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THERMAL DIFFUSION AND DIFFUSION THERMO EFFECTS ON MHD FLOW OF A CHEMICALLY REACTING FLUID PAST A POROUS PLATE WITH TIME DEPENDANT TRANSPIRATION VELOCITY AND HALL CURRENT

Kotagiri Srihari

Department of Mathematics, MGIT, Gandipet, Hyderabad

Abstract

Effects of Soret, Dufour and Chemical reaction on unsteady free-convection flow of an electrically conducting viscous incompressible fluid along an infinite vertical porous plat subjected to a time dependant transpiration velocity with Hall Effect is analyzed. A magnetic field is applied perpendicular to the flow. The governing equations in non-dimensional form are solved using implicit finite difference method. Graphical results for velocity, temperature and concentration fields and tabular values of shearing stresses are presented and discussed. It is found that main and secondary velocity of the fluid and shearing stresses increase with the increasing values of Soret and Dufour. Soret and Dufour effects greatly influence the concentration and temperature profiles in the thermal and solutal boundary layers.

Keywords

Hall effect; Magnetic field, Soret and Dufour; Chemical reaction, Finite-difference technique.

1 Introduction

Due to the gyration and drift of charged particles, the conductivity parallel to the electric field is reduced and the current is induced in the direction normal to both electric nd magnetic fields. This phenomenon is known as the "Hall Effect". In many works on plasma physics, the Hall Effect is ignored when the strength of applied magnetic field is very strong and the number density of electrons is small, the Hall Effect cannot be disregarded as it has a significant effect on the flow pattern of an ionized gas. The effect of Hall currents on the fluid with variable concentration has a lot of applications in MHD power generators, several astrophysical and meteorological studies as well as in flow of plasma through MHD power generators. From the point of applications, this effect can be taken into account within the range of magneto hydro dynamical approximation. Even though it is of considerable importance to study how the results of the hydro dynamical problems get modified by the effects of Hall currents. A broad discussion of Hall currents is given by Cowling [1]. Soundalgekar and Uplekar [2] analyzed Hall effects in MHD Couette flow with heat transfer. Hiroshi Sato [3] has studied the effect of Hall currents on the steady hydro magnetic flow between two parallel plates. Masakazu Katagiri [4] studied the steady incompressible boundary layer flow past a semi infinite flat plate in a transverse magnetic field at small magnetic Reynolds number considering with the effect of Hall current. On the other hand Hossain [5] studied the unsteady flow of incompressible fluid along an infinite vertical porous flat plate subjected to suction/injection velocity proportional to $(time)^{-\frac{1}{2}}$. Hossain *et al* [6] investigated the effect of Hall current on the unsteady free-convection flow of a viscous incompressible fluid with mass transfer along a vertical porous plate subjected to a time dependant transpiration velocity when the constant magnetic field is applied normal to the flow. Srigopal Agarwal [7] discussed the effect of Hall current on the unsteady hydromagnetic flow of viscous stratified fluid through a porous medium in the presence of free-convection currents. Rajashaker *et al* [8] studied the effect of Hall current on free convection and mass transfer flow through a porous medium bounded by an infinite vertical porous plate, when the plate was subjected to a constant suction velocity and heat flux. Biswal *et al* [9] discussed the Hall-effect on oscillatory hydromagnetic free convective flow of a visco-elastic fluid past an infinite vertical porous flat plate with mass transfer Ajay Kumar Singh [10] made an attempt to study the steady MHD free-convection and mass transfer flow with Hall current, viscous dissipation and joule heating, taking into account the thermal diffusion effect.. Sriramulu *etal* [11] studied the effect of Hall current on MHD flow and heat transfer along a porous plate with mass transfer numerically. In addition to this, Srihari *etal* [12] analyzed the effects of Source/Sink on free-convective MHD flow and mass transfer of an electrically conducting viscous incompressible fluid along an infinite vertical porous plate with hall current effect. Sharma and Chaudhary [13] reported the effect of Hall current on hydromagnetic unsteady mixed convection and mass transfer flow past a vertical porous plate immersed in a porous medium. Satyanarayana et al. [14] studied the steady magneto-hydrodynamic free convection viscous incompressible fluid flow past a semi infinite vertical porous plate with mass transfer and Hall current.

In nature and technology, many transport processes can be found in different ways in which the heat and mass transfer occur due to buoyancy forces which are caused by temperature and differences. When heat and mass transfer occurs simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are more intricate nature. Energy fluxes are generated by both temperature and concentration gradients. The energy flux is created by a composition gradient is called as Dufour effect whereas mass fluxes caused by temperature a gradients known as Soret effect. Such effects play an important role when density differences exist in the flow regime. For example, when species are introduced at a surface in a fluid domain, both Soret and Dufour effects are become influential, with a different (lower) density than the surrounding fluid. In heat and mass transfer problems, Soret and Dufour effects are very important for intermediate molecular weight gases in fluid binary systems, which are often encountered in high-speed aerodynamics and chemical process engineering. In view of these applications, ,Dursunkaya and Worek [15], Anghel et al. [16] discussed the Soret and Dufour effects on transient and steady natural convection flow from vertical surface. Postelnicu [17] studied the effects of a magnetic field, Soret and Dufour on heat and mass transfer by natural convection from vertical surfaces in porous media. Sparrow et al. [18] reported the effects of transpiration induced buoyancy, Soret and Dufour effects in a helium–air free convection boundary layer flow. Dursunkaya and Worek [19] studied the Soret and Dufour effects on transient and steady natural convection flow from a vertical surface. Alam and Rahman [20] studied the Dufour and Soret effects on steady magneto-hydrodynamic free convective heat and mass transfer flow past a semi-infinite vertical porous plate. Alam and Rahman [21] investigated the Dufour and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction. The effects of temperature dependent viscosity, Soret and Dufour number variations on free convective heat and mass transfer flow over a vertical isothermal flat plate is studied by Afify [22]. Soret and Dufour effects on steady hydromagnetic free convective boundary layer flow past a semi-infinite moving vertical plate embedded in a porous medium, taking viscous dissipation term into account was examined Reddy and Reddy [23]. Hydro-magnetic mixed convection flow past a vertical plate embedded in a porous medium with Soret and Dufour effects was discussed by Olanrewaju et al. [24], Makinde [25] and Sharma et al. [26].

In the above all stated studies, the effects of Soret and Dufour on unsteady flow along porous flat pl*a*te subjected to a time dependant transpiration velocity is not investigated when the magnetic field taken place in the direction of normal to the flow. And also Combined heat and mass transfer problems with chemical reaction are of significance in many processes and have received a substantial amount of interest in recent years. In processes such as evaporation at the surface of water body, drying, energy transfer in wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. So, the objective present investigation is to study the effects of Soret, Dufour and chemical reaction on free convective flow of an electrically conducting, viscous incompressible fluid along an infinite vertical porous plate subjected to a time dependant transpiration velocity with Hall Effect is analyzed. Magnetic field is applied normal to the flow.

To describe the physics of the problem, the present non-linear boundary value problem is solved numerically using implicit finite difference formulae.

2 Formulation of the problem

An unsteady free-convection flow of an electrically conducting viscous incompressible fluid with mass transfer along an infinite vertical porous plate has been considered. The flow is assumed to be in x' - direction, which is taken along the plate in upward direction. The y' axis is taken to be normal to the direction of plate. At time $t \geq 0$, the temperature and the species concentration at the plate are raised to $T_w\ (\neq T_\infty)$ *and* $C_w\ (\neq C_\infty)$ and are maintained uniform thereafter. It is also assumed that the species concentration level is very low and hence species thermal diffusion as well as diffusion thermal energy effects are neglected. A magnetic field of uniform strength is assumed normal to the porous plate. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field can be neglected. The equation of conservation of electric charge $\nabla . J = 0$ *gives* j_y=constant, where $J = (j_x, j_y, j_z)$.It is further assumed that the plate is non-conducting. This implies $j_y = 0$ at the plate and hence zero everywhere. When the strength of magnetic field is very large the generalized Ohm's law, in the absence of electric field takes the following form:

$$J + \frac{\omega_e \tau_e}{B_0} J \times B = \sigma\left(\mu_e V \times B + \frac{1}{en_e} \nabla P_e\right) \tag{1}$$

Where V is the velocity vector, σ is the electric conductivity, μ_e is the magnetic permeability, ω_e is the electron frequency, τ_e is the electron collision time, e is the electron charge, n_e is the number density of the electron and P_e is the electron pressure. Under the assumption that the electron pressure (for weakly ionized gas), the thermo-electric pressure and ion-slip are negligible, equation (1) becomes:

$$J_x = \frac{\sigma \mu_e B_0}{1+m^2}(mu - w) \text{ and } j_z = \frac{\sigma \mu_e B_0}{1+m^2}(u + mw) \tag{2}$$

Where u is the x component of V, w is the z component of V and $m(= w_e \tau_e)$ is the Hall parameter.

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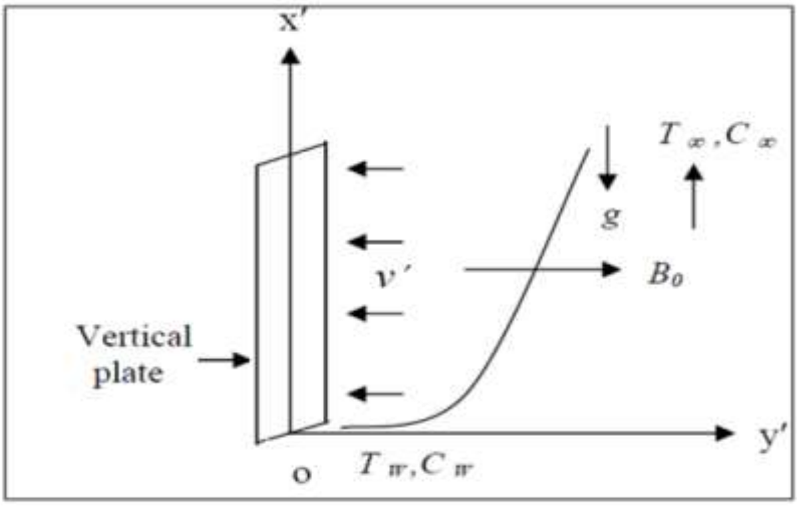

Fig 1(a) : Schematic diagram of flow geometry

Within the above framework, the problem is governed by the following non-dimensional equations under the usual Boussinesq approximations;

$$\frac{\partial v}{\partial y} = 0 \tag{3}$$

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \frac{M}{1+m^2}(u + mw) + Gr\theta + GmC \tag{4}$$

$$\frac{\partial w}{\partial t} + v\frac{\partial w}{\partial y} = \frac{\partial^2 w}{\partial y^2} - \frac{M}{1+m^2}(w - mu) \tag{5}$$

$$\frac{\partial \theta}{\partial t} + v\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} + Du\frac{\partial^2 C}{\partial y^2} \tag{6}$$

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + So\frac{\partial^2 C}{\partial y^2} - Ch.C \tag{7}$$

with corresponding boundary conditions

$$t \le 0: \quad u=0,\ w=0,\ T=0, C=0 \ \text{for all}\ y$$

$$t>0: \begin{cases} u=0,\ w=0,\ \theta=1,\ C=1 & at\ y=0 \\ u=0,\ w=0,\ \theta=0,\ C=0 & as\ y\to\infty \end{cases} \tag{8}$$

From equation (3), it is seen that v is either constant or a function of time t. Similarity solutions of equations (4)-(7) with the boundary conditions (8) exist only if we choose the following

$$v = -\lambda t^{\frac{-1}{2}} \tag{9}$$

Where, λ is a non-dimensional transpiration parameter and t is a time, which is small,

$$t = \frac{t' U_0^2}{\upsilon},\ y = \frac{y' U_0}{\upsilon},\ u = \frac{u'}{U_0},\ v = \frac{v'}{U_0},\ w = \frac{w'}{U_0},$$

$$\theta = \frac{(T - T_\infty)}{(T_w - T_\infty)},\ C = \frac{(C' - C_\infty)}{(C'_w - C_\infty)},\ So = \frac{D_m k_T (T_w - T_\infty)}{\upsilon T_m (C_w - C_\infty)},\ \text{(Soret number)}$$

$$Du = \frac{D_m k_T (C_w - C_\infty)}{\upsilon C_S C_P (T_w - T_\infty)}\ \text{(Dufour number)},\quad M = \frac{\sigma \mu_e^2 B_0^2 \upsilon}{\rho U^2}\ \text{(Magnetic parameter)},$$

$$\Pr = \frac{\mu c_p}{k}\ \text{(Prandtl number)},\ Sc = \frac{\upsilon}{D}\ \text{(Schmidth number)},$$

$$Gr = \frac{\upsilon g \beta (T_w - T_\infty)}{U^3}\ \text{(Grashof number)},\ Ch = \frac{k_r'^2 \upsilon}{U_0^2},\ \text{(Chemical reaction parameter)}$$

$$Gm = \frac{\upsilon g \beta^* (C_w - C_\infty)}{U^3}$$ (Modified Grashof number) and g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, β^* is the coefficient of volume expansion with species concentration, T is the temperature of the fluid within the boundary layer, C' is the species concentration, $\rho, \mu, \upsilon, k, c_p$ are respectively density, viscosity, kinematics viscosity, thermal conductivity, specific heat at constant pressure and D is the chemical molecular diffusivity. For suction, $\lambda > 0$ and for blowing $\lambda < 0$.

3 Method of solution

Substituting following finite difference formulae, $\frac{\partial G}{\partial t} = \frac{G_i^{j+1} - G_i^j}{\Delta t}$, $\frac{\partial G}{\partial y} = \frac{G_{i+1}^j - G_i^j}{\Delta y}$

$$\frac{\partial^2 G}{\partial y^2} = \frac{1}{2}\left(\frac{G_{i-1}^j - 2G_i^j + G_{i+1}^j}{(\Delta y)^2} + \frac{G_{i-1}^{j+1} - 2G_i^{j+1} + G_{i+1}^{j+1}}{(\Delta y)^2} \right),$$ where G stands u, θ, w and C

In to the equations (4) to (7) and simplifying implicitly according to the **Crankand Nicholson method**, the following are obtained

$$-r u_{i-1}^{j+1} + 2(r+1) u_i^{j+1} - r u_{i+1}^{j+1} = A_i^j \tag{10}$$

$$-rw_{i-1}^{j+1} + 2(r+1)\,w_i^{j+1} - rw_{i+1}^{j+1} = B_i^j \tag{11}$$

$$-r\theta_{i-1}^{j+1} + 2(r+\Pr)\,\theta_i^{j+1} - r\,\theta_{i+1}^{j+1} = D_i^j \tag{12}$$

$$-rC_{i-1}^{j+1} + 2(r+S_c)\,C_i^{j+1} - rC_{i+1}^{j+1} = E_i^j \tag{13}$$

with boundary conditions in finite difference form

$$\begin{aligned} &u\,(i,j)=0,\quad \theta(i,j)=0,\quad \phi(i,j)=1,\quad \text{for all } i,j \\ &u\,(0,j)=1,\quad \theta(0,j)=1,\quad \phi=1.\ \forall\ j \\ &u(\infty,j)\to 0,\ \theta(\infty,j)\to 0,\ \phi(\infty,j)\to 1.\ \forall\ j \end{aligned} \tag{14}$$

where, $r = \Delta t/(\Delta y)^2$

$$A_i^j = ru_{i-1}^j - 2\left(r + \frac{M\,\Delta t}{1+m^2} - 1 - r\,\Delta y\,v_i^j\right)u_i^j - r\left(2\,\Delta y\,v_i^j - 1\right)u_{i+1}^j - \frac{2m\,M\,\Delta t}{1+m^2}\,w_i^j + 2\Delta t\left(Gr\theta_i^j + GmC_i^j\right)$$

$$B_i^j = rw_{i-1}^j - 2\left(r + \frac{M\,\Delta t}{1+m^2} - r\Delta y\,v_i^j - 1\right)w_i^j - r\left(2\Delta y\,v_i^j - 1\right)w_{i+1}^j + \frac{2m\,M\,\Delta t}{1+m^2}\,u_i^j$$

$$D_i^j = r\theta_{i-1}^j - 2\left(r - \Pr - r\,\Delta y \Pr v_i^j\right)\theta_i^j - r\left(2\,\Delta y \Pr v_i^j - 1\right)\theta_{i+1}^j + 2Du\Pr r\left\{C(i-1) - 2C(i) + C(i+1)\right\}$$

$$E_i^j = rC_{i-1}^j - 2\left(r - Sc - r\,\Delta y\,Sc\,v_i^j - Ch\,\Delta t\right)C_i^j - r\left(2\Delta y\,Sc\,v_i^j - 1\right)C_{i+1}^j + 2SoSc\,r\left\{\theta(i-1) - 2\theta(i) + \theta(i+1)\right\}$$

Here Δy and Δt are mesh sizes along y and time direction, respectively. Index i refers to space and j for time. To obtain the difference equations, the region of the flow is divided into a grid or mesh of lines parallel to y and t axes. Solutions of difference equations are obtained at the intersection of these mesh lines called nodes. The finite-difference equations at every internal nodal point on a particular n-level constitute a tri-diagonal system of equations. These equations are solved by using the Thomas algorithm. In order to obtain the numerical solution with slight error and to verify the convergence of present numerical scheme, a grid independent test is applied by experimenting with various grid sizes i.e. the computation is carried out by slightly changed values of Δy and Δt. This process is repeated until we get the results up to the desired degree of accuracy 10^{-8}. No significant change is observed in the values of velocity, temperature and concentration profiles. Thus, it is concluded that the finite difference scheme is convergent and stable.

4 Shearing stresses

The shearing stress at the wall along x-axis is given by

$$\tau_1 = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{15}$$

and shearing stress at the wall along w-axis is given by

$$\tau_2 = \left(\frac{\partial w}{\partial y}\right)_{y=0} \tag{16}$$

5 Results and Discussion

The definition of the Soret number So is the effect of the temperature gradients to the inducing significant mass diffusion. Figures (1), (7) and (13) show the effect of Soret number on primary velocity, secondary velocity and concentration respectively. A comparative study of the graph reveals that the main and secondary flow velocities and concentration of the fluid increase with the increasing values of Soret number So. This means that Soret number increase speed the primary velocity of the flow throughout the boundary layer. growing Soret number shows a decrease in the viscosity of the fluid. It directs to enhanced inertia effects and weakened viscous effects. Consequently the concentration and velocity of the fluid enhance. Dufour number defines the contribution of the concentration gradients to the thermal energy flux in the flow. The effect of the Dufour on main flow velocity, secondary velocity and temperature is presented in figures (2), (8) and (12) respectively. It is observed that the main and secondary flow velocities raise with the growing values of Du. This is due to the fact that as soret number increases, thermal acceleration comes into play causing the enhancement of fluid velocity.

The effect chemical reaction parameter (Ch) on primary and secondary velocities and concentration field is displayed by the curves shown in figs (5), (9) and (14) respectively. From these it is observed that for increasing values of Ch, both the velocities and concentration of the fluid reduce. Figure (4) reveals that the velocity of the flow decreases as the value of non dimensional transpiration parameter increases because the transpiration velocity is inversely proportional to the square-root of time.

Figures (3) and (10) show the effect of Hall current (m) on velocity field's u and w respectively. It is noted that velocity profiles u and w increase across the boundary layer with the increasing values of m. This owing to the reality that an increase in hall current produces a deflection which influences in the both the velocity profiles. Magnetic parameter M depicts the ratio of electromagnetic force to the viscous force. It is seen from the figure (6) that an increase in magnetic parameter leads to reduce in the main flow velocity. This is due to the fact that the presence of magnetic field in an electrically conducting fluid initiates a force called Lorentz force. This kind of magnetic full of Lorentz force slows down the main flow velocity. But from figure (11), it is noted that the secondary velocity increases with increase in M because the resulting Lorentz force works as an supporting body force on the secondary flow. The results obtained are in good agreement with realistic physical phenomenon.

6 Conclusions:

Effect of Soret and Dufour on hydromagnetic unsteady free-convection flow of an electrically conducting viscous incompressible fluid along an infinite vertical porous plate with Hall current and chemically reaction is analyzed. From this study the following conclusions are drawn.

1. Primary, secondary velocities of the fluid enhance for increasing values of So, Du, and *m*. But they decrease with increase in Ch and λ.
2. Shearing stresses τ_1 and τ_2 decrease with increase in Ch and λ but they increase as the values of So, Du, and *m* increases.
3. The effect of increasing values of Magnetic parameter results in decreasing main flow velocity profiles while reverse effect is noted in the case of secondary flow velocity.

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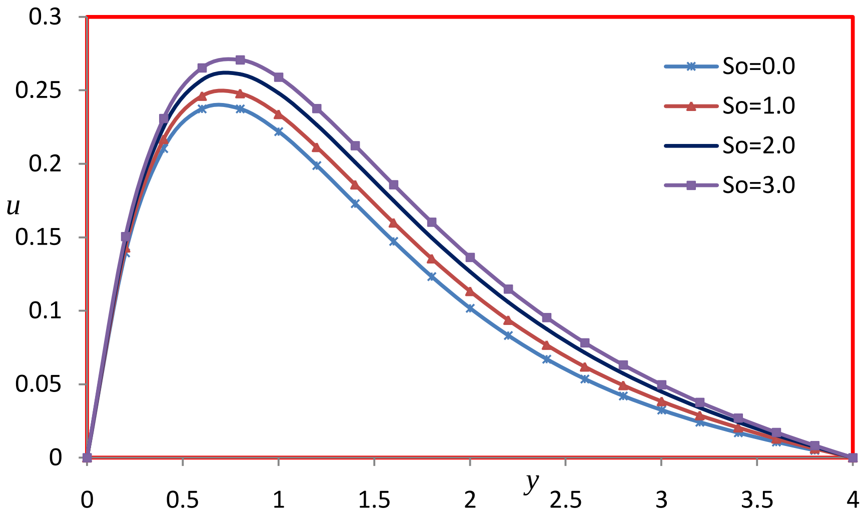

Fig 1: Effectof Soret number So on Velocity field u

(Gr=1.0, Gm=1.0, Pr=0.71, Ch=1.0,Sc=0.22, m=1.0, M=1.0, λ=0.5 ,Du=1,0 and t=1.0)

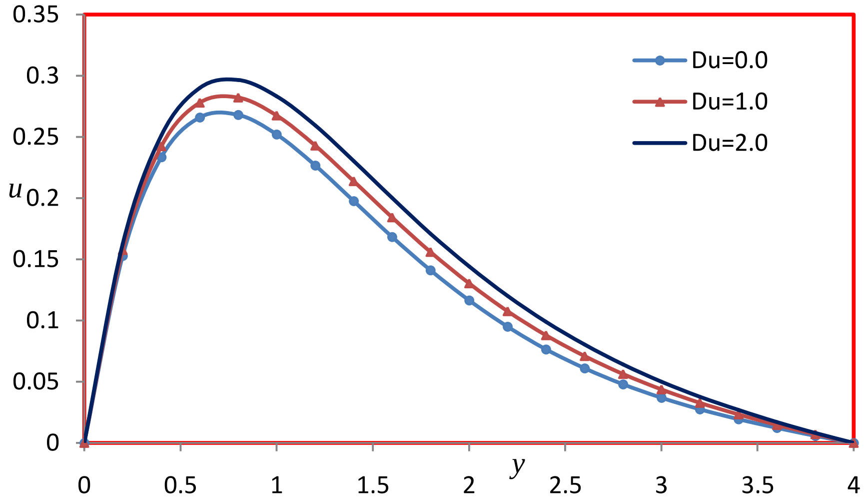

Fig 2: Effect of Dufour number Du on velocity field u

(Gr=1.0, Gm=1.0, Pr=0.71, Sc=0.22,Ch=1.0, m=1.0, So=1.0,λ=0.5 and t=1.0)

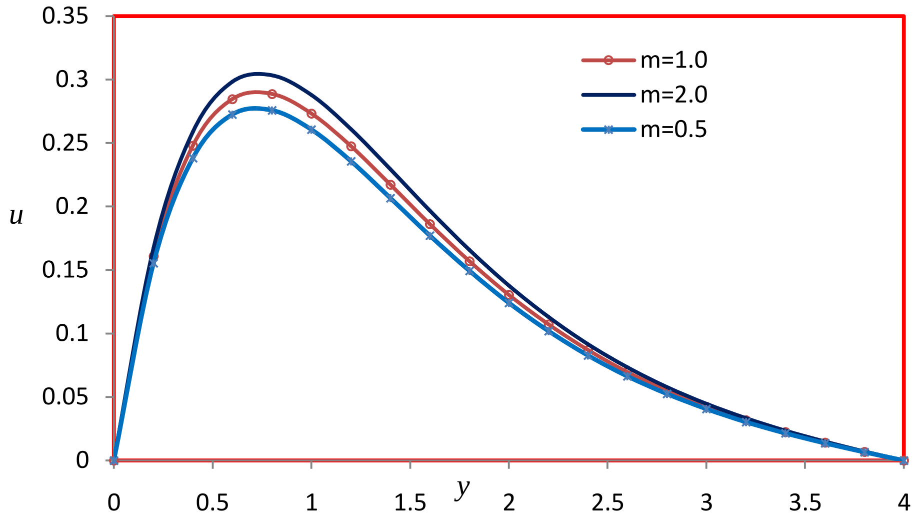

Fig 3: Hall effect on velocity field u

(Gr=1.0, Gm=1.0, Pr=0.71, Sc=0.22, M=1.0, Ch=1.0, λ=0.5 and t=1.0)

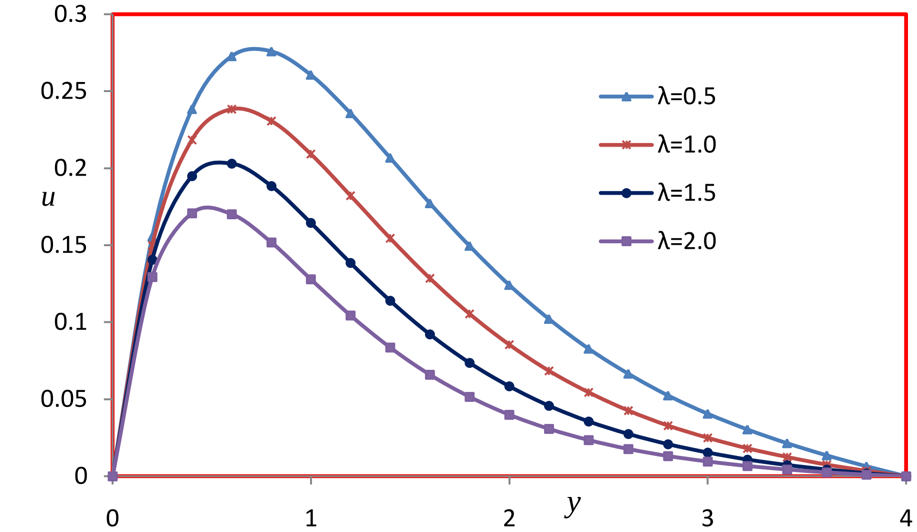

Fig 4: Effect of transpiration parameter on velocity field u

(Gr=1.0, Gm=1.0, Pr=0.71, So=1.0, Sc=0.22, m=0.5, M=1.0, Du=1.0 and t=1.0

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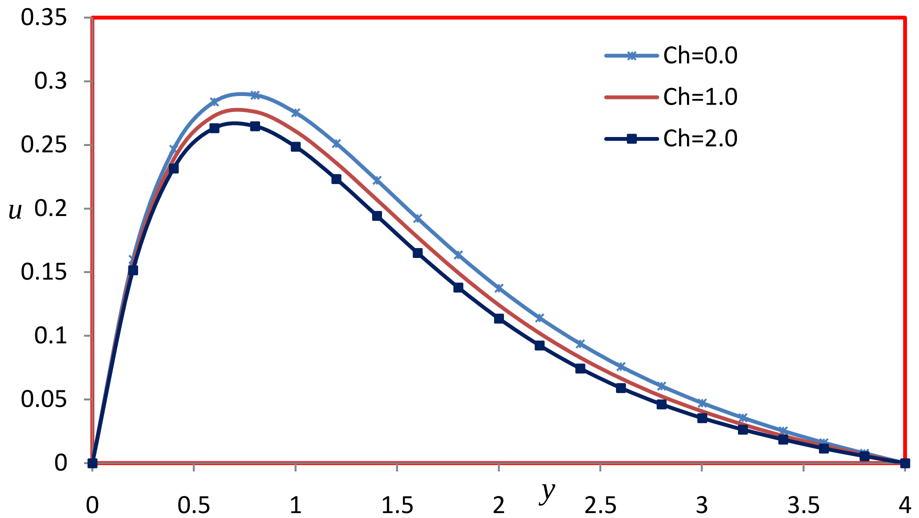

Fig 5: Effect of chemical reaction on velocity field u

(Gr=1.0, Gm=1.0, Pr=0.71, λ=0.5, Du=1.0, Sc=0.22, m=0.5, So=1.0, M=1.0 and t=1.0

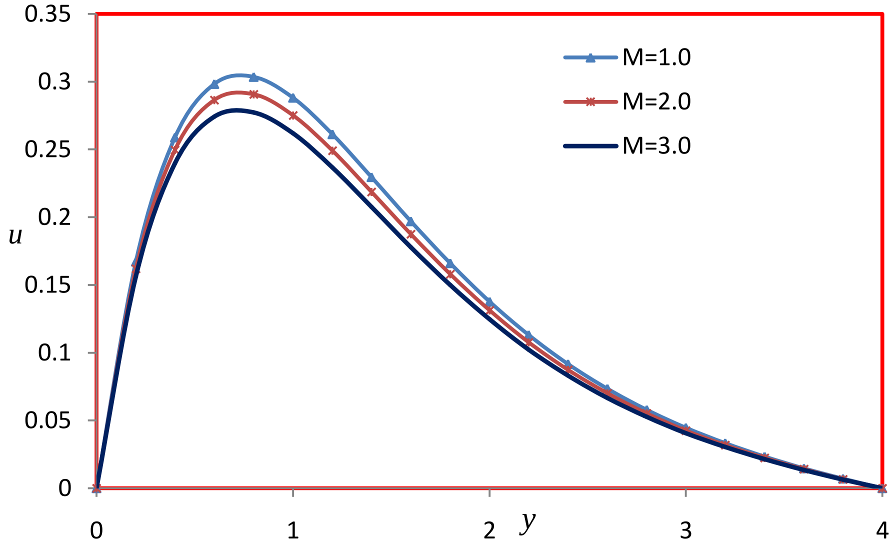

Fig 6: Effect of Magnetic parameter on velocity field u

(Gr=1.0, Gm=1.0, m=0.5, Pr=0.71, So=1.0, Du=1.0,Ch=1.0,Sc=0.22, λ=0.5, and t=1.0

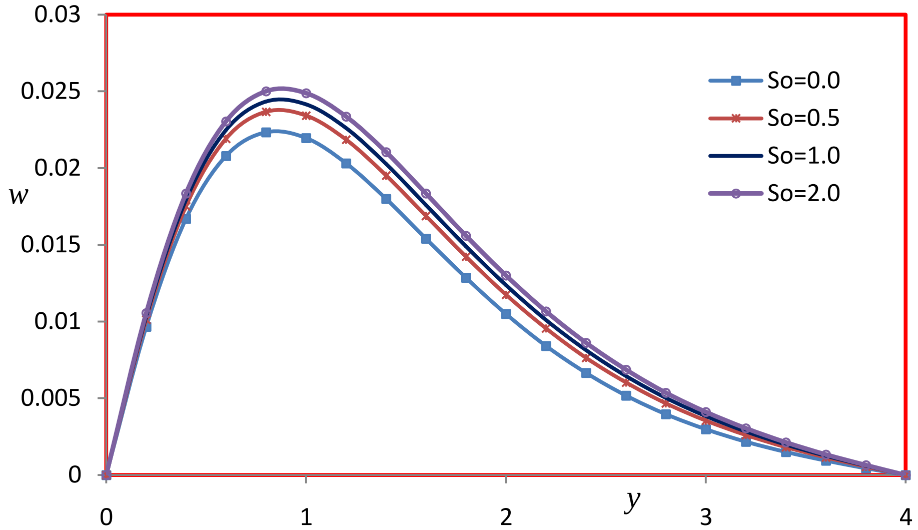

Fig 7: Effect of Soret number So on velocity field w

(Gr=1.0, Gm=1.0, Pr=0.71, Du=1.0, Sc=0.22, m=0.5,Ch=1.0, M=1.0, λ=0.5 0 and t=1.0

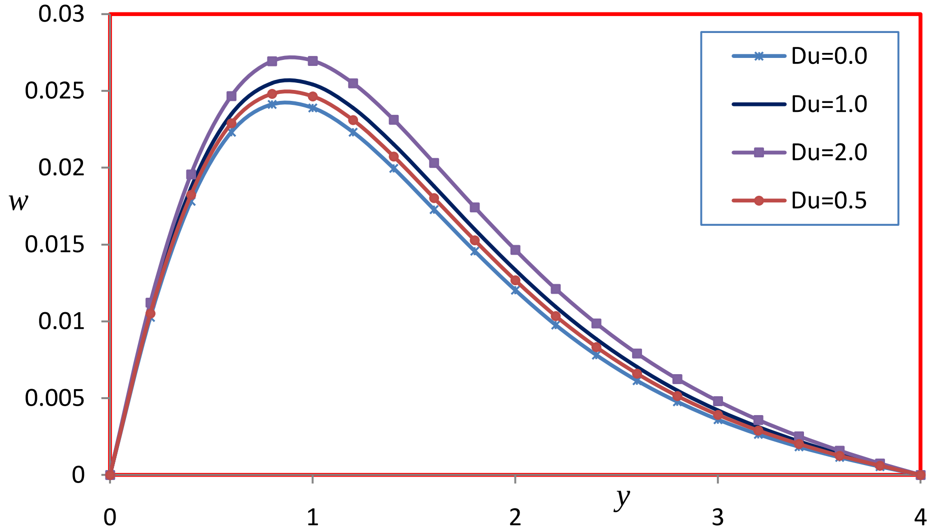

Fig 8: Effect of Dufour number on velocity field w

(Gr=1.0, Gm=1.0, Pr=0.71, So=1.0, Sc=0.22, m=0.5,Ch=1.0, M=1.0, λ=0.5 0 and t=1.0

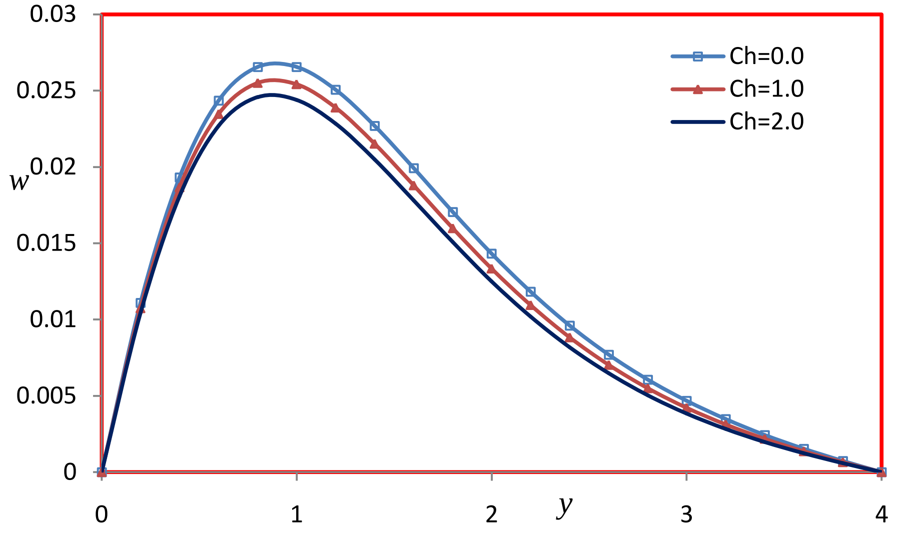

Fig 9: Effect of chemical reaction on velocity field w

(Gr=1.0, Gm=1.0, Pr=0.71, Sc=0.22, So=1.0, Du=1.0,m=0.5, M=1.0, λ=0.5 and t=1.0

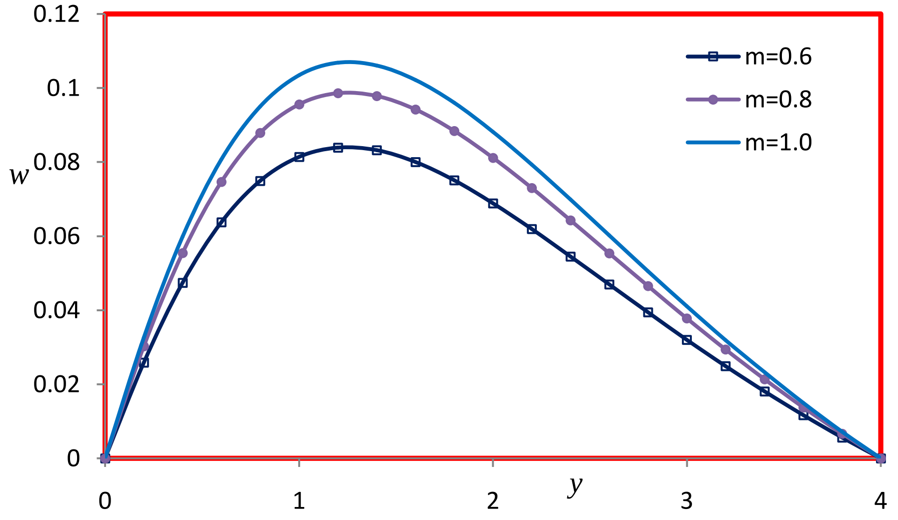

Fig 10: Hall effect on velocity field w

(Gr=1.0, Gm=1.0, Pr=0.71, Sc=0.22, So=1.0, Du=1.0,Ch=1.0, M=1.0, λ=0.5 and t=1.0

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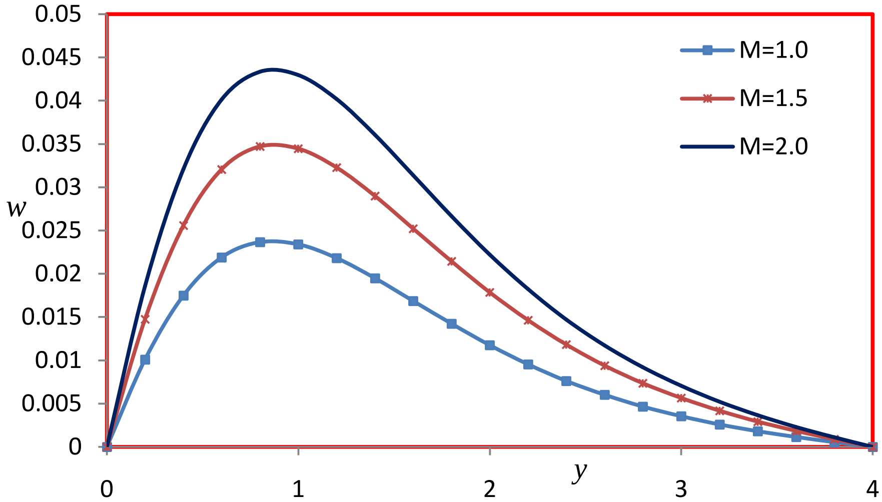

Fig 11: Effect of Magnetic parameter on velocity field w

(Gr=1.0, Gm=1.0, Pr=0.71, Sc=0.22,Ch=1.0, m=0.5, So=1.0, Du=1.0, λ=0.5 and t=1.0

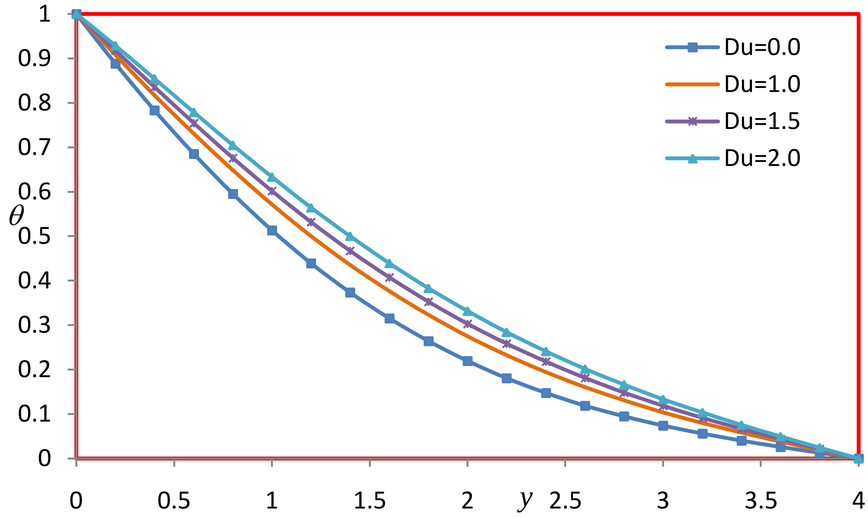

Fig 12: Effect of Dufour on temperature field

(Pr=0.71, and t=1.0)

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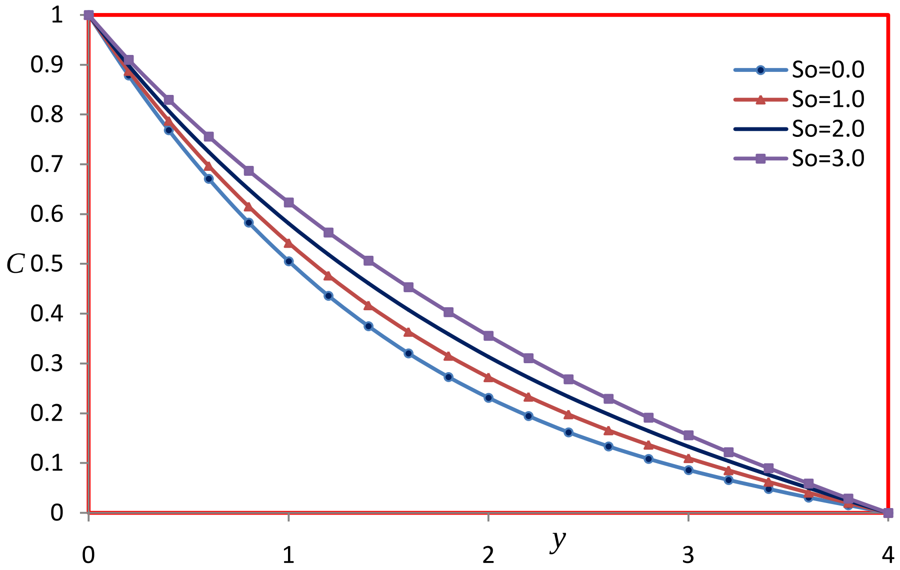

Fig 13: Effect of Soret number on Concentration field
(Sc=0.22, Ch=1.0 and t=1.0)

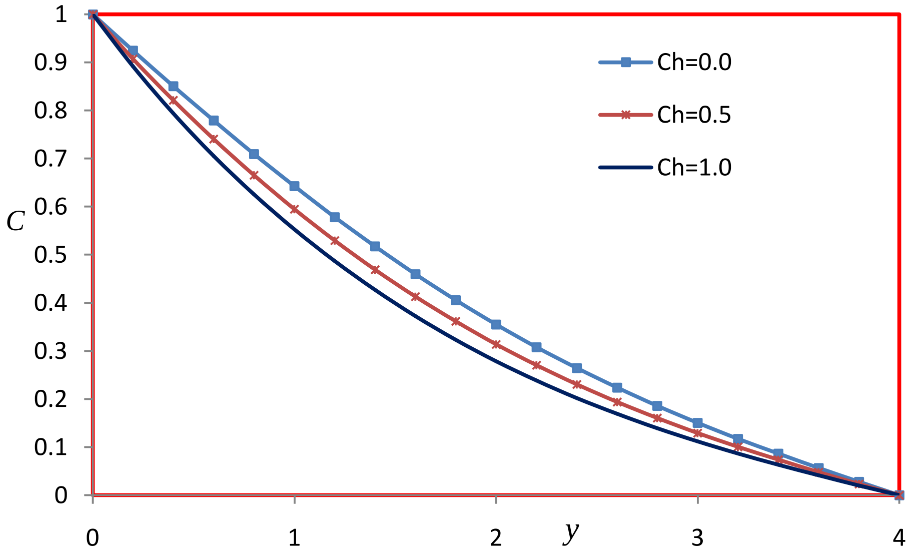

Fig 14: Effect of Chemical reaction on Concentration field
(Sc=0.22,So=1.0 and t=1.0)

Table 4.1: Variation of shearing stress τ_1 and τ_2
(G_r,=1.0, G_m,=1.0,Pr=0.71,Sc=0.22 and t =1.0)

m	**M**	λ	**So**	Du	Ch	Shearing stress	
						τ_1	τ_2
1.0	1.00	0.5	0.0	0.0	0.0	0.881074	0.049423
1.0	1.00	0.50	1.0	0.0	0.0	0.915281	0.052689
1.0	1.00	0.50	1.0	1.0	0.0	0.938856	0.055004
1.0	1.00	0.50	1.0	1.0	2.0	0.893338	0.051731
1.0	1.00	2.0	1.0	1.0	2.0	0.799298	0.039079
2.0	1.00	0.50	1.0	1.0	2.0	0.925952	0.044265
1.0	2.00	0.50	1.0	1.0	2.0	0.837781	0.091948

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