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Dufour Effect On MHD Free Convection Flow of Chemically Reactive and Radiation Absorption Fluid Past a Vertical Permeable Moving Plate with Variable Suction

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Abstract

Electrically conducting, chemically reacting and heat generation/absorbing fluid flow through a porous medium is examined over a semi-infinite vertical permeable surface in the presence of a radiation absorption and diffusion-thermo effects. The plate is assumed to move with a constant velocity in the direction of fluid flow. A uniform magnetic field of strength B_0 is applied perpendicular to the porous surface, which absorbs the fluid with a variable suction velocity. The dimensionless governing equations are solved analytically using two term harmonic and non-harmonic functions. The effect of velocity, temperature, concentration, skin friction coefficient, Nusselt number and Sherwood number for different flow parameters are shown in graphical and tabular forms.

Keywords: Chemical reaction; Mass diffusion; Radiation absorption; Diffusion-thermo (Dufour number).

1. Introduction

In nature and industries many transport process exist in which heat and mass transfer takes place simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of Chemical species. Unsteady free convection and mass transfer flows of a viscous fluid through high porous medium play an important role in chemical engineering, petroleum industries, ground water technology, polymer protection and food processing industries. Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have therefore, received a considerable amount of attention in recent years. In process 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 mass transfer occur simultaneously.

Diffusion rates can be altered tremendously by chemical reactions. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion in much faster than chemical reaction, then only chemical reaction factors influences the chemical reaction rate: when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects.

Chabre and Young(1958) have analyzed a first order chemical reaction in the neighborhood of a horizontal plate.Das(1994) et.al.have studied the effects of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Deka et al(1994). Studied the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer.

Muthucumaraswamy and Ganesan (2001) studied effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate. The effect of radiation on MHD flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants , gas turbines and the various propulsion devices for aircraft , missiles , satellites and space vehicles are examples of such engineering areas.

Lighthill(1954) intiated the time-dependent viscous flow problem in which he considered the response of the laminar boundary layer flow of a fixed cylinder body to unsteady fluctuations of the free-stream velocity. Staurt(1955) extended this problem to the case of oscillatory flow over an infinite plate which was subjected to a constant suction velocity when the free stream oscillates in time about a constant mean.Chem(2004) studied heat and mass transfer with variable wall temperature and concentration .In recent years hydromagnetic flows and heat transfer have become more important because of numerous applications, for example,metallurgical processes in cooling of continuous strips through a quiescent fluid ,thermonuclear fusion, aerodynamics , among others. Several studies were continued on magneto hydrodynamic free convection flows past a vertical surface under different physical situations .Predikis and rapits (2006) studied the unsteady MHD flow in the presence of radiation .Kim (2000) presented an analysis of an Unsteady MHD convection flow past a vertical moving plate embedded in a porous medium in the presence of Magnetic field.Comprehensive reviews of porous media ,Thermal/ Species Convection have been presented by Nield and Bejan(2006) and Vafai K(2000).Singh(2003) studied MHD free convection and mass transfer flows with Hall current ,Dissipation and Thermal diffusion.Chamkha(2000) presented Thermal radiation and buoyancy effects on Hydro-Magnetic flow over an acceleratory permeable surface with heat source or sink. Gebhart and pera(1971) have studied the laminar flow which arise in fluids due to the interaction of the force of gravity and density differences caused by the simultaneous diffusion of thermal energy and of chemical species.Rapits et.al.(1981) have studied the steady free convection flow and mass transfer through a porous medium bounded by an infinite vertical plate for the flow near the plate by using the model of Yamamoto and Iwamura (1976).Bestman(1990) examined the natural convection boundary layer with suction and mass transfer in a porous medium. His results confirmed the hypothesis that suction stabilises the boundary layer and affords the most efficient method in boundary layer control yet known. Makinde(2005) examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate. Recently, Ibrahim et al(2005). have studied nonclassical thermal effects in Stokes' second problem for micropolar fluids by using perturbation method. Raptis(1998) investigate the steady flow of a viscous fluid through a high porous medium bounded by a porous plate subjected to a constant suction velocity in the presence of thermal radiation.

The analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electically conducting and heat generation/absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and mass flux are reported in Ibrahim et.al(2008).

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,

Due to the importance of thermal-diffusion and diffusion- thermo effects for the fluids with very light molecular weight as well as medium molecular weight many investigators have studied and reported results for these flows and the contributors such as Eckert and Drake(1972).Dursunkaya and Worek(1992),Anghel et al.(2000),Postelnicu (2004) are worth mentioning .Alam et al.(2006) studied the Dufour and Soret effects on steady MHD free convective heat and mass transfer flow past a vertical porous plate embedded in a porous medium.

The main object of the present investigation is to study the effects of diffusion-thermo, radiation absorption, Chemical reaction, mass transfer and heat source parameter of heat generating fluid past a semi-infinite vertical plate subjected to the 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. Mathematical analysis

Consider an unsteady two-dimensional flow of a laminar, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects and diffusion thermo effects. It is assumed that there is no applied voltage which implies the absence of an electrical field. The fluid properties are assumed to be constant except that the influence of density variation with temperature has been considered only in the body-force term. The chemical reactions are taking place in the flow and all thermophysical properties are assumed to be constant of the linear momentum equation which is approximated according to the Boussinesq approximation. Due to the semi-infinite plane surface assumption, the flow variables are functions of y* and the time t^* only. Under these assumptions, the equations that describe the physical situation are given by

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

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

$$\frac{\partial T^*}{\partial t^*}+\vartheta^*\frac{\partial T^*}{\partial y^*}=\frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{Q_0}{\rho c_p}(T^*-T_\infty)+\frac{{Q_1}^*}{\rho c_p}(C^*-C_\infty)+\frac{D_m K_T}{\rho c_p C_s}\frac{\partial^2 C^*}{\partial y^{*2}} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*}+\vartheta^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C}{\partial y^{*2}}-K_1(C^*-C_\infty) \tag{4}$$

Where x*, y*, and t^* are the dimensional distances along and perpendicular to the plate and dimensional time, respectively. u* and v* are the components of dimensional velocities along x* and y* directions, respectively, $T^*$is the dimensional temperature, C^* is the dimensional concentration, C_w and T_w are the concentration and temperature at the wall, respectively. C_∞ and T_∞ are the free stream dimensional concentration and temperature, respectively. ρ is the fluid density, v is the kinematic viscosity, σ is the fluid electrical conductivity, B_0 is the magnetic induction, K^* is the permeability of the porous medium, Q_0 is the dimensional heat absorption coefficient, Q_1^* is the coefficient of proportionality for the absorption of radiation, D_m is the mass diffusivity,K_T is the thermal diffusion,C_s is the concentration susceptibility,C_p is the specific heat capacity at constant pressure, g is the gravitational acceleration, and β_T and β_C are the thermal and concentration expansion coefficients, respectively and $K_1$is the chemical reaction parameter. The magnetic and viscous dissipations are neglected in this study. The third and fourth terms on the RHS of the momentum equation (2) denote the thermal and concentration buoyancy effects, respectively. Also, the second and third terms on the RHS of the energy equation (3) represents the heat and radiation absorption effects, respectively. It is assumed that the permeable plate moves with a variable velocity in the direction of fluid flow. In addition, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time.

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are

$$u^*=u_p^*\ ,T^*=T_w+\in(T_w-T_\infty)e^{n^*t^*},C^*=C_w+\in(C_w-C_\infty)e^{n^*t^*}.\ y^*=0$$

$$u^*=0,\ T^*\to T_\infty,\ C^*\to C_\infty,\ y^*\to\infty, \tag{5}$$

where u_p^* is the wall dimensional velocity, $n^*$is constant. It is clear from Eq. (1) that the suction velocity at the Plate surface is a function of time only. Assuming that it takes the following exponential form:

$$\vartheta^*=-V_0(1+\in Ae^{n^*t^*}) \tag{6}$$

Where A is a real positive constant, ∈ and ∈A are small less than unity, and V_0 is a scale of suction velocity which has non-zero positive constant. On the introducing the dimensionless quantities:

$$u=\frac{u^*}{V_0},\ v=\frac{v^*}{V_0},\ y=\frac{V_0 y^*}{v},\ t=\frac{V_0^2 t^*}{v},\ u_p=\frac{u_p^*}{V_0},n=\frac{n^* v}{V_0^2},\theta=\frac{T^*-T_\infty}{T_w-T_\infty},C=\frac{C^*-C_\infty}{C_w-C_\infty} \tag{7}$$

In view of the above non-dimensional variables, the basic field Eqs. (2)–(4) can be expressed in non dimensional form as

$$\frac{\partial u}{\partial t}-(1+\in Ae^{nt})\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\left(M+\frac{1}{K}\right)u+Gr\theta+GmC \tag{8}$$

$$\frac{\partial\theta}{\partial t} - (1+\in Ae^{nt})\frac{\partial\theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2\theta}{\partial y^2} - \emptyset\theta + \frac{Q_1C}{Pr} + \frac{Du}{Pr}\frac{\partial^2 C}{\partial y^2} \quad (9)$$

$$\frac{\partial C}{\partial t} - (1+\in Ae^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - \gamma C \quad (10)$$

The boundary conditions are

$$u = u_{p,}\theta = 1+\in e^{nt}, C = 1+\in e^{nt}, on\ y = 0$$
$$u \to 0, \theta \to 0, C \to 0, as\ y \to \infty \quad (11)$$

where Gr is the Grashof number, Gm is the solutal Grashof number, Pr is the Prandtl number, M is the magnetic field parameter, K is the permability parameter, γ is the Chemical reaction parameter, Sc is the Schmidt number, $\emptyset$ is the heat source parameter and Q_1 is the absorption of radiation parameter

$$Gr = \frac{vg\beta_T(T_w - T_\infty)}{V_0^3},\ Gm_= \frac{vg\beta_C(C_w - C_\infty)}{V_0^3}, Pr = \frac{uc_p}{k},\ M = \frac{\sigma B_0^2 v}{\rho V_0^2}, K = \frac{K^* V_0^2}{v^2}, \gamma = \frac{K_1 v}{V_0^2},$$

$$S_c = \frac{v}{D}, \emptyset = \frac{vQ_0}{\rho c_p V_0^2}, Q_1 = \frac{v^2 Q_1^*(C_w - C_\infty)}{kV_0^2(T_w - T_\infty)}, Du = \frac{Dm\mathrm{K_T}(C_w^* - C_\infty^*)}{C_s k(T_w^* - T_\infty^*)}$$

The mathematical statement of the problem is now complete and embodies the solution of Eqs. (8)–(10) subject to boundary conditions (11).

3. Method of solution

Eqs. (8)–(10) represent a set of partial differential equations that cannot be solved in enclosed form. However, it can reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. this can be done by representing the velocity, temperature and the concentration as

$$u(x,t) = u_0(y) + \in e^{nt}u_1(y) + O(\in^2),$$

$$\theta(x,t) = \theta_0(y) + \in e^{nt}\theta_1(y) + O(\in^2), \quad (12)$$

$$C(x,t) = C_0(y) + \in e^{nt}C_1(y) + O(\in^2),$$

Substituting Eqs. 12 into Eqs. (8)–(10), equating the harmonic and non-harmonic terms, and neglecting the higher order of $O(\in^2)$, and simplifying we obtains the following pairs of equations u_0, θ_0, C_0 and u_1,θ_1, C_1.

$$u_0'' + u_0' - (M + \frac{1}{K})u_0 = -Gr\theta_0 - GmC_0 \quad (13)$$

$$\theta_0'' + Pr\theta_0' - Pr\theta_0\emptyset = -Q_1C_0 - D_uC_0'' \quad (14)$$

$$C_0'' + ScC_0' - Sc\gamma C_0 = 0 \quad (15)$$

Subject to the boundary conditions

$$u_0 = u_p,\ \theta_0 = 1,\ C_0 = 1, on\ y = 0 \quad (16)$$

$$u_0 \to 0, \theta_0 \to 0, C_0 \to 0\ \ as\ y \to \infty$$

for O (1) equations, and

$$u_1'' + u_1' - (M + \frac{1}{K} + n)u_1 = -Gr\theta_1 - GmC_1 - Au_0' \tag{17}$$

$$\theta_1'' + Pr\theta_1' - Pr\theta_1(\emptyset + n) = -Q_1C_1 - DuC_1'' - PrA\theta_0' \tag{18}$$

$$C_1'' + ScC_1' - Sc(\gamma + n)C_1 = -AScC_0' \tag{19}$$

With the boundary conditions

$$u_1 = 0, \ \theta_1 = 1, \ C_1 = 1, on\ y = 0 \tag{20}$$

$$u_1 \to 0, \theta_1 \to 0, C_1 \to 0 \ \ as\ y \to \infty$$

Without going into detail, the solutions of Eqs. (13,14,15) and (17,18,19) subject to Eqs. (16), (20) can be shown to be

$$u(x,t) = A_2e^{-m_1y} + A_3e^{-m_2y} + A_4e^{-m_3y} + \in e^{nt}\{A_{10}e^{-m_1y} + A_{11}e^{-m_2y} + A_{12}e^{-m_3y} + A_{13}e^{-m_4y} + A_{14}e^{-m_5y} + A_{15}e^{-m_6y}\} \tag{21}$$

$$\theta(x,t) = e^{-m_2y} + A_1(e^{-m_1y} - e^{-m_2y}) + \in e^{nt}\{A_6e^{-m_1y} + A_7e^{-m_2y} + A_8e^{-m_4y} + A_9e^{-m_5y}\} \tag{22}$$

$$C(x,t) = e^{-m_1y} + \in e^{nt}\{e^{-m_4y} + A_5(e^{-m_1y} - e^{-m_4y})\} \tag{23}$$

The physical quantities of interest are the wall shear stress τ_w and the local surface heat transfer rate q_w.These are defined by

$$\tau_w = \mu(\frac{\partial u^*}{\partial y^*})_{\text{at y=0}} = \rho V_0^2\, u'(0)$$

Therefore, the local friction factor C_f is given by

$$C_f = \frac{\tau_w}{\rho V_0^2} = u'(0)$$

$$= -m_1A_2 - m_2A_3 - m_3A_4 + \in e^{nt}(-m_1A_{10} - m_2A_{11} - m_3A_{12} - m_4A_{13} - m_5A_{14} - m_6A_{15})\,. \tag{24}$$

The local surface heat flux is given by

$$q_w = -k(\frac{\partial T^*}{\partial y^*})_{\text{ at y=0}}, \tag{25}$$

Where k is the effective thermal conductivity, together with the definition of the local Nusselt number

$$Nu_x = \frac{q_w}{T_w - T_\infty}\frac{x}{k} \tag{26}$$

One can write

$$\frac{Nu}{Re_x} = -\theta'(0) = m_2 + A_1(m_1 - m_2) + \in e^{nt}(m_1A_6 + m_2A_7 + m_4A_8 + m_5A_9)\,, \tag{27}$$

Where $Re_x = \frac{V_0x}{v}$ is the local Reynolds number.

The local Sherwood number is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{at\ y=0} = m_1 + \in e^{nt}\{m_4(1 - A_5) + A_5m_1\} \tag{28}$$

4. Results and discussion:

Numerical evaluation of the analytical results reported in the previous section was performed and a representative set of results is reported graphically in Figs. 1–14. These results are obtained to illustrate the influence of the Diffusion thermo parameter(Du) the chemical reaction parameter γ , the absorption radiation parameter Q_1, the Schmidt number Sc the heat absorption coefficient $\emptyset$, the magnetic field parameter M and permeability parameter K on the velocity, temperature and the concentration profiles, while the values of the physical parameters are fixed at real constants, A = 0.5, $\in$ = 0.2, the frequency of oscillations n = 0.1, scale of free stream velocity u_p = 0.5, Prandtl number Pr = 0.71 and t = 1.0.

The concentration profiles for different values of chemical reaction parameter γ are presented in figure1.It is observed that the concentration increases as $\gamma(\leq 0)$ increases i.e., generative reaction and the concentration boundary layer thickness decreases as the chemical reaction parameter $\gamma(\geq 0)$ increases i.e,. destructive reaction.

Figure 2 displays the effects of Schmidt number Sc on the concentration. It is found that the concentration decreases with an increase in Sc.

Figure.3.depicts the effect of Chemical reaction parameter (γ) on the fluid temperature in the boundary layer ,it is observed that the temperature increases with increasing Chemical reaction parameter (γ) in the Vicinity of the plate and exhibits opposite trend away from the plate (i.e. nearly at y$\geq$ 0.4).Also it is interesting to note that in the presence of Diffusion thermo effect the thermal boundary layer thickness increasing with increasing γ near the plate when D$u \neq 0$.where as it decreasing when Du=0 while was also observe by Ibrahim(2008).

The influence of the absorption radiation parameter Q_1 on the temperature and velocity profiles near a uniformly moving plate are illustrated in figures 4 &9. it is seen that an increase in the absorption radiation parameter (Q_1) produces significant increase in the temperature and velocity profiles with in the boundary layer , as well as an increasing in the thermal and hydrodynamic boundary layer thickness. This is because the large absorption radiation parameter(Q_1) values correspond to an increased dominance of conduction over absorption radiation there by increasing buoyancy force and thickness of the thermal and momentum boundary layers.

Temperature and velocity profiles for different values of Schmidt number (Sc) are presented in figures 5 & 10. It is noticed that the temperature and velocity decreases fastly with an increase in the values of Schmidt number(Sc). It is also observed that the velocity is maximum near the plate and it is shifting towards the plate with increasing Sc and decreases exponentially away from the plate.

The effect of the heat absorption (Q_1 >0) and heat generation ($\emptyset < 0$) on the temperature field is shown in fig 6.It is clear that the boundary layer causes the energy level to decrease and thus the temperature of the field decreases. on the other hand, in the presence of heat generation within the boundary layer produces the opposite effect and thus the temperature of the fluid increases .

The influence of diffusion thermo parameter Du on temperature profiles is depicted in figure 7. it is noticed that the thermo diffusion effect on the temperature is highly significant, as the temperature profiles in the presence of diffusion are higher in comparison to absence of dufour effect. Fluid temperature increases with the increase in the Dufour number and hence the magnitudes of temperature profiles are higher in the presence of thermo diffusion. Thermal boundary layer thickness increase considerably in the presence of Dufour effect.

It is seen that the velocity decreases in the values of chemical reaction parameter (γ) .The maximum Velocity attains near the plate and slowly decreases to free stream are shown in figure 8..

The influence of heat absorption parameter $\emptyset$ on the velocity profiles is presented in figure 11 .It is noticed that the velocity decreases with increasing heat absorption parameter ($\emptyset > 0$).

The effect of increasing the magnetic field strength on the momentum boundary layer thickness is illustrated in figure 12. It is clear that the magnetic field presents a damping effect on the velocity field by creating a drag force that opposes the fluid motion causing the velocity to decrease.Also it is noticed that the boundary layer thickness decreases considerably on introduction of the magnetic field.The point of maximum velocity which occurs near the moving plate is shifting towards the palte with an increasing in the magnetic field intensity (M).

The velocity profiles for different values of the permeability parameter K are depicted in figure.13 .It is observed that, the velocity increases as the permeability parameter K increases. The parameter K is directly proportional to the actual permeability $K^*$of the porous Medium. Hence an increase in K will decrease the resistance of the porous medium which will tend to accelerate the flow and increase the velocity.

Figure 14.depicts the diffusion thermo effect on velocity field. It is seen that the velocity field is influenced considerably by the diffusion thermo effect as the velocity profiles are higher in Comparison to the absence of Dufour effect.Also it is noticed that the momentum boundary layer thickness increases with the increase in dufour number.

Graphs

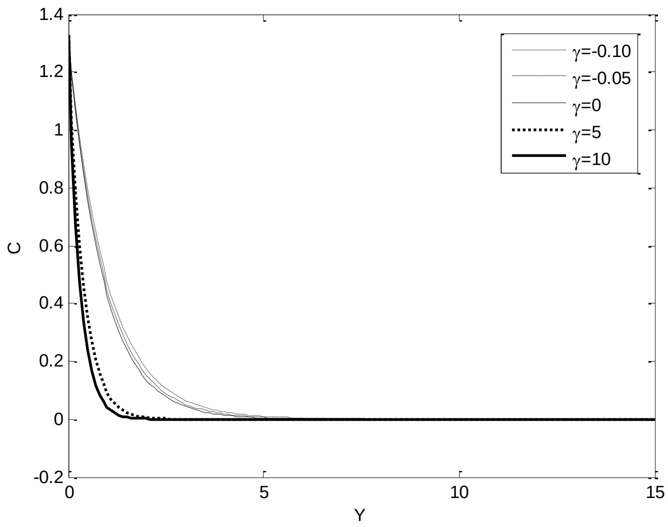

Fig: 1 Concentration profiles against spanwise coordinate y for different values of (Chemical reaction parameter gamma) with
$Gr = 4; Gm = 2\ ;\ Sc = 0.78;\ K = 2; M = 2; \emptyset = 2; Q_1 = 2; n = 0.5; A = 2; Pr = 0.71; t = 1;$
$\in= 0.2; Du = 0.5.$

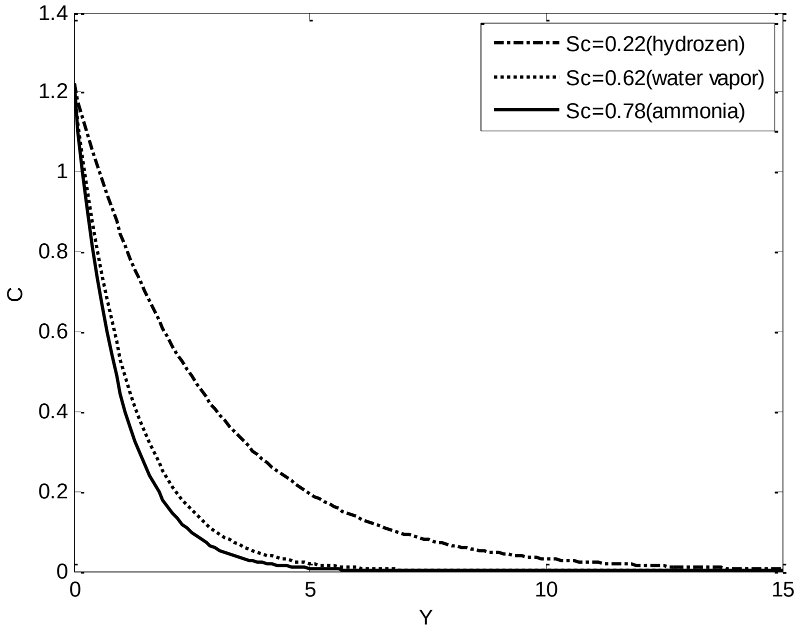

Fig:2 Concentration profiles against spanwise coordinate y for different values of(the Schmidt number S_c) with $Gr = 4; Gm = 2; K = 2; M = 2; \emptyset = 2; Q_1 = 2; n = 0.1; A = 0.5; Pr = 0.71; t = 1;$ $\in= 0.2; Du = 0.5; \gamma = 0.2;$

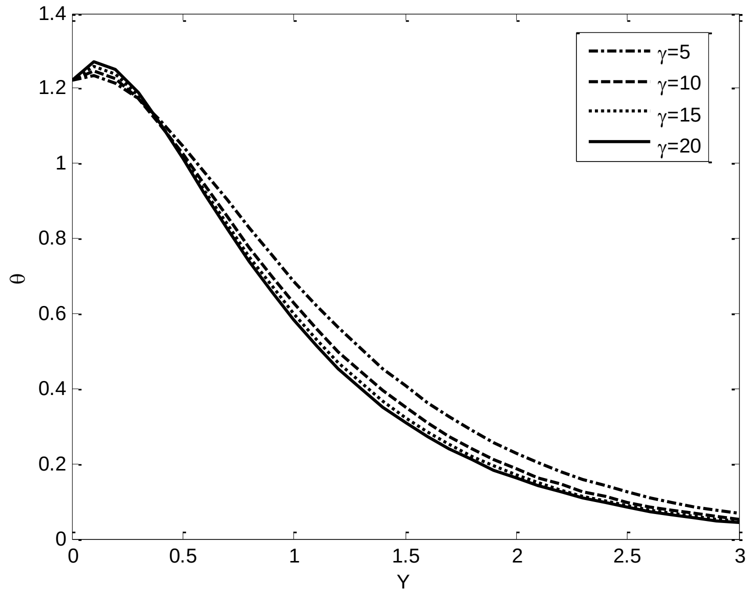

Fig:3 Temperature profiles against spanwise coordinate y for different values of (Chemical reaction parameter γ) with $Gr = 2; Gm = 1; Q_1 = 2; K = 0.5; M = 0.2; \emptyset = 1$ and $Sc = 0.6;$ and $Du = 0.5.$

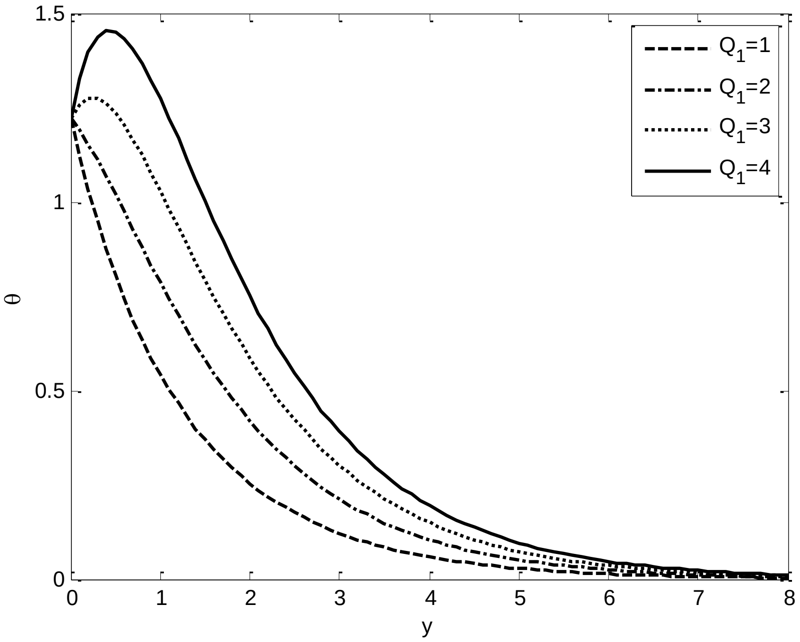

Fig: 4 Temperature profiles against spanwise coordinate y for different values of (absorption radiation parameterQ_1) with $Gr = 10; Gm = 2; \gamma = 0.5; K = 0.5; M = 2; \emptyset = 2\ and\ Sc = 0.4; and\ Du = 0.5$.

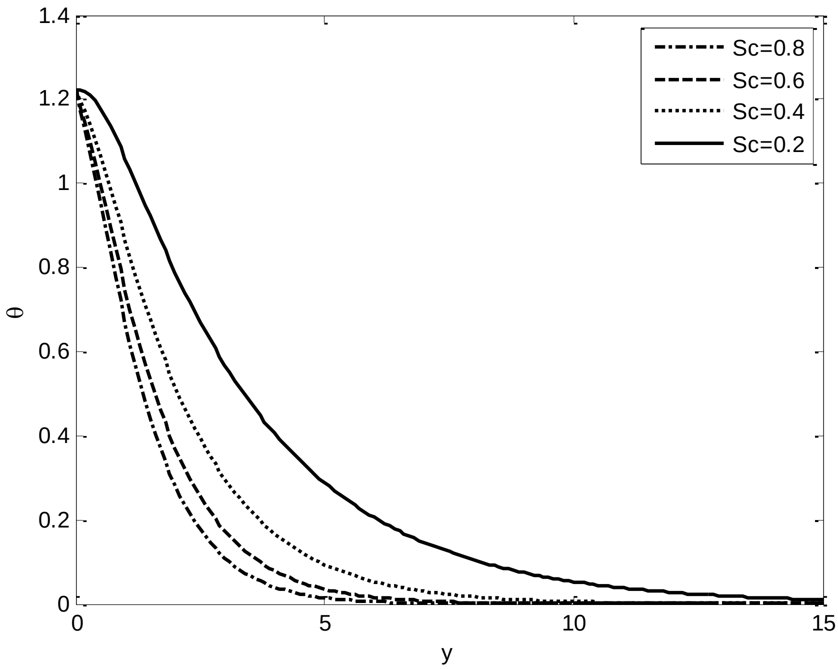

Fig:5. Temperature profiles against spanwise coordinate y for different values of (Schmidt numberSc) with $Gr = 4; Gm = 2; Q_1 = 2; K = 2; M = 2; \emptyset = 2; \gamma = 0.2 and\ Du = 0.5$.

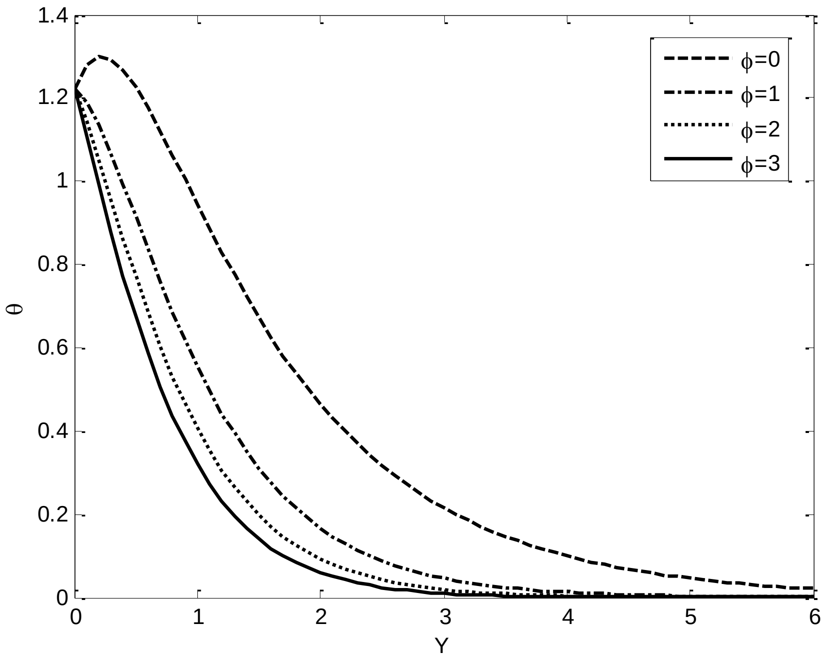

Fig:6. Temperature profiles against spanwise coordinate y for different values of (Heat absorption parameter ∅) with $Gr = 4; Gm = 2; Q_1 = 0.5; K = 0.5; M = 2;\ \gamma = 5\ Sc = 0.8; and\ Du = 0.5$.

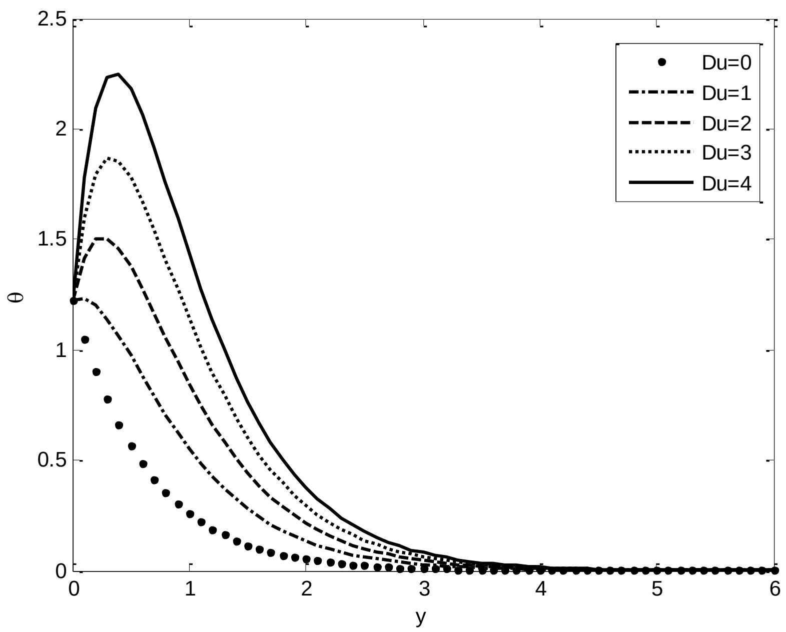

Fig:7. Temperature profiles against spanwise coordinate y for different values of Dufour effect with $Gr = 4; Gm = 2; Q_1 = 0.5; K = 0.5; M = 2;\ \gamma = 5\ ; Sc = 0.8; \gamma = 5; and\ \emptyset = 2$.

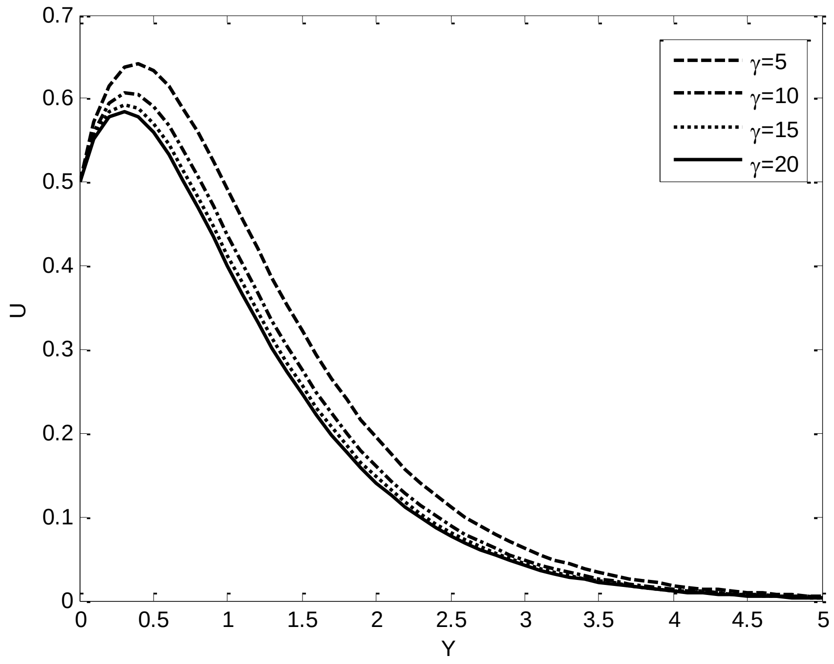

Fig:8. Velocity profiles against spanwise coordinate y for different values of (Chemical reaction parameter γ) with $Gr = 2; Gm = 1; Q_1 = 2; \emptyset = 1; K = 0.5; M = 0.2;\ \ Sc = 0.6; and\ Du = 0.5$.

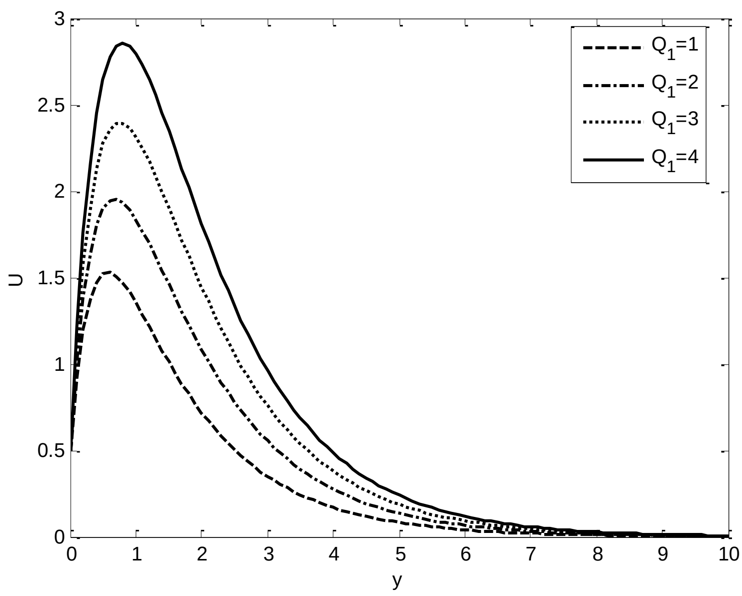

Fig: 9. Velocity profiles against spanwise coordinate y for different values of (absorption radiation parameterQ_1) with $Gr = 10; Gm = 2; \gamma = 0.5; K = 0.5; M = 2; \emptyset = 2\ and\ Sc = 0.4; and\ Du = 0.5$

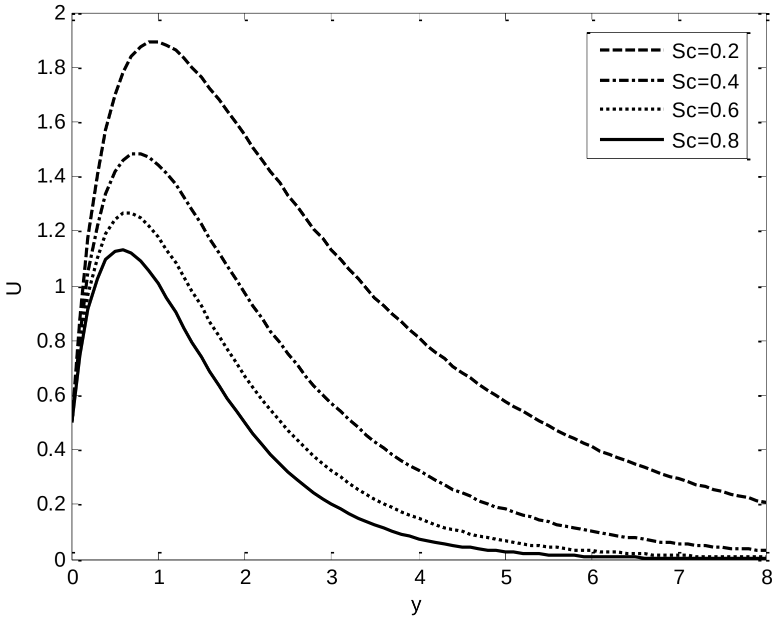

Fig: 10. Velocity profiles against spanwise coordinate y for different values of (Schmidt number Sc) with $Gr = 4; Gm = 2; Q_1 = 2; K = 2; M = 2; \emptyset = 2; \gamma = 0.2 and\ Du = 0.5$.

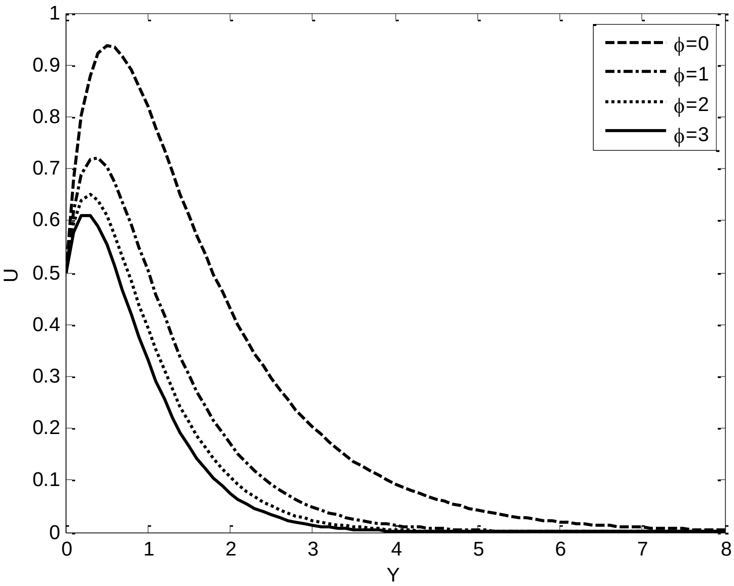

Fig:11. Velocity profiles against spanwise coordinate y for different values of (Heat absorption parameter $\emptyset$) with $Gr = 4; Gm = 2; Q_1 = 0.5; K = 0.5; M = 2;\ \gamma = 5\ ; Sc = 0.8; n = 0.1; A = 0.5; \in = 0.2; Pr = 0.71 and\ Du = 0.5$.

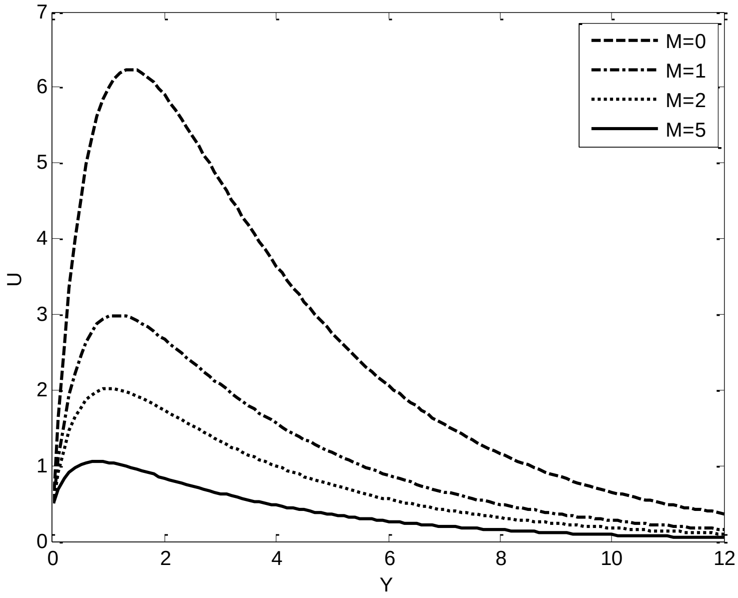

Fig: 12. velocity profiles against spanwise coordinate y for different values of (Magnetic parameter M) with $Gr = 4; Gm = 2; Q_1 = 2; \emptyset = 2; K = 2;\ \gamma = 0.1;\ Sc = 0.2; and\ Du = 0.5.$

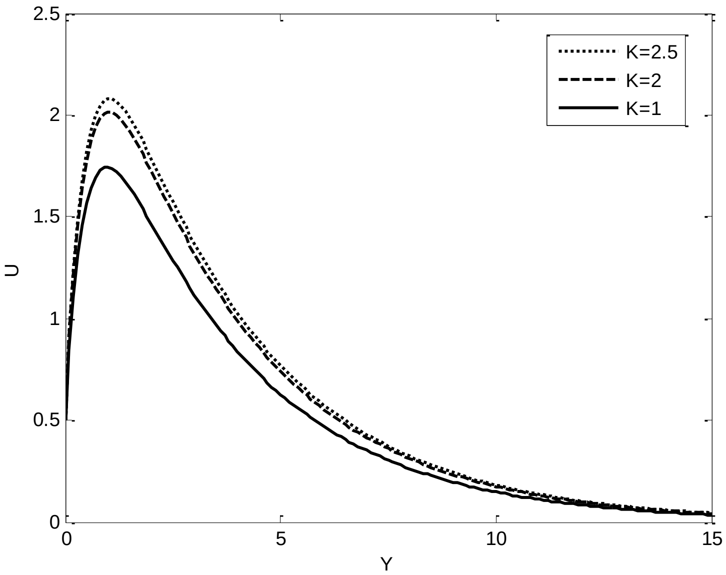

Fig: 13. velocity profile against spanwise coordinate y for different values of (Permeability parameter K) with $Gr = 4; Gm = 2; Q_1 = 2; K = 0.5; M = 2;\ \gamma = 0.1;\ Sc = 0.2; \emptyset = 2; and\ Du = 0.5.$

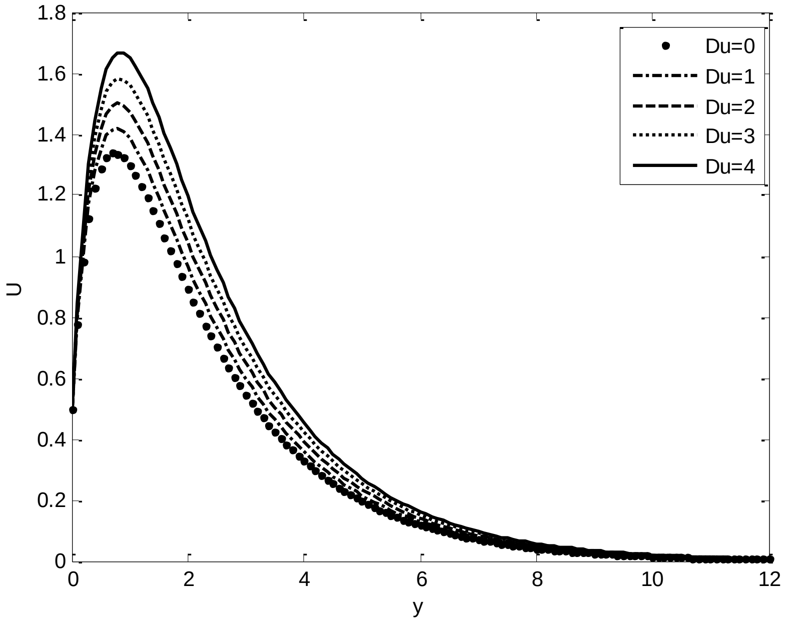

Fig:14.velocity profiles against spanwise coordinate y for different values of Dufour effect with

$$Gr = 4; Gm = 2; Q_1 = 2; K = 1; M = 2;\ \gamma = 0.1;\ Sc = 0.4; \emptyset = 2; and\gamma = 0.1.$$

Sc	t	γ	Sh
0.22	1	0.2	0.4493
0.62	1	0.2	1.0184
0.78	1	0.2	1.2379
0.22	**0.1**	0.2	0.4405
0.22	**2**	0.2	0.4600
0.22	**5**	0.2	0.4996
0.22	1	**-0.05**	0.2199
0.22	1	**0**	0.3033
0.22	1	**5**	1.4376

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

Du	Sc	M	Gr	Gm	$\emptyset$	Q_1	γ	K	t	Cf
0.1	0.6	0.2	2	1	1	2	0.5	0.5	1	1.2889
1.0	0.6	0.2	2	1	1	2	0.5	0.5	1	1.5765
3.0	0.6	0.2	2	1	1	2	0.5	0.5	1	2.2156
0.5	0.6	0.2	2	1	1	2	**5**	0.5	1	0.8822
0.5	0.6	0.2	2	1	1	2	**10**	0.5	1	0.7623
0.5	0.6	0.2	2	1	1	2	**15**	0.5	1	0.7065
0.5	0.4	2	10	2	2	**1**	0.5	0.5	1	4.9687
0.5	0.4	2	10	2	2	**2**	0.5	0.5	1	6.0438
0.5	0.4	2	10	2	2	**3**	0.5	0.5	1	7.1188
0.5	**0.2**	2	4	2	2	2	0.2	2	1	4.3322
0.5	**0.4**	2	4	2	2	2	0.2	2	1	3.6105
0.5	**0.6**	2	4	2	2	2	0.2	2	1	3.1633
0.5	0.8	2	4	2	**0**	0.5	5	0.5	1	2.1638
0.5	0.8	2	4	2	**1**	0.5	5	0.5	1	1.5118
0.5	0.8	2	4	2	**2**	0.5	5	0.5	1	1.2410
0.5	0.2	**0**	4	2	2	2	0.1	2	1	12.1750
0.5	0.2	**1**	4	2	2	2	0.1	2	1	6.4968
0.5	0.2	**2**	4	2	2	2	0.1	2	1	4.5298
0.5	0.2	2	4	2	2	2	0.1	**1**	1	3.9203
0.5	0.2	2	4	2	2	2	0.1	**2**	1	4.5298
0.5	0.2	2	4	2	2	2	0.1	**2.5**	1	4.6725
0.5	0.2	2	4	2	2	2	0.1	2	**0.1**	4.4452
0.5	0.2	2	4	2	2	2	0.1	2	**2.0**	4.6332
0.5	0.2	2	4	2	2	2	0.1	2	**5.0**	5.0133

Table-2: **Numerical values of Nussulet Number(Nu)**

Du	Sc	$\emptyset$	Q_1	γ	t	Nu
0.1	0.6	1	2	0.5	1	-0.0765
1.0	0.6	1	2	0.5	1	-0.7592
3.0	0.6	1	2	0.5	1	-2.2765
0.5	0.6	1	2	**5**	1	-0.3273
0.5	0.6	1	2	**10**	1	-0.5490
0.5	0.6	1	2	**15**	1	-0.7724
0.5	0.4	2	**1**	0.5	1	1.0406
0.5	0.4	2	**2**	0.5	1	0.2727
0.5	0.4	2	**3**	0.5	1	-0.4952
0.5	**0.2**	2	2	0.2	1	-0.0661
0.5	**0.4**	2	2	0.2	1	0.1820
0.5	**0.6**	2	2	0.2	1	0.3146
0.5	0.8	**0**	0.5	5	1	-0.8012
0.5	0.8	**1**	0.5	5	1	0.1658
0.5	0.8	**2**	0.5	5	1	0.7017
0.5	0.8	2	0.5	5	**0.1**	0.6890
0.5	0.8	2	0.5	5	**2.0**	0.7173
0.5	0.8	2	0.5	5	**5.0**	0.7744

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

The numerical values of the rate of mass transfer coefficient at the plate in terms of Sherwood number Sh for different values of Sc, t and γ are shown in Table 1.It is noticed that Sherwood number Sh increases with the increasing values of Schmidt number Sc or time t or Chemical reaction parameter γ .Also it is observed that the effect of Schmidt number Sc and Chemical reaction parameter γ on Sherwood number Sh are significant.

The numerical values of the rate of heat transfer coefficient at the plate interms of Nusselt number Nu for different values of Schmidt number Sc, Heat absorption $\emptyset$,Radiation absorption Q_1,Chemical reaction parameter γ and time t are shown in Table 2. It is clear that Nusselt number Nu increases with the increasing values of Schmidt number Sc or Heat absorption $\emptyset$ or time t and Nusselt number Nu decreases with the increasing values of Dufour number Du or Chemical reaction parameter γ or Radiation absorption Q_1.Also it is observed that the effect of Radiation absorption Q_1 and Heat absorption $\emptyset$ on Nussult number Nu are significant.

The numerical values of Skin friction coefficient Cf for different values of Schmidt number Sc, Magnetic field parameter M ,Grashof number Gr, Solutal Grashof number Gm , Heat absorption parameter $\emptyset$,Radiation absorption Q_1, Chemical reaction parameter γ,Permeability parameter K and time t are shown in table 3.It is observed that the Skin friction coefficient Cf increases with the increasing values of Dufour number Du or Chemical reaction parameter γ, Permeability parameter K or time t and it decreases with the increasing values of Radiation absorption Q_1 or Schmidt number Sc or Heat generation parameter $\emptyset$ or Chemical reaction parameter γ or Magnetic field parameter M. Also it is observed that the effect of Dufour number Du and

Radiation absorption Q_1 and Heat absorption parameter $\emptyset$ and Magnetic field parameter M and time t are significant.

Appendix:

$$m_1 = \frac{(S_c + \sqrt{S_c^2 + 4\gamma S_c})}{2}, m_2 = \frac{(P_r + \sqrt{P_r^2 + 4\emptyset P_r})}{2}, m_3 = \frac{(1 + \sqrt{1+4}(M + \frac{1}{K}))}{2}, m_4 = \frac{(S_c + \sqrt{S_c^2 + 4(\gamma+n)S_c})}{2},$$

$$m_5 = \frac{(P_r + \sqrt{P_r^2 + 4P_r(\emptyset+n)})}{2}, m_6 = \frac{(1+\sqrt{1+4}(M+\frac{1}{K}+n))}{2}$$

$$A_1 = \frac{-(Q_1 + Dm_1^2)}{(m_1^2 - P_r m_1 - P_r\emptyset)}, A_2 = \frac{-(G_m + AG_r)}{(m_1^2 - m_1 - (M+\frac{1}{K}))}, A_3 = \frac{G_r(A_1 - 1)}{(m_2^2 - m_2 - (M+\frac{1}{K}))}, A_4 = u_p - (A_2 + A_3)$$

$$A_5 = \frac{m_1 A S_c}{m_1^2 - m_1 S_c - S_c(\gamma+n)}, A_6 = \frac{(AA_1 P_r m_1 - Q_1 A_5 - DA_5 m_1^2)}{m_1^2 - P_r m_1 - P_r(\emptyset+n)}, A_7 = \frac{AP_r m_2(1 - A_1)}{(m_2^2 - P_r m_2 - P_r(\emptyset+n))},$$

$$A_8 = \frac{Q_1 A_5 - Q_1 - Dm_4^2 + Dm_4^2 A_5}{m_4^2 - P_r m_4 - P_r(\emptyset+n)}, A_9 = 1 - (A_6 + A_7 + A_8), A_{10} = \frac{AA_2 m_1 - G_r A_6 - G_m A_5}{(m_1^2 - m_1 - (M+\frac{1}{K}+n))}$$

$$A_{11} = \frac{AA_3 m_2 - G_r A_7}{(m_2^2 - m_2 - (M+\frac{1}{K}+n))}, A_{12} = \frac{AA_4 m_3}{(m_3^2 - m_3 - (M+\frac{1}{K}+n))}$$

$$A_{13} = \frac{A_5 G_m - G_m - G_r A_8}{(m_4^2 - m_4 - (M+\frac{1}{K}+n))}, A_{14} = \frac{-G_r A_9}{(m_5^2 - m_5 - (M+\frac{1}{K}+n))}, A_{15} = -(A_{10} + A_{11} + A_{12} + A_{13} + A_{14})$$

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