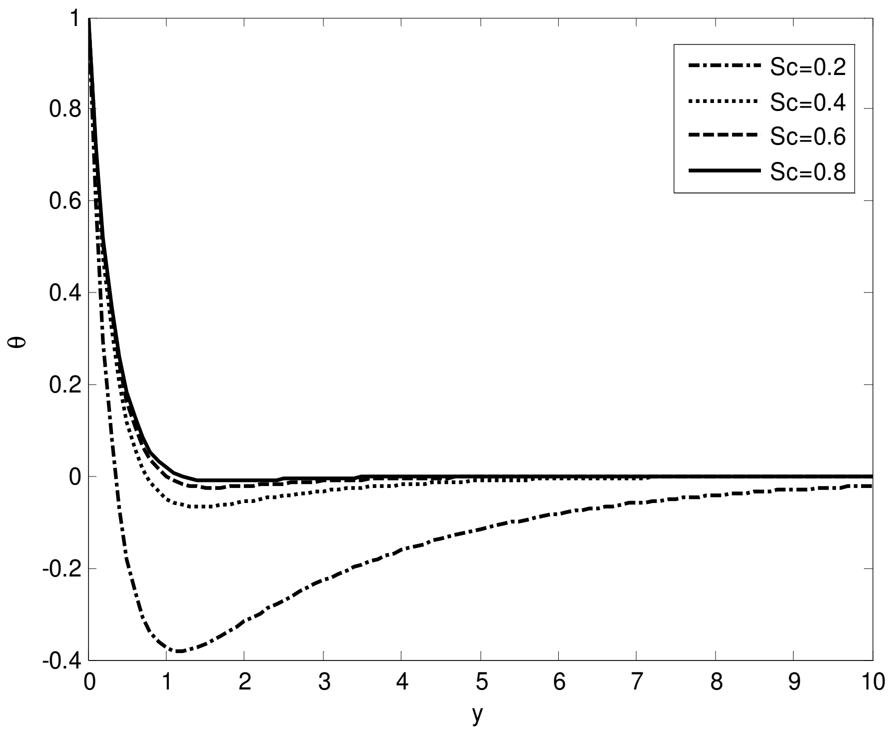

Fig.5: Temperature profiles against span wise coordinate y for different values of Schmidt number (Sc) with $N = 0.1, Df = 0.8, K = 2, M = 2, \emptyset = 0.5, Q_1 = 0.5$

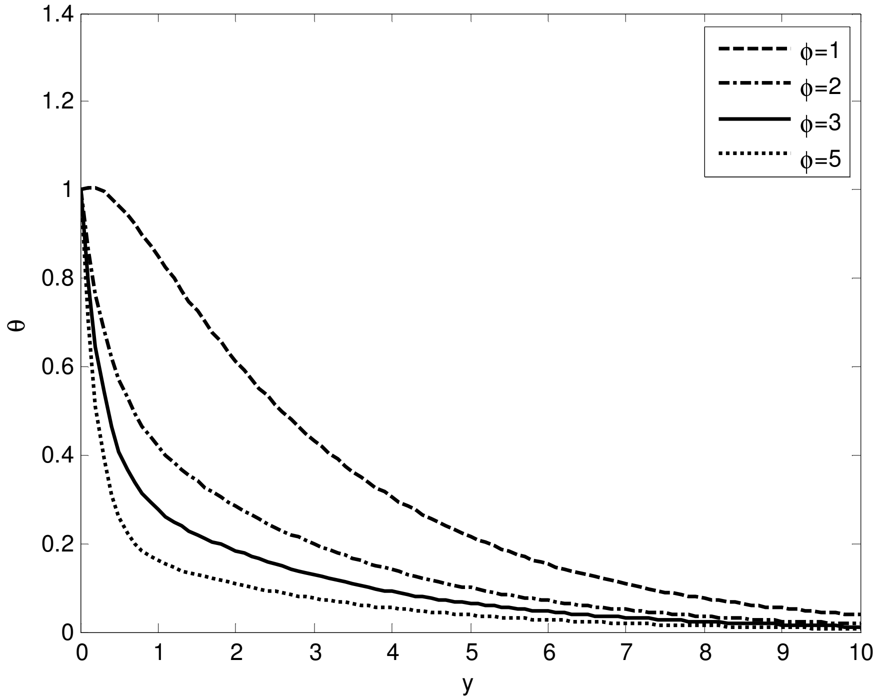

Fig.6: Temperature profiles against span wise coordinate y for different values of Heat absorption coefficient($\emptyset$) with $N = 0.5, Df = 0.5, K = 2, M = 2, Q_1 = 1$.

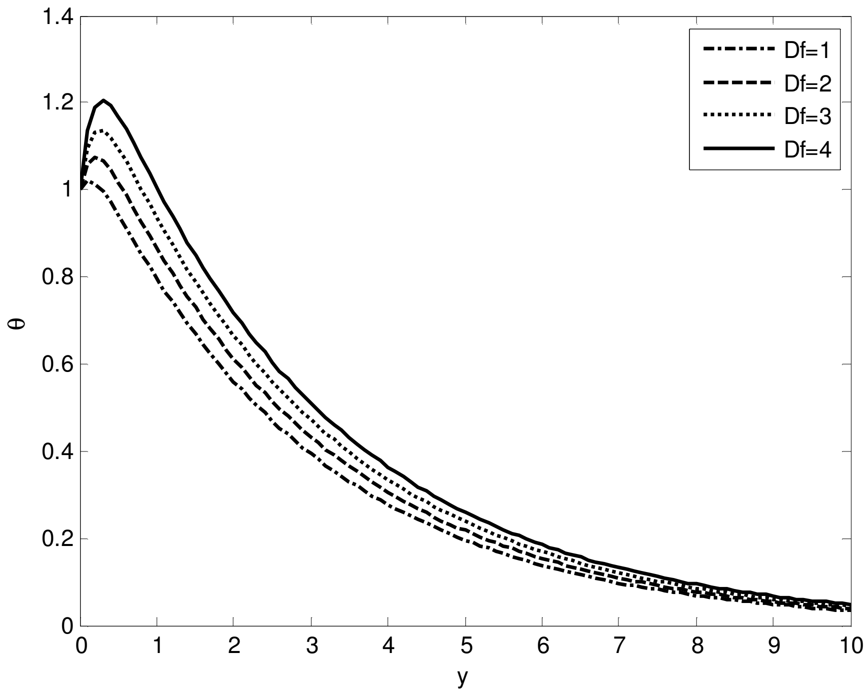

Fig.7: Temperature profiles against span wise coordinate y for different values of Dufour number (Df) with $N = 0.1, , K = 2, M = 2, \emptyset = 2, Q_1 = 0.5$.

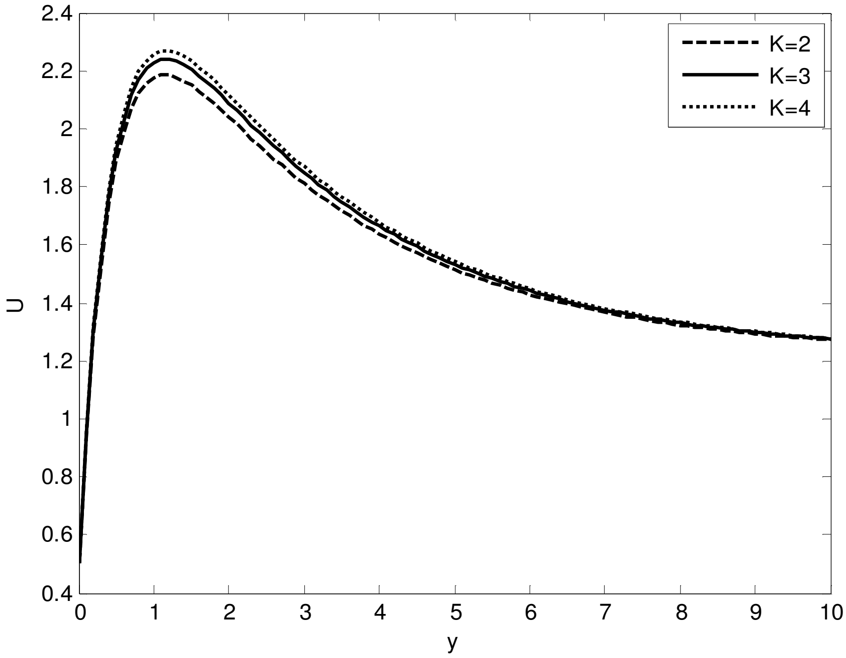

Fig.8: velocity profile against span wise coordinate y for different values of Permeability parameter(K)
$N = 0.1, Df = 0.5, Q_1 = 1, M = 2, \emptyset = 3, up = 0.5, Gc = 2, Gr = 4.$

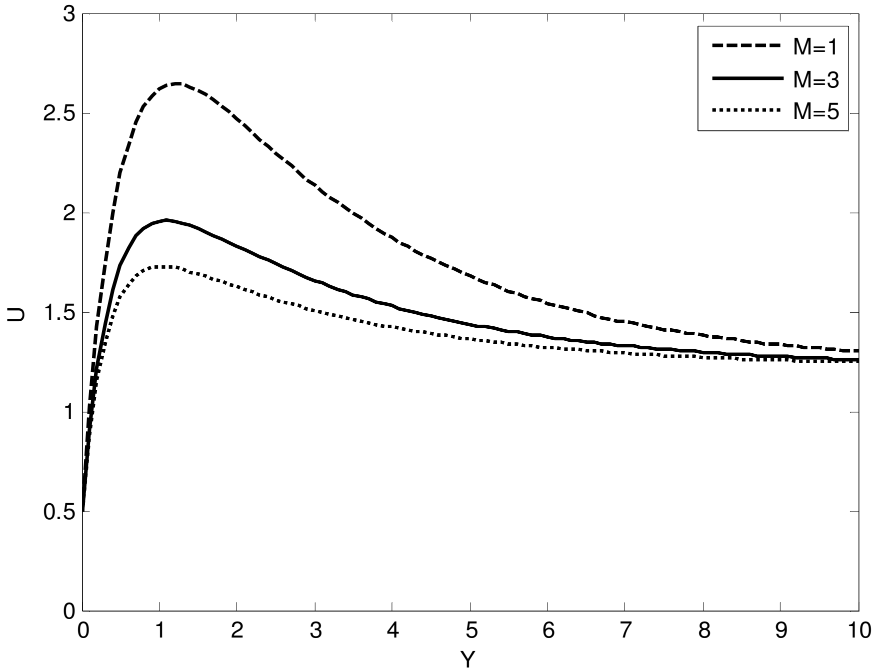

Fig.9: velocity profiles against span wise coordinate y for different values of Magnetic parameter (M)
$N = 0.1, Df = 0.5, Q_1 = 1, K = 2, \emptyset = 3, up = 0.5, Gc = 2, Gr = 4.$

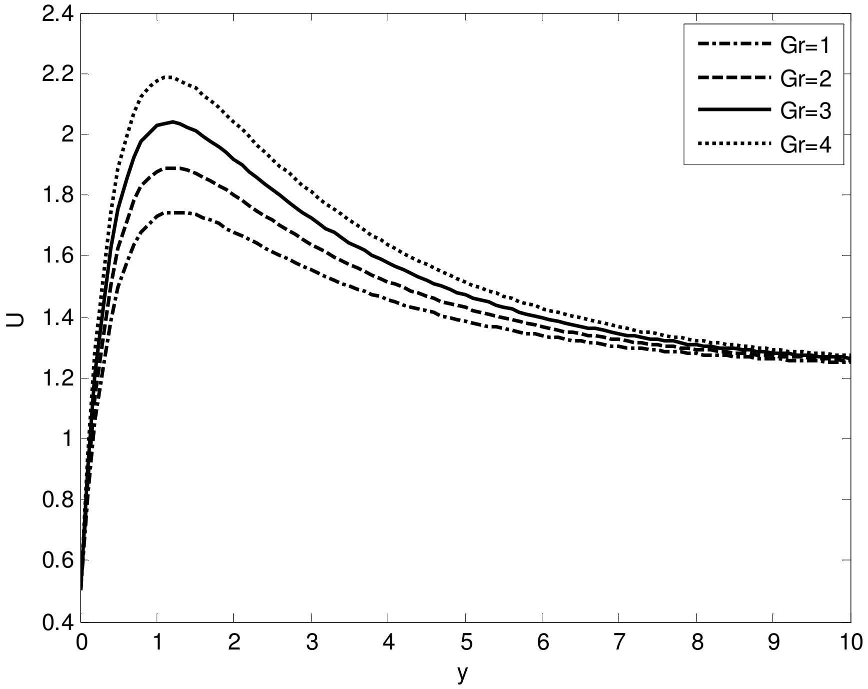

Fig.10: velocity profiles against span wise coordinate y for different values of Grashof number (Gr) with $N = 0.1, Df = 0.5, Q_1 = 1, M = 2, \emptyset = 3, up = 0.5, Gc = 2, K = 2.$

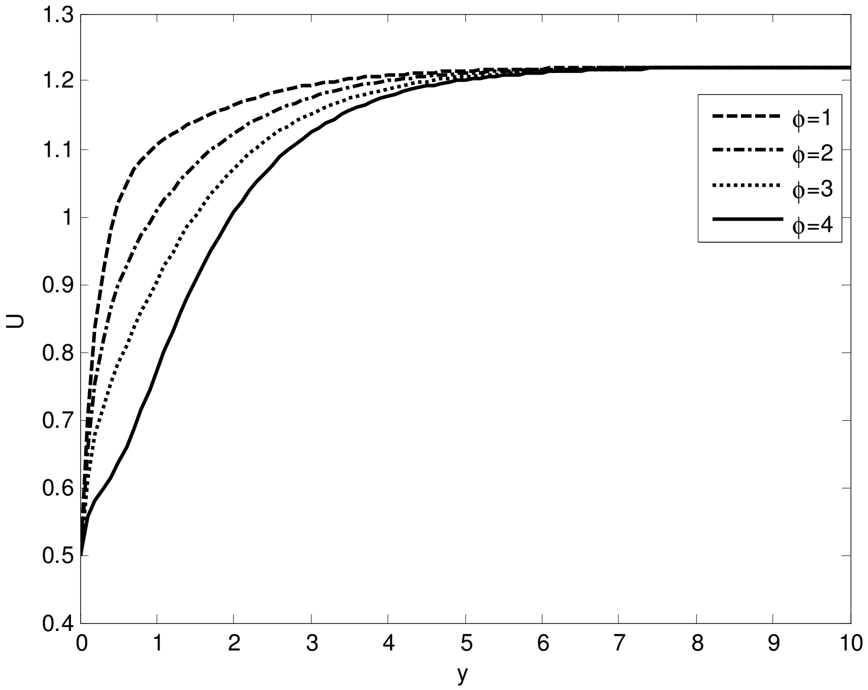

Fig.11: velocity profiles against span wise coordinate y for different values of Heat absorption coefficient($\emptyset$) with $Sc = 0.5, N = 0.1, Df = 0.5, Q_1 = 4, M = 2, K = 2, up = 0.5, Gc = 2, Gr = 4.$

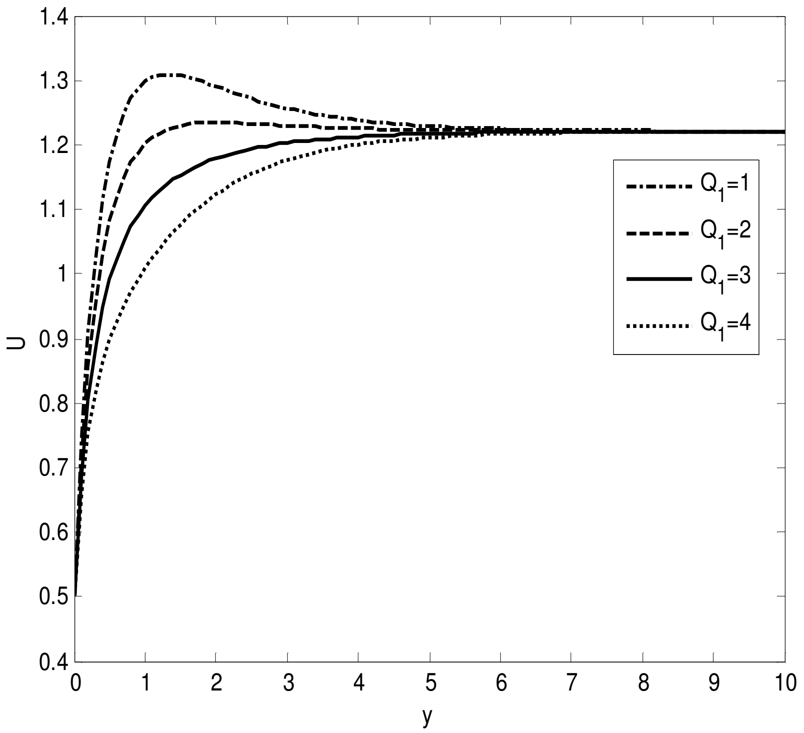

Fig.12: velocity profiles against span wise coordinate y for different values of Radiation absorption coefficient (Q_1) $Sc = 0.5, N = 0.1, Df = 0.5, K = 2, M = 2, \emptyset = 2, up = 0.5, Gc = 2, Gr = 4$

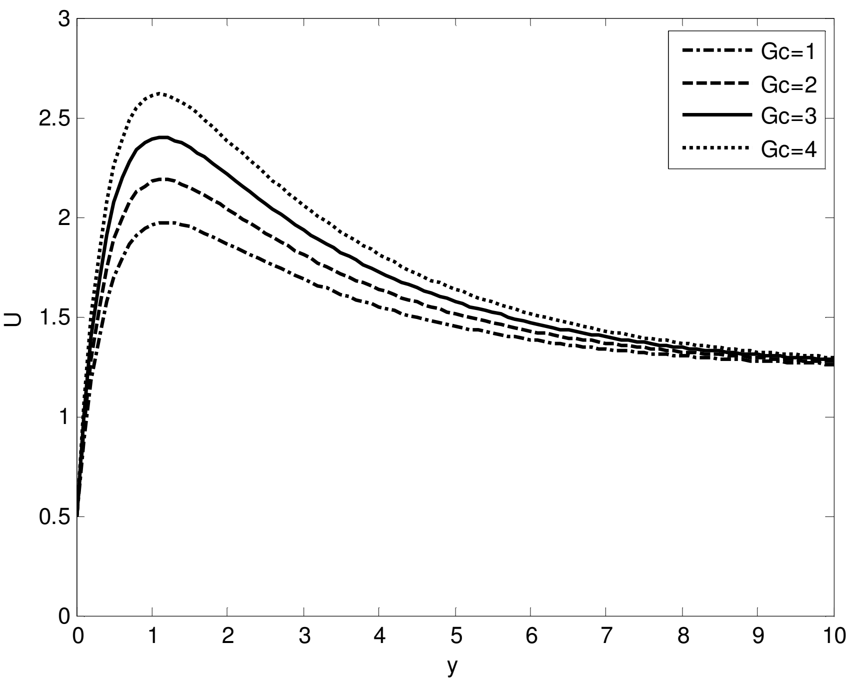

Fig.13: velocity profiles against span wise coordinate y for different values of Solutal Grashof number (Gc) $Sc = 0.2, N = 0.1, Df = 0.5, Q_1 = 1, M = 2, \emptyset = 3, up = 0.5, K = 2, Gr = 4.$

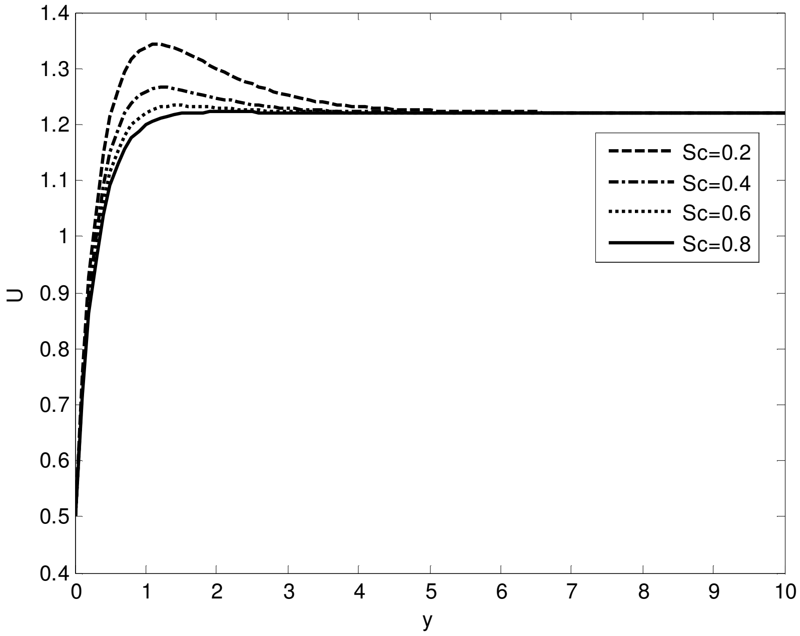

Fig.14: velocity profiles against span wise coordinate y for different values of Schmidt number (Sc) with $K = 2, \gamma = 5, N = 0.1, Df = 0.5, Q_1 = 0.5, M = 1, \emptyset = 2, up = 0.5, Gc = 2, Gr = 4$.

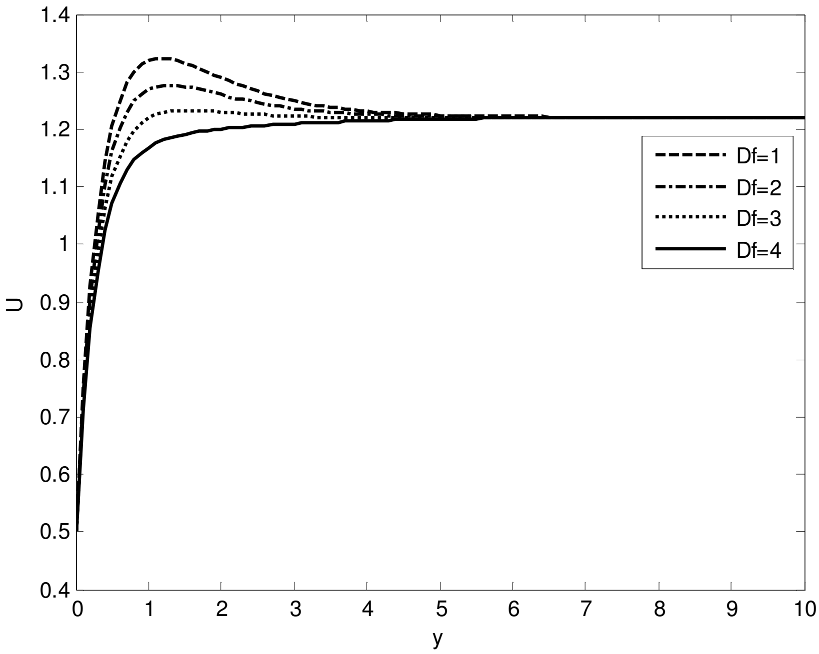

Fig.15: velocity profiles against span wise coordinate y for different values of Dufour number (Df) with $Sc = 0.6, \gamma = 0.5, N = 0.1, K = 1, Q_1 = 2, M = 0.2, \emptyset = 1, up = 0.5, Gc = 2, Gr = 4$.

Sc	t	γ	Sh
0.22	1	0.2	0.3795
0.62	1	0.2	0.8859
0.78	1	0.2	1.0836
0.22	**0.1**	0.2	0.3767
0.22	**2.0**	0.2	0.3830
0.22	**5.0**	0.2	0.3956
0.22	1	**-0.05**	0.1808
0.22	1	**0**	0.2563
0.22	1	**5**	1.1913

Table.1:Numerical values of Sherwood Number (Sh)

Df	Sc	$\emptyset$	Q_1	γ	t	Pr	Nu
0.1	0.2	2	0.5	0.2	1	0.71	1.9874
1.0	0.2	2	0.5	0.2	1	0.71	1.8909
3.0	0.2	2	0.5	0.2	1	0.71	1.6763
0.5	0.2	2	**1**	0.2	1	0.71	1.3998
0.5	0.2	2	**2**	0.2	1	0.71	0.3103
0.5	0.2	2	**3**	0.2	1	0.71	-0.7792
0.5	**0.2**	2	2	0.2	1	0.71	0.3103
0.5	**0.4**	2	2	0.2	1	0.71	0.0420
0.5	**0.6**	2	2	0.2	1	0.71	-1.1322
0.5	0.2	0.5	2	**5**	1	0.71	2.1408
0.5	0.2	0.5	2	**10**	1	0.71	1.4515
0.5	0.2	0.5	2	**15**	1	0.71	1.2632
0.5	0.2	**1**	2	0.2	1	0.71	-1.2582
0.5	0.2	**2**	2	0.2	1	0.71	0.3103
0.5	0.2	**3**	2	0.2	1	0.71	1.2053
0.5	0.2	2	2	0.2	**0.1**	0.71	0.3050
0.5	0.2	2	2	0.2	**2**	0.71	0.3168
0.5	0.2	2	2	0.2	**5**	0.71	0.3406
0.5	0.2	2	2	0.2	1	**0.71**	0.3103
0.5	0.2	2	2	0.2	1	**1**	0.4459
0.5	0.2	2	2	0.2	1	**1.5**	0.6912

Table:2: Numerical values of Nusselt Number(Nu)

Df	Sc	M	Gr	Gc	$\emptyset$	Q_1	γ	K	t	Cf
0.1	0.6	0.2	4	2	0.5	0.5	0.5	1	1	4.0754
1.0	0.6	0.2	4	2	0.5	0.5	0.5	1	1	3.3130
3.0	0.6	0.2	4	2	0.5	0.5	0.5	1	1	1.6188
0.5	0.2	2	2	1	3	1	0.2	**2**	1	4.6374
0.5	0.2	2	2	1	3	1	0.2	**3**	1	4.6949
0.5	0.2	2	2	1	3	1	0.2	**4**	1	4.7269
0.5	0.2	**1**	4	2	2	1	0.2	2	1	5.6784
0.5	0.2	**3**	4	2	2	1	0.2	2	1	4.7173
0.5	0.2	**5**	4	2	2	1	0.2	2	1	4.4896
0.5	0.4	2	4	2	**1**	1	0.2	2	1	5.9426
0.5	0.4	2	4	2	**2**	1	0.2	2	1	4.7966
0.5	0.4	2	4	2	**3**	1	0.2	2	1	4.3953
0.5	0.4	2	4	2	2	**1**	0.2	2	1	4.7966
0.5	0.4	2	4	2	2	**2**	0.2	2	1	5.5624
0.5	0.4	2	4	2	2	**3**	0.2	2	1	6.3281
0.5	0.4	2	4	2	2	2	**5**	2	1	2.9522
0.5	0.4	2	4	2	2	2	**10**	2	1	3.2643
0.5	0.4	2	4	2	2	2	**15**	2	1	3.2865
0.5	0.2	2	4	**1**	2	2	0.2	2	1	5.1573
0.5	0.2	2	4	**2**	2	2	0.2	2	1	5.8547
0.5	0.2	2	4	**3**	2	2	0.2	2	1	6.5520
0.5	0.2	2	**1**	2	2	2	0.2	2	1	3.7353
0.5	0.2	2	**2**	2	2	2	0.2	2	1	4.4417
0.5	0.2	2	**3**	2	2	2	0.2	2	1	5.1482
0.5	0.2	2	4	2	2	2	0.2	2	**0.1**	5.7968
0.5	0.2	2	4	2	2	2	0.2	2	**2**	5.9254
0.5	0.2	2	4	2	2	2	0.2	2	**5**	6.1852
0.5	**0.2**	2	4	2	2	2	0.5	2	1	5.6801
0.5	**0.4**	2	4	2	2	2	0.5	2	1	5.6359
0.5	**0.6**	2	4	2	2	2	0.5	2	1	7.4314

Table:3: : Numerical values of Skin-Friction Coefficient (Cf)

Numerical values of the rate of mass transfer in terms of Sherwood number are shown in table-1.This table displays the effects of chemical reaction ,Schmidt number and time on Sherwood number. From this table we observe that the effect of Schmidt number Sc on Sherwood number is very significant, that is the rate of mass transfer increases with increasing values of Sherwood number Sc and also Shear wood number increases with increasing values of time t and chemical reaction parameter γ.

Numerical values of the rate of heat transfer in terms of Nusselt number Nu are shown in table-2.This table depicts the effects of Dufour number Df, Schmidt number Sc, Radiation absorption parameter Q_1, prandtl number Pr, heat absorption parameter $\emptyset$, Chemical reaction parameter γ and time t on Nusselt number.From this table we observe that the effects of Radiation absorption parameter Q_1, Schmidt number Sc are significant ,that is the rate of heat transfer is decreases significantly with increasing values of $Q_1$and the rate of heat transfer is decreases significantly with increasing values of Sc.In the two cases the heat transfer from fluid to the plate and the effect of heat absorption on Nusselt number Nu is also significant because the rate of heat transfer Nu increases with increasing values of heat absorption parameter $\emptyset$.From this discussion we observe that the heat transfer from the plate to the fluid. Finally the rate of heat transfer decreases with increasing values of Dufour number Df and Chemical reaction parameter γ also the effect heat transfer increases with increasing values of prandtl number Pr and time t.

Numerical values of skin friction coefficient Cf for different fluid flow parameters are depicted in table-3.This table shows that the effects of Dufour number,Radiation absorption parameter and Grashof number on skin friction are very significant. Also we observe that skin friction coefficient Cf decreases rapidly with increasing values of Dufour number and skin friction coefficient Cf increases rapidly with increasing values of Radiation absorption parameter $Q_1$and Grashof number Gr.It is clear that skin friction coefficient Cf increases with the increasing values of time t, Chemical reaction parameter γ, Schmidt number Sc,permeability parameter k and Solutal Grashof number Gc and it decreases with increasing values of heat absorption parameter $\emptyset$ and Magnetic field parameter M.

5. Conclusions

The Unsteady hydromagnetic free convection heat and mass transfer flow through high porous medium bounded by vertical surface has been investigated in the presence of Diffusion-Thermo effect. The resulting partial differential equations have been solved with the help of perturbation technique. The effects of Schmidt number Sc, Magnetic field parameter M, Grashof number Gr,Solutal Grashof number Gc,Radiation absorption parameter Q_1 ,Heat absorption parameter $\emptyset$ chemical reaction parameter γ and permeability parameter Pr on the velocity, temperature and concentration fields ,Skin friction Cf , Nussult number Nu,Sherwood number Sh have been discussed. The conclusions from these results are

1. Due to the uniform magnetic field ,the concentration of the fluid decreases with the increase in chemical reaction parameter γ.It is observe that the effects of destructive reaction on concentration profiles are much more pronounced than that of the generative reaction.
2. The velocity boundary layer becomes thin as Magnetic field parameter M increases but concentration boundary layer becomes thick. Hence velocity profiles become steeper with increasing Magnetic field parameter M,but concentration profiles become less steep.In the presence of the magnetic field, the velocity boundary layer is thinner than the concentration boundary layer but for $M = 0$, an opposite trend is observed.
3. It is noticed that the velocity of the fluid decreases with increasing values of Dufour number, but the temperature is increases with increasing values of Dufour number.
4. The effect of Schmidt number on Sherwood number is considerable.
5. The effects of radiation absorption, Schmidt number, Heat absorption on Nusselt number and the effects of Radiation absorption ,Dufour number, Grashof number on Skin friction coefficient are significant.

Appendix:

Appendix:

h_1=$\gamma + \omega$,h_2=$\emptyset + \omega Pr$, h_3=M+$\frac{1}{K}$, $h_4 = h_3 + \omega$, m_1=$\frac{\mathrm{Sc}+\sqrt{Sc^2}+4Sc\gamma}{2}$, m_2=$\frac{\mathrm{Sc}+\sqrt{Sc^2}+4Sch1}{2}$

A_1=$\frac{Scm_1}{m_1^2-Scm_1-Sch_1}$, $N_1 = 1 + \frac{4}{3N}$, $m_3 = \frac{\mathrm{Pr}+\sqrt{Pr^2}+4N_1\emptyset}{2}$, $A_2 = \frac{-(Q_1+m_1^2Df)}{N_1m_1^2-Prm_1-\emptyset}$, $A_3 = 1 - A_2$

$m_4 = \frac{\mathrm{Pr}+\sqrt{Pr^2}+4N_1h_2}{2}$, $a_1 = Prm_1A_2 - Q_1A_1 - Dfm_1^2$, a_2=$Q_1A_1 + Dfm_2^2$, $a_3 = Prm_3A_3$

$B_1 = \frac{a_1}{N_1m_1^2-Prm_1-h_2}$, $B_2 = \frac{a_2}{N_1m_2^2-Prm_2-h_2}$, $B_3 = \frac{a_3}{N_1m_3^2-Prm_3-h_2}$, $A_4 = -(B_1 + B_2 + B_3)$

$m_5 = \frac{(1+\sqrt{1}+4h_3)}{2}$, $B_4 = \frac{-(GrA_2+Gc)}{m_1^2-m_1-h_3}$, $B_5 = \frac{-(GrA_3)}{m_3^2-m_3-h_3}$, $A_5 = u_p - (1 + B_4 + B_5)$

$m_6 = \frac{(1+\sqrt{1}+4h_4)}{2}$, $b_1 = m_1B_4 - GrB_1 - GcA_1$, $b_2 = GcA_1 - GrB_2$, $b_3 = m_3B_5 - GrB_3$

$b_4 = -GrA_4$, $b_5 = m_5A_5$, $D_1 = \frac{b_1}{m_1^2-m_1-h_4}$, $D_2 = \frac{b_2}{m_2^2-m_2-h_4}$, $D_3 = \frac{b_3}{m_3^2-m_3-h_4}$, $D_4 = \frac{b_4}{m_4^2-m_4-h_4}$

$D_5 = \frac{b_5}{m_5^2-m_5-h_4}$, $A_6 = -(1 + D_1 + D_2 + D_3 + D_4 + D_5)$.

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