MHD FREE CONVECTION HEAT AND MASS TRANSFER FLOW PAST AN ACCELERATED VERTICAL PLATE THROUGH A POROUS MEDIUM WITH EFFECTS OF HALL CURRENT, ROTATION AND DUFOUR EFFECTS

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Abstract-The rotation and Hall current and Dufour effects on MHD free convection heat and mass transfer flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical embedded in a porous medium taking in account. It is assumed that the entire system rotates with a uniform angular velocity Ω' about the normal to the plate and a uniform transverse magnetic field is applied along the normal to the plate directed into the fluid region. The magnetic Reynolds number is considered to be so small that the induced magnetic field can be neglected. The governing partial differential equations are solved by using perturbation technique.

Keywords: **Hall current, Dufour effect, MHD, Free convection**

I. INTRODUCTION

Most of the time Hall current was ignored while applying Ohm's law because it has no significant effect for small and average values of the magnetic field. Because for strong magnetic field electromagnetic force is prominent. The recent research for the applications of MHD is current is very important. Actually in an ionized gas of low density subjected to a strong magnetic field, the conductivity perpendicular to the magnetic field is decreased by free spiral movement of electrons and ions about the magnetic lines of force before suffering collisions. A current produced in a direction at right angle to the electric and magnetic fields is called Hall current. The important engineering applications for MHD boundary layer flows with heat transfer including the effects of Hall current are encountered in MHD power generators and pumps, in flight MHD, solar physics involved in the sunspot development, the solar cycle, the structure of magnetic stars, electronic system cooling, cool combustors, fiber and granular insulation, oil extraction, thermal energy storage and flow through filtering devices and porous material regenerative heat exchangers. Some of the authors studied Ogulu and Makinde [1] Unsteady hydromagnetic free convection flow of a dissipative and radiating fluid past a vertical plate with constant heat flux, Mahmoud [2] Thermal radiation effects on unsteady MHD free convection flow past a vertical plate with temperature dependent viscosity, Pop and Watanabe [3] Hall effect on magnetohydrodynamic free convection about a semi-infinite vertical flat, Abo-Eldahad and Elbarbary [4] Hall current effect on magnetohydrodynamic free convection flow past a semi-infinite vertical plate with mass transfer, Takhar et.al. [5] Unsteady free convection flow over an infinite vertical porous plate due the combined effects of thermal and mass diffusion, magnetic field and hall currents, Saha et.al. [6] Effect of Hall current on MHD natural convection flow from vertical permeable flat plate with uniform surface heat flux.

It is noticed that when the density of an electrically conducting fluid is low and or applied magnetic field is strong. Hall current is produced in the flow-field which plays an important role in determining flow features of the problems because it induces secondary flow in the flow – filed. Keeping in view this fact, significant investigations on hydromagnetic free convection flow past a flat plate with Hall effects under different thermal conditions are carried out by several researchers in the past. Satyanarayana et.al. [7] Effects of Hall current and radiation absorption on MHD micropolar fluid in a rotating system, Seth et.al. [8] Effects of Hall current and rotation on MHD natural convection flow past an impulsively moving vertical plate with ramped temperature in the presence of thermal diffusion with heat absorption, Takhar et.al. [9] MHD flow over a moving plate in a rotating fluid with magnetic field, Hall currents and free stream velocity, Bhavana and Chenna Kesavaiah [12] Perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation, Srinathuni Lavanya and Chenna Kesavaiah [13] Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, Srinathuni Lavanya and Chenna Kesavaiah [14] Radiation effects on MHD natural convection heat transfer flow from spirally enhanced wavy channel through a porous medium, Bhavana et.al. [15] The Soret effect on free convective unsteady MHD flow over a vertical plate with heat source, Ch Kesavaiah et.al. [16] Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, Chenna Kesavaiah and Jahagirdar [17] has been studied radiation absorption and chemical reaction effects on MHD flow through porous medium past an exponentially accelerated inclined plate, Chenna Kesavaiah and Jahagirdar [18] MHD Free Convective Flow through Porous Medium under the Effects of Radiation and Chemical reaction.

The present study deals with the study of the Hall current, rotation, Dufour effects and MHD free convection flow of a viscous, incompressible, electrically conducting fluid past an impulsively moving vertical plate in a porous medium. Exact solution of the governing equations is obtained in closed form by perturbation technique. Exact solution is also obtained in case of unit Schmidt number. The expressions for primary and secondary fluid velocity, fluid temperature, spices concentration, skin friction due to primary and secondary velocity fields at the plate are obtained.

II. FORMULATION OF THE PROBLEM

Consider unsteady MHD natural convection flow heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current into account. Assuming Hall currents, the generalized Ohm's la [10] may be put in the following form:

$$\vec{j} = \frac{\sigma}{1+m^2}\left(\vec{E} + \vec{V}\times\vec{B} - \frac{1}{\sigma n_e}\vec{j}\times\vec{B}\right)$$

where $\vec{V}$ represent the velocity vector, $\vec{E}$ is the intensity vector of the electric field, $\vec{B}$ is the magnetic induction vector, $\vec{j}$ is the electric current density vector, m is the Hall current parameter, is the electrical conductivity and is the number density of the electron. A very interesting fact that the effect of Hall current gives rise to a force in the z' direction which in turn produces a cross flow velocity in this direction and thus the flow becomes three-dimensional.

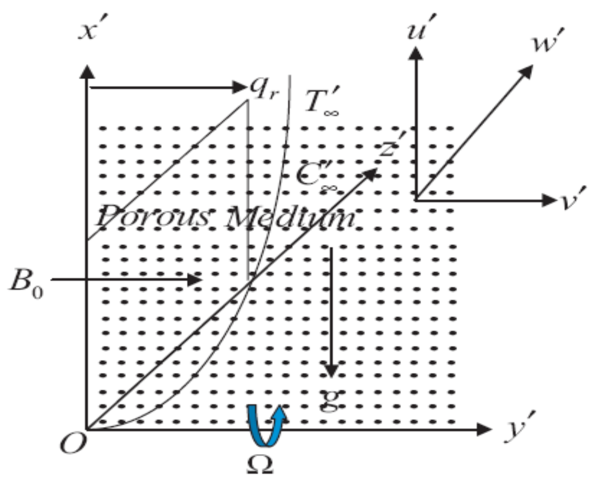

Figure (1): Geometry of the problem

Coordinate system is chosen in such a way that $x'-$ is considered along the plate in upward direction and $y'-$ axis normal to plane of the plate in the fluid. A uniform transverse magnetic field B_0 is applied in a direction which is parallel to $y'-$ axis. The fluid and plate rotate in unison with uniform angular velocity Ω' about $y'-$ axis. Initially, i.e. at time $t' \le 0$, both the fluid and plate are at rest and are maintained at a uniform temperature, both the fluid and plate are at rest and are maintained at a uniform temperature T'_∞. Also species concentration at the surface of the plate as well as at every point within the fluid is maintained at uniform concentration C'_∞. At the time $t' > 0$, plate starts moving in $x'-$ direction with a velocity $u'' = U t'$ in its plane. The temperature at the surface of the plate is raised to uniform temperature T'_w and the spices concentration at the surface of the plate is raised to uniform species concentration C'_w and is maintained thereafter. Geometry of the problem is presented in figure (1). Since plate is of infinite extent in x' and z' directions and is electrically non-conducting, all physical quantities except pressure depend on y' and t' only. Also no applied or polarized voltage exists so the effect of polarization of fluid is negligible. This correspondence to the case where no energy is added or extracted from the fluid by electrical means [11]. It is assumed that the induced magnetic field generated by fluid motion is negligible in comparison to the applied one. This assumption is justified because magnetic Reynolds number is very small for liquid metals and partially ionized fluids which are commonly used in industrial applications.

Keeping in view the assumptions made above, governing equations for natural convection flow with heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current, chemical reaction effect with radiation absorption into account, are given by

Conservation of momentum

$$\frac{\partial u'}{\partial t'} + 2\Omega w' = \nu \frac{\partial^2 u'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(u' + m w'\right) + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \frac{\nu}{K'_1} u' \quad (1)$$

$$\frac{\partial w'}{\partial t'} + 2\Omega u' = \nu \frac{\partial^2 w'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(m u' - w'\right) - \frac{\nu}{K'_1} w' \quad (2)$$

Conservation of energy

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{D_M}{C_s}\frac{k_T}{C_p}\frac{\partial^2 C'}{\partial y'^2} \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D_M \frac{\partial^2 C'}{\partial y'^2} - Kr'\left(C' - C'_\infty\right) \quad (4)$$

with boundary conditions

$$\begin{aligned} & u' = 0, T' - T'_\infty = \theta_w(x)\left[1 + \varepsilon e^{i\omega' t'}\right], C' - C'_\infty = C_w(x)\left[1 + \varepsilon e^{i\omega' t'}\right] \quad at \quad y' = 0 \\ & u' \to \infty, \quad T' \to \infty, \qquad C' \to \infty \qquad as \quad y' \to \infty \end{aligned} \quad (5)$$

where $U', \nu, g, \beta, \beta^*, T', k, \rho, C_p, D_1, \sigma, B_0, K', C', K^*, u', \varepsilon, \omega'$ and t' are stream velocity, kinematic viscosity coefficient, gravitational force, coefficient of volume expansion due to temperature, coefficient of volume expansion due to concentration, dimensional temperature, thermal conductivity, fluid density, specific heat at constant pressure, coefficient of diffusion, electrical conductivity, externally imposed magnetic field in the y-direction, dimensional concentration, dimensional chemical reaction parameter, axial velocity, a small parameter, dimensional frequency of the oscillation, and dimensional time.

The following dimensionless variables and parameters of the problem are

$$\begin{aligned} & u = \frac{u'_0}{U},\ y = \frac{U y'}{\nu}, t = \frac{t' U^2}{\nu},,\ \omega = \frac{\nu \omega'}{U^2}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty} \\ & Gr = \frac{\nu^2 \beta g \theta_w(x)}{U^4 L}, Gc = \frac{\nu^2 \beta^* g\left(C'_w - C'_\infty\right)}{U^4 L}, Du = \frac{C'_w - C'}{T'_w - T'_\infty}\frac{D_M K_T}{\nu C_s C_p} \\ & Da = \frac{K'}{U^2}, \quad \Pr = \frac{\nu \rho C_p}{k}, \quad Sc = \frac{\nu}{D}, \quad M^2 = \frac{\sigma B_0^2 \nu}{\rho U^2},\ Kr = \frac{Kr^* \nu}{D_1 U^2} \end{aligned} \quad (6)$$

Using (8) into (1) to (4) yield the following

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}-\left(S^2+M^2\right)u-Gr\,\theta-Gc\,C \tag{7}$$

$$\frac{\partial w}{\partial t}+2K^2u=\frac{\partial^2 w}{\partial y^2}+\frac{M^2}{\left(1+m^2\right)}\left(mu-w\right)-\frac{w}{K_1} \tag{8}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}+Du\frac{\partial^2 C}{\partial y^2} \tag{9}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-KrC \tag{10}$$

where $M, Gr, Gc, K, Kr, Sc, \Pr$ and Du are Hartmann number, the Grashof number, mass Grashof number, permeability of the porous medium, chemical reaction parameter, Schmidt number, Prandtl number and Dufour number shape factor respectively, with the following boundary conditions
The relevant initial and boundary conditions in non- dimensional form are given by

$$\begin{aligned} &u=w=0,\theta=0,C=0 && \text{for all } y \text{ and } t\le 0\\ &u=t,w=0,\theta=1,C=1 && \text{at } y=0 \text{ and } t>0\\ &u\to 0,\ w\to 0,\ \theta\to 0_\infty,\ C\to 0 && as\ y\to\infty \text{ for } t>0 \end{aligned} \tag{11}$$

Equations (7) and (8) are presented, in complex form, as

$$\frac{\partial F}{\partial t}=\frac{\partial^2 F}{\partial y^2}-\alpha F+Gr\,\theta+Gm\,C \tag{12}$$

where $F=u+iv$ and $\alpha=\dfrac{M^2(1-im)}{1+m^2}+\dfrac{1}{K_1-2iK^2}$

The initial and boundary conditions (11) in compact form, become

$$\begin{aligned} &F=0,\theta=0,C=0 && \text{for all } y \text{ and } t\le 0\\ &F=t,\theta=1,C=1 && \text{at } y=0 \text{ and } t>0\\ &F\to 0,\ \theta\to 0_\infty,\ C\to 0 && as\ y\to\infty \text{ for } t>0 \end{aligned} \tag{13}$$

The system of differential Equations (9), (10) and (12) together with the initial and boundary conditions (13) describes our model for the MHD free convective heat and mass transfer flow of a viscous, incompressible, electrically conducting fluid past an infinite vertical plate embedded in a porous medium taking Hall current, rotation and Soret effect into consideration.

III. METHOD OF SOLUTION

In order to reduce the above system of partial differential equations (9), (10) and (12) under the boundary conditions given equations (13) we assume in complex form the solution of the problems as

$$\begin{aligned} F\left(y,t\right)&=F_0\left(y\right)e^{i\omega t}\\ \theta\left(y,t\right)&=\theta_0\left(y\right)e^{i\omega t}\\ C\left(y,t\right)&=C_0\left(y\right)e^{i\omega t} \end{aligned} \tag{14}$$

Substitute equation (14) in to the equations (9), (10) and (12) the set of ordinary differential equations are the following form

$$F_0''-\left(i\omega+\alpha\right)F_0=-Gr\theta_0-Gm\phi_0 \tag{15}$$

$$\theta_0''-i\omega\Pr\theta_0=-Du\Pr\phi_0'' \tag{16}$$

$$C_0''-\left(i\omega+Kr\right)Sc\,C_0=0 \tag{17}$$

The initial and boundary conditions (14) in compact form, become

$$F_0 = t, \theta_0 = 1, C_0 = 1 \quad \text{at} \quad y = 0 \quad \text{and} \quad t > 0$$
$$F_1 \to 0, \quad \theta_0 \to 0, \quad C_0 \to 0 \quad as \quad y \to \infty \ \text{for} \ t > 0 \tag{18}$$

The exact solution for the fluid temperature $\theta(y,t)$, species concentration $C(y,t)$ and fluid velocity $F(y,t)$ are obtained and expressed from equations from (15) - (17) under the boundary condition (18) in the following form:

$$F_0 = L_1 e^{m_2 y} + L_2 e^{m_4 y} + L_3 e^{m_2 y} + L_4 e^{m_6 y}$$
$$\theta_0 = Z_1 e^{m_2 y} + Z_2 e^{m_4 y}$$
$$C_0 = e^{m_2 y}$$

In view of the above set of equation we get the solution

$$F(y,t) = \left\{ L_1 e^{m_2 y} + L_2 e^{m_4 y} + L_3 e^{m_2 y} + L_4 e^{m_6 y} \right\} e^{i\omega t}$$
$$\theta(y,t) = \left\{ Z_1 e^{m_2 y} + Z_2 e^{m_4 y} \right\} e^{i\omega t}$$
$$\phi(y,t) = \left\{ e^{m_2 y} \right\} e^{i\omega t}$$

Skin-friction

$$\tau = \left(\frac{\partial F}{\partial y} \right)_{y=0} = \left\{ m_3 L_1 + m_4 L_2 + m_2 L_3 + m_6 L_4 \right\} \cos \omega t$$

Heat transfer

$$Nu = \left(\frac{\partial \theta}{\partial y} \right)_{y=0} = \left\{ m_2 Z_1 + m_4 Z_2 \right\} \cos \omega t$$

Sherwood number

$$Sh = \left(\frac{\partial \phi}{\partial y} \right)_{y=0} = \left\{ m_2 \right\} \cos \omega t$$

Table (1): Skin friction (τ) versus Gr

Gc	Du	Pr	Sc	m	Kr	K_1	M	ω	K	t	τ
1.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**- 1.196**
2.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**- 0.491**
3.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**0.213**
4.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**0.917**
5.0	**5.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**10.25**
5.0	**10.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**10.36**
5.0	**15.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**10.47**
5.0	**20.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**10.59**
5.0	1.0	**0.71**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**15.45**
5.0	1.0	**1.0**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**14.16**
5.0	1.0	**7.0**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**10.030**
5.0	1.0	**100.0**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**2.643**
5.0	1.0	0.71	**0.16**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**1.594**
5.0	1.0	0.71	**0.22**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**1.663**
5.0	1.0	0.71	**0.31**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**1.680**
5.0	1.0	0.71	**0.60**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	**1.784**
5.0	1.0	0.71	0.22	**0.5**	1.0	1.0	1.0	0.5	1.0	1.0	**1.622**
5.0	1.0	0.71	0.22	**1.0**	1.0	1.0	1.0	0.5	1.0	1.0	**1.732**
5.0	1.0	0.71	0.22	**1.5**	1.0	1.0	1.0	0.5	1.0	1.0	**1.765**
5.0	1.0	0.71	0.22	**2.0**	1.0	1.0	1.0	0.5	1.0	1.0	**1.774**
5.0	1.0	0.71	0.22	0.5	**1.0**	1.0	1.0	0.5	1.0	1.0	**1.6.3**
5.0	1.0	0.71	0.22	0.5	**2.0**	1.0	1.0	0.5	1.0	1.0	**1.622**

5.0	1.0	0.71	0.22	0.5	**3.0**	1.0	1.0	0.5	1.0	1.0	**1.727**
5.0	1.0	0.71	0.22	0.5	**4.0**	1.0	1.0	0.5	1.0	1.0	**1.996**
5.0	1.0	0.71	0.22	0.5	1.0	**1.0**	1.0	0.5	1.0	1.0	**1.622**
5.0	1.0	0.71	0.22	0.5	1.0	**2.0**	1.0	0.5	1.0	1.0	**1.754**
5.0	1.0	0.71	0.22	0.5	1.0	**3.0**	1.0	0.5	1.0	1.0	**1.787**
5.0	1.0	0.71	0.22	0.5	1.0	**4.0**	1.0	0.5	1.0	1.0	**1.807**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**0.5**	0.5	1.0	1.0	**1.707**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**1.0**	0.5	1.0	1.0	**1.622**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**1.5**	0.5	1.0	1.0	**1.443**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**2.0**	0.5	1.0	1.0	**1.132**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**0.5**	1.0	1.0	**1.622**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**1.0**	1.0	1.0	**0.712**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**1.5**	1.0	1.0	**-2.778**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**2.0**	1.0	1.0	**-9.394**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**0.5**	1.0	**1.881**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**1.0**	1.0	**1.622**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**1.5**	1.0	**0.404**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**2.0**	1.0	**-1.805**

Table (2): Nusselt number versus Pr					
Du	Sc	ω	t	Kr	Nu
1.0	0.22	0.5	0.2	1.0	**0.7736**
2.0	0.22	0.5	0.2	1.0	**1.5470**
3.0	0.22	0.5	0.2	1.0	**2.3210**
4.0	0.22	0.5	0.2	1.0	**3.0950**
1.0	**0.16**	0.5	0.2	1.0	**0.3995**
1.0	**0.22**	0.5	0.2	1.0	**0.4685**
1.0	**0.31**	0.5	0.2	1.0	**0.5561**
1.0	**0.60**	0.5	0.2	1.0	**0.7736**
1.0	0.22	**0.5**	0.2	1.0	**0.7736**
1.0	0.22	**1.0**	0.2	1.0	**0.7707**
1.0	0.22	**1.5**	0.2	1.0	**0.7659**
1.0	0.22	**2.0**	0.2	1.0	**0.7592**
1.0	0.22	0.5	**0.2**	1.0	**0.7707**
1.0	0.22	0.5	**0.4**	1.0	**0.7592**
1.0	0.22	0.5	**0.6**	1.0	**0.7400**
1.0	0.22	0.5	**0.8**	1.0	**0.7135**
1.0	0.22	0.5	0.2	**1.0**	**0.7736**
1.0	0.22	0.5	0.2	**2.0**	**1.0940**
1.0	0.22	0.5	0.2	**3.0**	**1.3400**
1.0	0.22	0.5	0.2	**4.0**	**1.5470**

Table (3): Sherwood number versus ω			
Kr	Sc	t	Sh
1.0	0.22	0.4	**- 0.4690**
2.0	0.22	0.4	**- 0.6633**
3.0	0.22	0.4	**- 0.8124**
4.0	0.22	0.4	**- 0.9381**
1.0	**0.16**	0.4	**- 0.4000**
1.0	**0.22**	0.4	**- 0.4690**
1.0	**0.31**	0.4	**- 0.5568**
1.0	**0.60**	0.4	**- 0.7746**

IV. RESULTS AND DISCUSSION

The rotation and Hall current and Dufour effects on MHD free convection heat and mass transfer flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical embedded in a porous medium taking in account. The solution for velocity profiles, temperature profiles, concentration profiles are derived analytically and results are shown graphically for various parameters involving in the governing equations, skin fiction, Nusselt number and Sherwood number are numerically showed in table (1) – (3). Figure (2) is plotted to show the effect of Grashof number (Gr) for heat transfer on the velocity profiles. It is observed that an increase in Grashof number lead to increase in the velocity. This is due to fact that buoyancy force enhances fluid velocity and increases the boundary layer thickness with increase in the values of Grashof number. It is also observed that distinctive peaks in the velocity profiles occur in the fluid adjacent to the wall for higher values of Grashof number. The presence of the peaks indicates that the maximum value of fluid velocity occurs in the body of the fluid close to the plate and not at the plate. Figure (3) illustrates the effect of Grashof number (Gc) for mass transfer on the velocity profiles. As seen from this figure that, the effect of Grashof number on the fluid velocity is the same as that Grashof number (Gr) This is the fact is achieved by comparing figure (2) and (3). Figure (4) describe when Dufour number increases, the velocity increases respectively. Figure (5) illustrate the effects of rotation parameter on the velocity profiles respectively. It is evident from this figure that the velocity decreases on increasing rotation parameter. This implies that rotation retards fluid flow in the flow direction and accelerates fluid flow in the boundary layer region. This may be attributed to the fact that when the frictional layer at the moving plate is suddenly set into the motion then the Coriolis force acts as a constraint in the fluid. The variation of velocity profiles with dimensionless permeability parameter (K_1) is presented in figure (6). This figure clearly indicates that the value of velocity profiles increases with increasing the dimensionless permeability parameter. Physically, this result can be achieved when the holes of the porous medium are very large so that the resistance of the medium maybe neglected. Figure (7) represents the dimensionless velocity profiles for increasing values of chemical reaction parameter (Kr). It is seem this figure that augmenting values of chemical reaction parameter lead to fall in the velocity of the fluid. Figure (8) shows the velocity profiles for various values of magnetic parameter (M). The velocity curves show that the rate of transport is remarkably reduced with increase of magnetic parameter. This result agrees qualitatively with the expectations, since the magnetic field exerts a retarding effect on the free convective flow. Figure (9) demonstrate the effect of Hall current on the velocity profiles respectively. It is perceived form this figure that, the velocity increasing on increasing the values of Hall current throughout the boundary layer region. This implies that, Hall current tends to accelerate the fluid velocity throughout the boundary layer region which is consistent with the fact that Hall current induces flow in the flow filled. Figure (10) is sketched to show the effects of Prandtl number on velocity profiles. Four different realistic values of Prandtl number that are physically correspond to air, electrolytic solution, water and engine oil respectively are chosen. It is observed that the velocity decreases with increasing values of Prandtl number. This is due to the fact that fluid with large Prandtl number has high viscosity and small thermal conductivity, which make the fluid thick and causes a decrease in fluid velocity. Figure (11) shows the effect of Schmidt number on the velocity profiles for $Sc = 0.16 \,\&\, Sc = 0.22$ (hydrogen), $Sc = 0.31$ (helium), $Sc = 0.6$ (water vapour). It is observed that the velocity decreases with increasing Schmidt number values due to the decrease in the molecular diffusivity, which results in a decrease in the concentration and velocity boundary layer thickness. Figure (12) has been plotted to depict the variation of temperature profiles against y for different values of Dufour number (Du) by fixing other parameter. It is observed from this graph that temperature increase with increasing Dufour parameter. It is observed in figure (13) that the temperature increases as the chemical reaction parameter (Kr) increases. It is evident form figure (14), that as the values of Prandtl number $(\Pr)$ increase we can find a decrease in the temperature profiles and hence there is a decrease in thermal boundary layer thickness and more uniform temperature distribution across the boundary layer. Physically, this behaviour is due to the fact that with increasing Prandtl number, the thermal conductivity of the fluid decreases and the fluid viscosity increases which in turn results in a decrease in the thermal boundary layer thickness. Figure (15) shown the temperature profiles for different values of Schmidt number; it is clear that an increasing values of Schmidt number the temperature profiles increases. The effect of chemical reaction parameter (Kr) on the concentration shown in figure (16). It is noticed from this figure that there is a marked effect of increasing values of on concentration distribution in the boundary layer. It is clearly observed from this figure that increasing values of decrease the concentration of species in the boundary layer. This happens because large values of chemical reaction parameter reduce the solutal boundary layer thickness and increase the mass transfer. Figure (17) observes the influence of Schmidt number (Sc) on the concentration. It is evident from this figure that the increasing values of Schmidt number lead to fall in the concentration profiles. Physically, the increase of Schmidt number means a decrease of molecular diffusion D. Hence, the concentration of the species is higher for small values of Schmidt number and lower for large values of Schmidt number. Table (1) shows the variation of (τ) versus Grashof number (Gr) for different values of mass Grashof number (Gc), Dufour number (Du), Prandtl number $(\Pr)$, Schmidt number (Sc), Hall current (m), Chemical reaction parameter (Kr), dimensionless permeability parameter (K_1), magnetic field parameter (M), dimensional frequency of the oscillation (ω), rotation parameter (K) and dimensional time (t). It is clear that increasing values of the parameters Gc, Du, Sc, m, Kr, K_1 the skin friction also increase, but the reverse effect observed for the parameters $\Pr, M, \omega, K$ and no effect for dimensional time. Table (2) shows that the Nusselt number versus Prandtl number $(\Pr)$ for various values of Dufour number (Du), Schmidt number (Sc), dimensional frequency of the oscillation (ω), dimensional time (t), Chemical reaction parameter (Kr). It is obedient that an increasing values of Du, Sc, Kr the Nusselt number increases, but the reverse effects for various values of ω, t. It can be seen from table (3) that the Sherwood number (Sh) is reduced with an increase of for all values of chemical reaction parameter (Kr) and Schmidt number (Sc) .

APPENDIX

$$m_2 = -\sqrt{(i\omega + Kr)Sc}, m_4 = -\sqrt{i\omega \Pr}, m_6 = -\sqrt{i\omega + \alpha}, L_1 = -\frac{GrZ_1}{m_2^2 - \alpha}, L_2 = -\frac{GrZ_2}{m_4^2 - \alpha}$$

$$L_3 = -\frac{Gc}{m_2^2 - \alpha}, L_4 = (t - L_1 - L_2 - L_3), Z_1 = -\frac{Du \Pr m_2^2}{m_2^2 - i\omega \Pr}, Z_2 = 1 - Z_1$$

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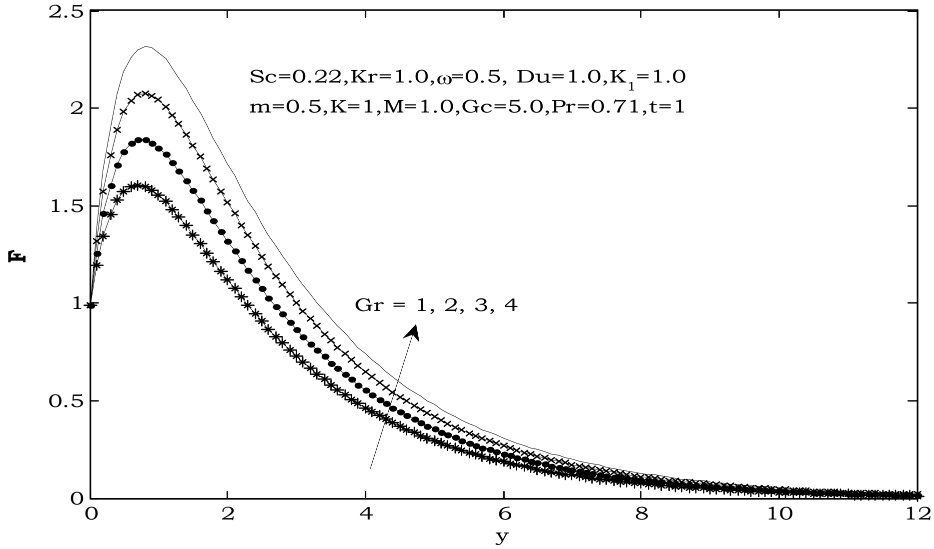

Figure (2): Velocity profiles for different values of Gr

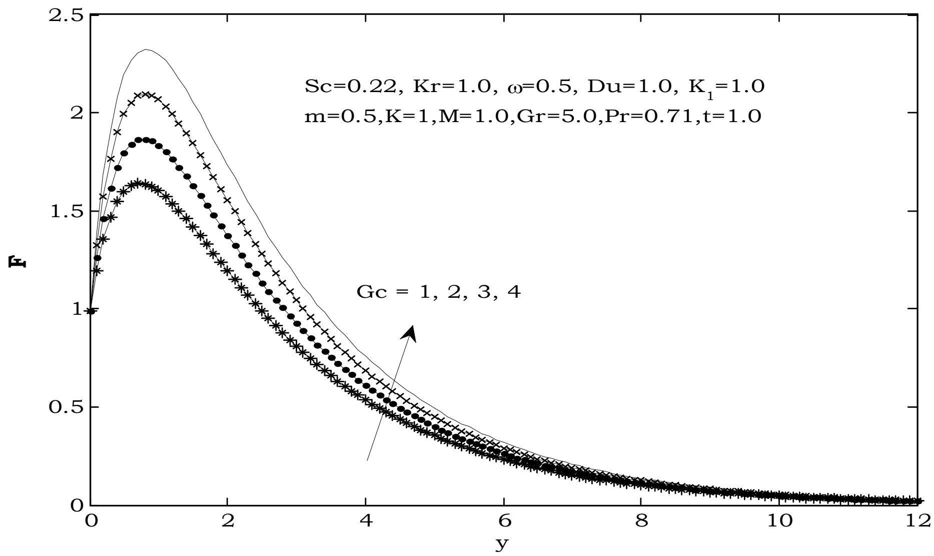

Figure (3): Velocity profiles for different values of Gc

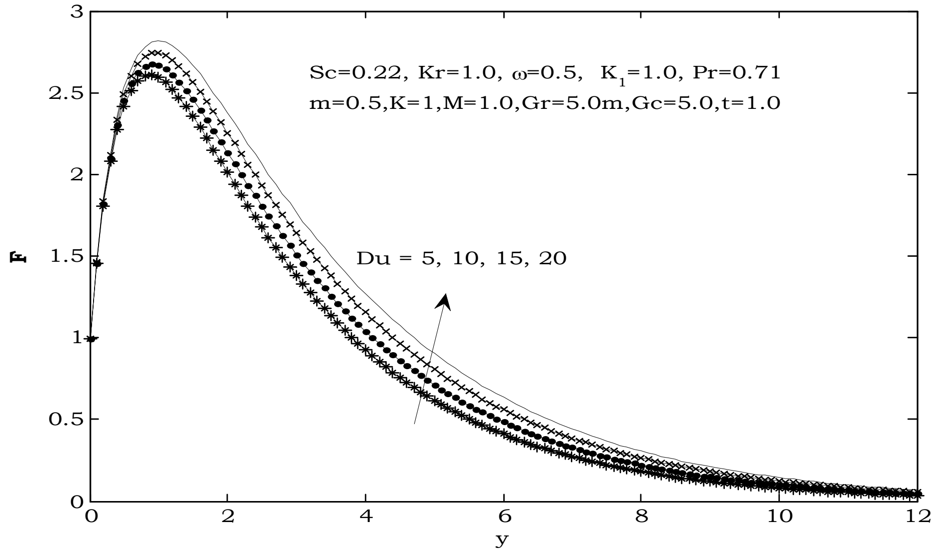

Figure (4): Velocity profiles for different values of Du

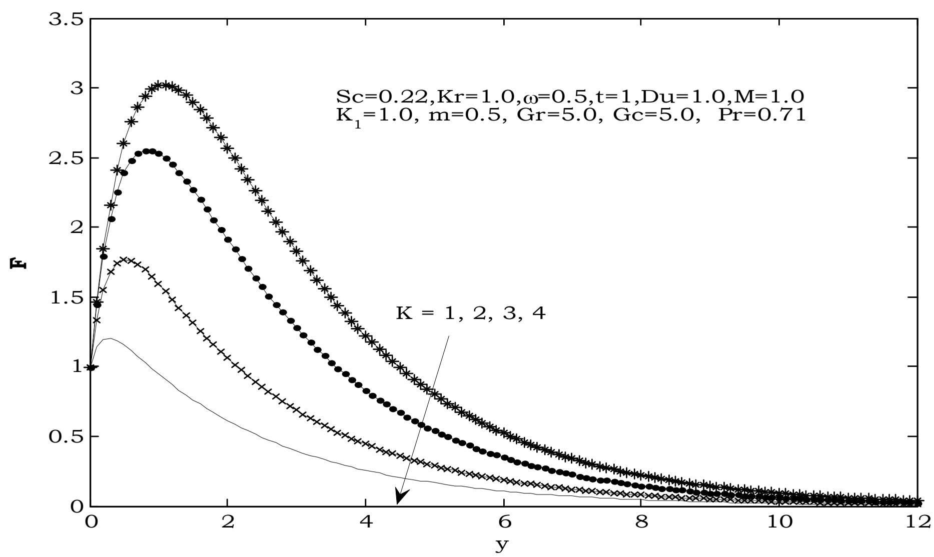

Figure (5): Velocity profiles for differet values of K

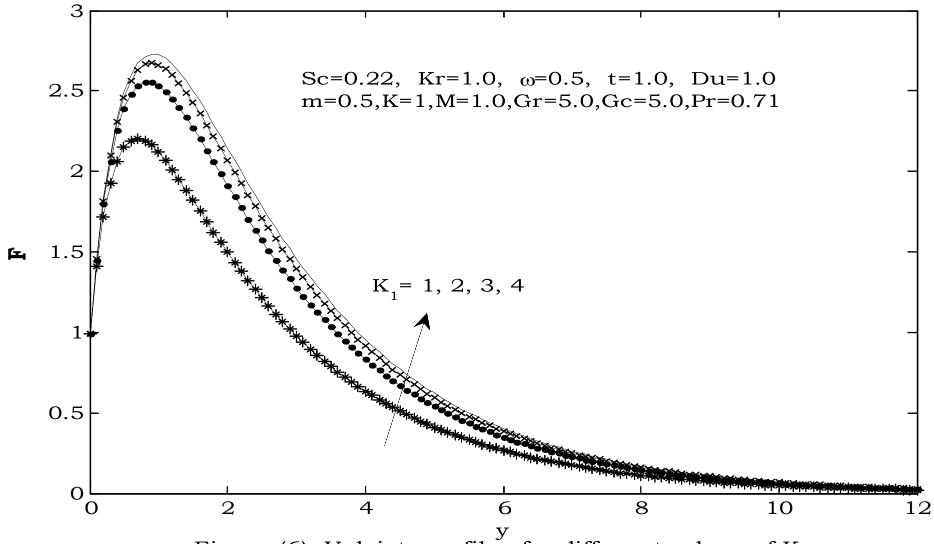

Figure (6): Veloicty profiles for different values of K_1

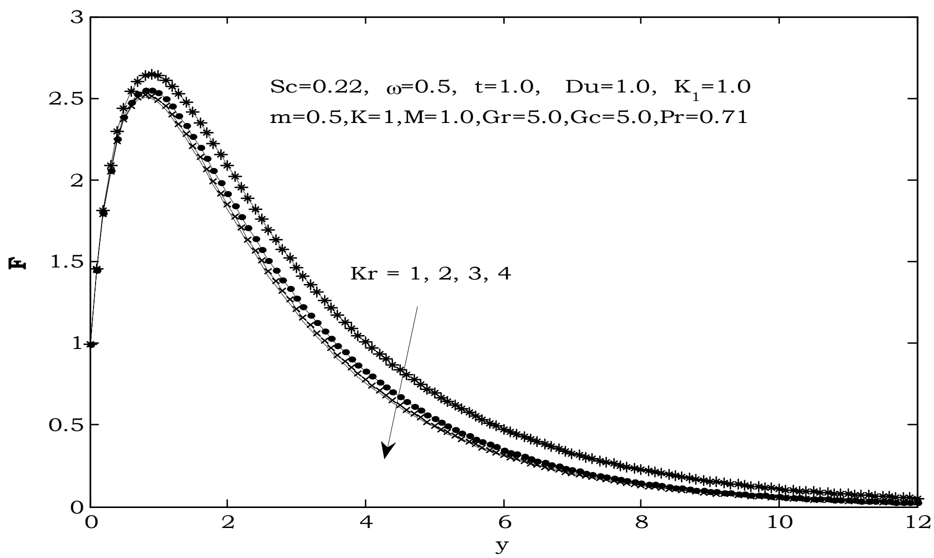

Figure (7): Veloicty profiles for different values of Kr

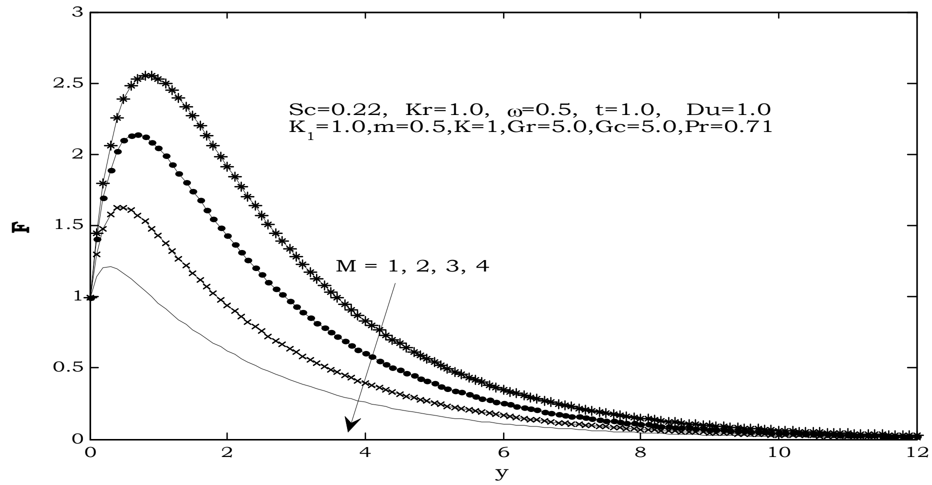

Figure (8): Veloicty profiles for different values of M

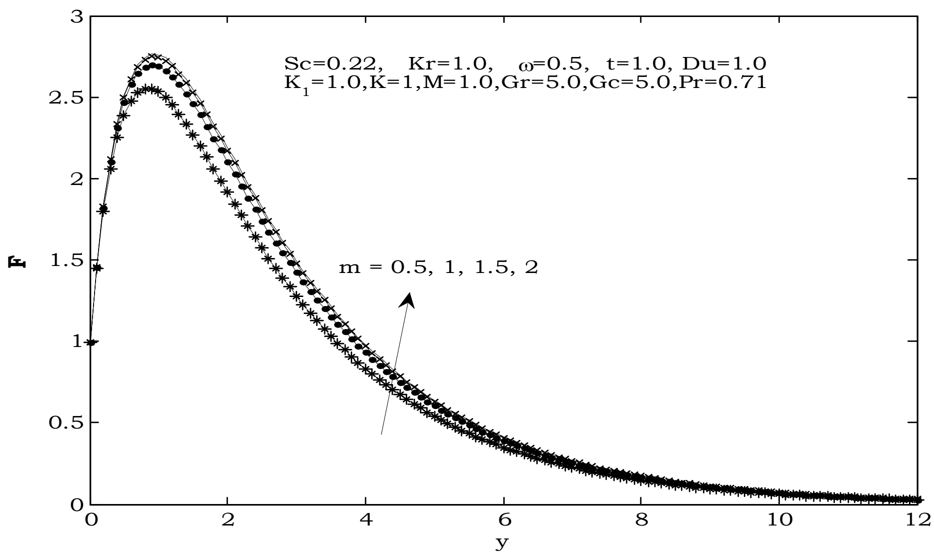

Figure (9): Veloicty profiles for different values of m

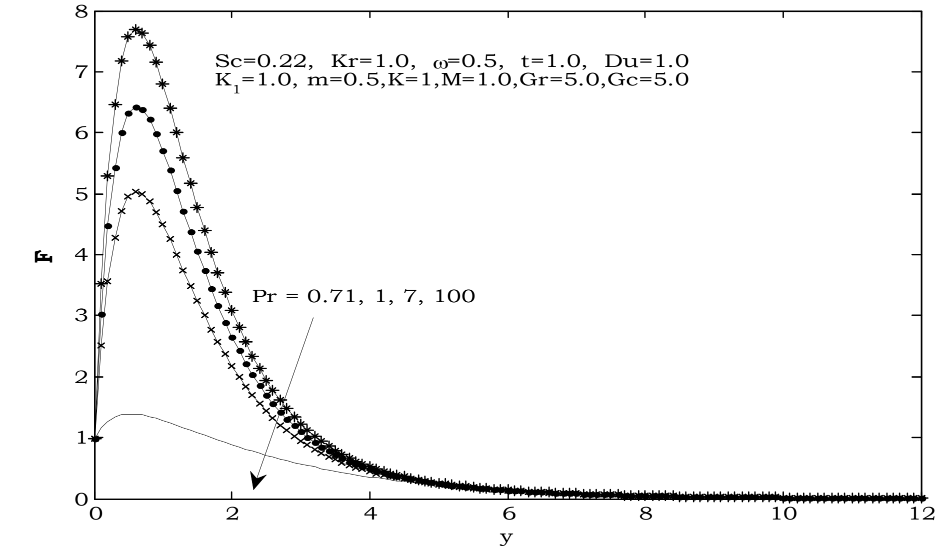

Figure (10): Velocity profiles for different values of Pr

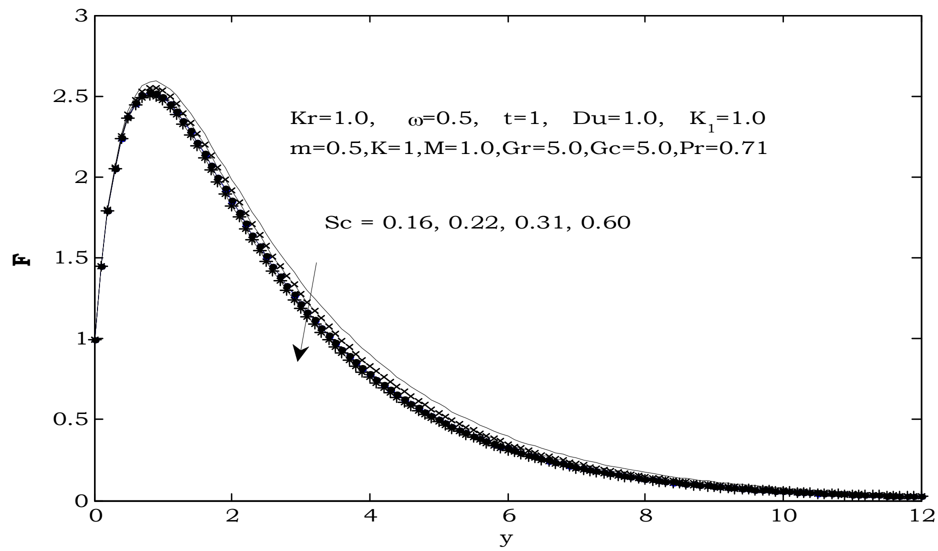

Figure (11): Velocity profiles for different values of Sc

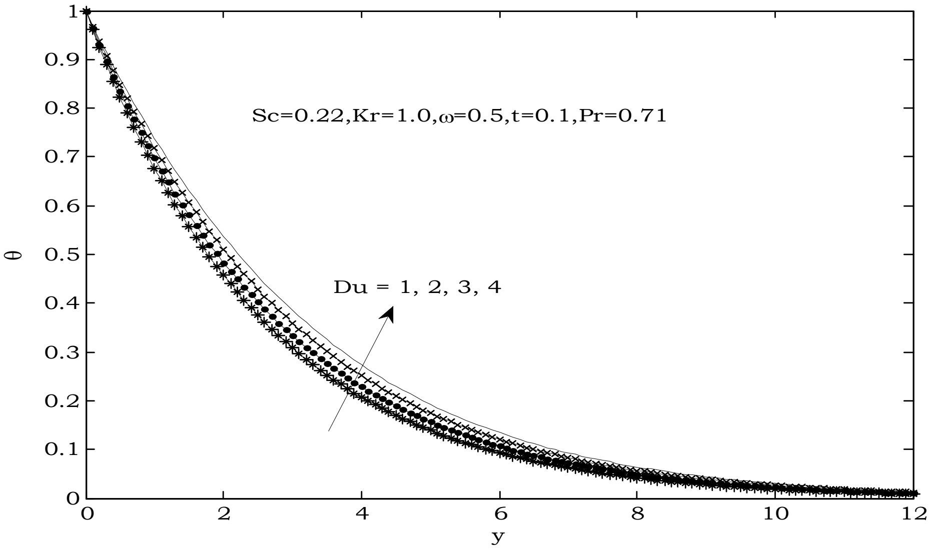

Figure (12): Temperatur profiles for different values of Du

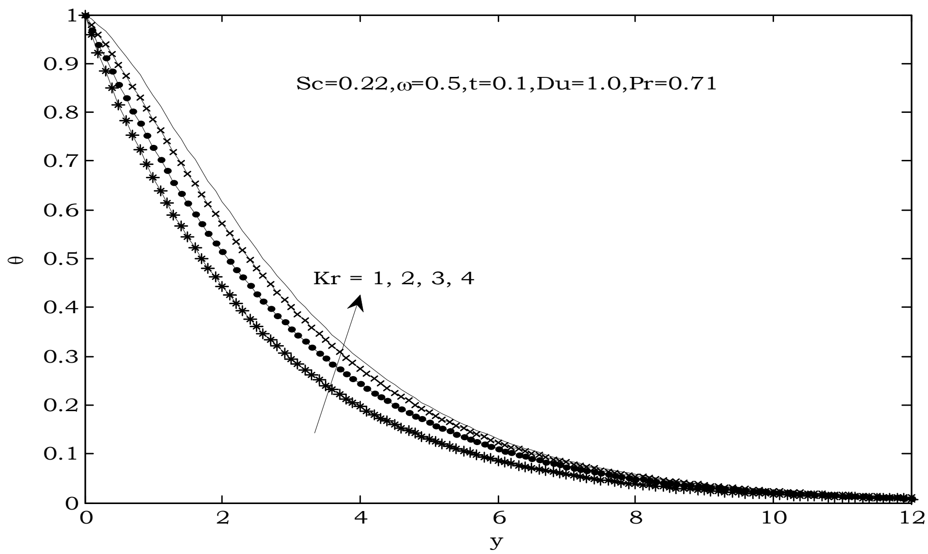

Figure (13): Temperature profiles for different values of Kr

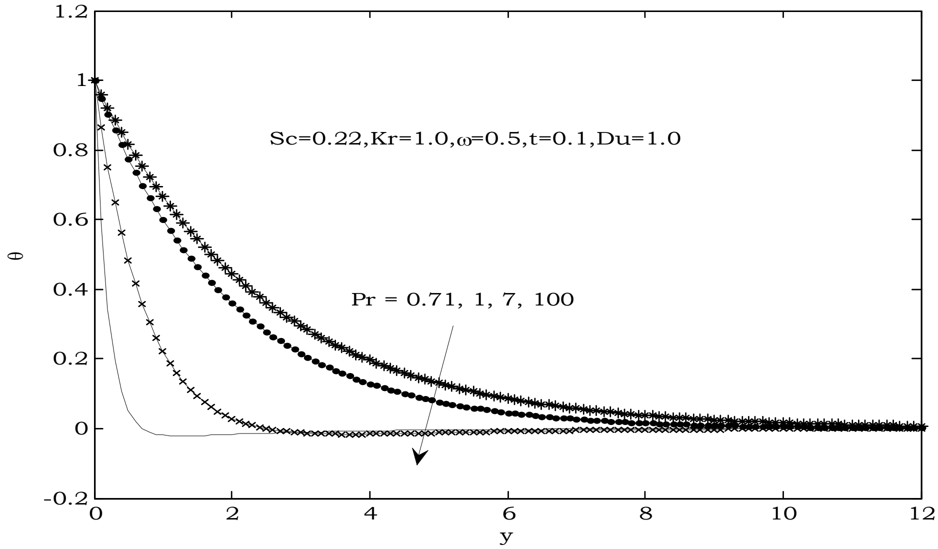

Figure (14): Temperature profiles for different values of Pr

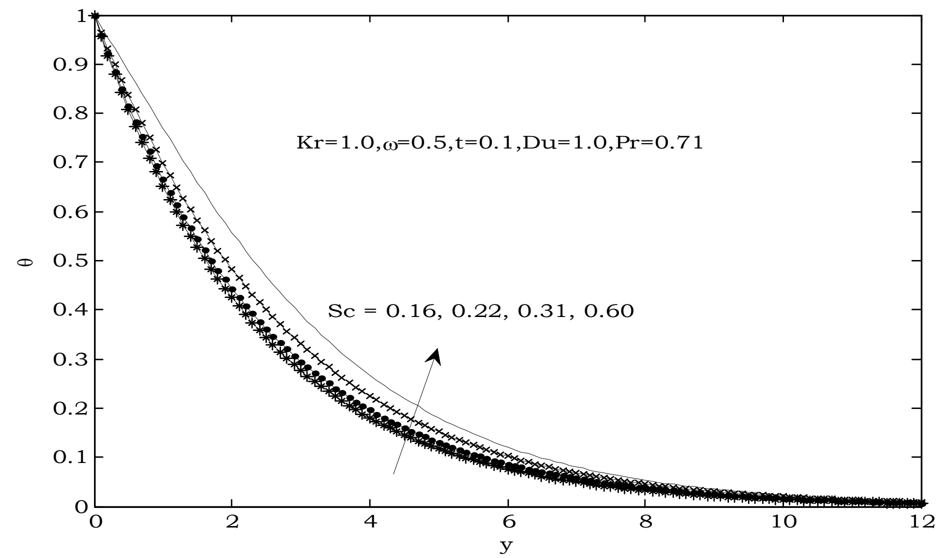

Figure (15): Temperature profiles for different values of Sc

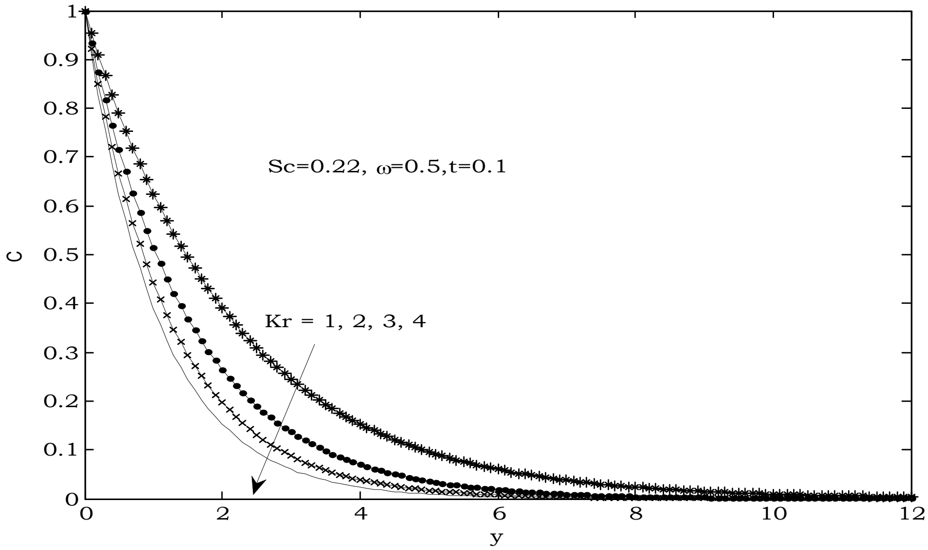

Figure (16): Concentration profiles for different values of Kr

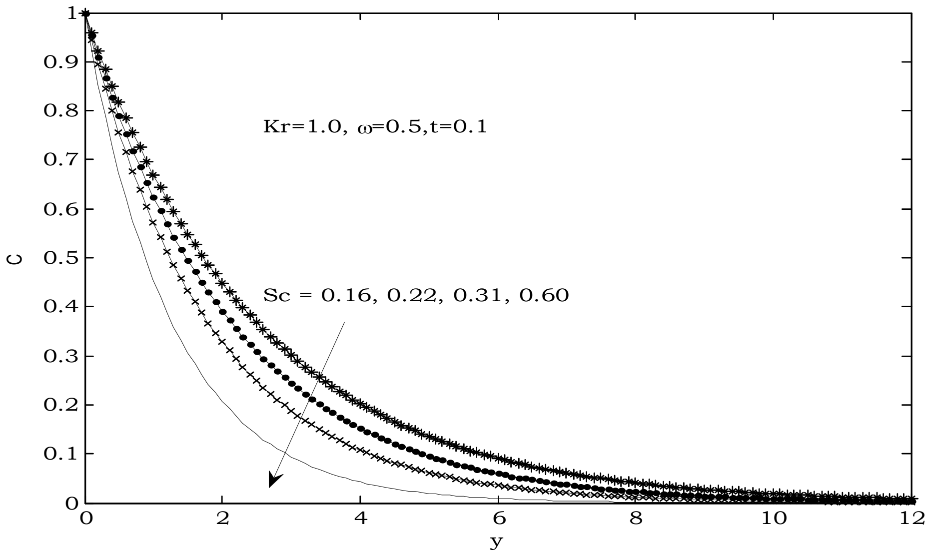

Figure (17): Concentration profiles for different values of Sc