Radiation Absorption and Aligned Magnetic Field Effects on Unsteady Convective Flow along a Vertical Porous Plate with Variable Temperature and Concentration

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Abstract: An analysis is carried out to study the effects of aligned magnetic field, radiation absorption and viscous dissipation on the magneto hydrodynamic unsteady convective heat and mass transfer flow of a viscous incompressible electrically conducting and heat absorbing fluid along a vertical porous plate embedded in a porous medium with variable temperature and concentration. Approximate solutions for velocity, temperature and concentration are obtained by solving the governing equations of the flow field using multi parameter perturbation technique. The expressions for skin friction at the plate in the direction of the main flow, the rate of heat transfer and mass transfer from the plate to the fluid are derived in non-dimensional form. The effects of various flow parameters affecting the flow field are discussed with the help of figures and tables with an increasing Schmidt number the concentration and velocity profiles decreases whereas the temperature profile increases with respect to the heat source and heat sink parameters. A growing magnetic field parameter or Prandtl number or angle ϕ retards the velocity and temperature of the flow field while the Grashof number for heat transfer or Grashof number for mass transfer or permeability parameter or viscous dissipation Ec reverses the effect with respect to the heat source parameter and heat sink parameter.

Keywords: Radiation Absorption, Porous Medium, Viscous Dissipation, Heat Source/Sink, Suction

I. INTRODUCTION

Flow problems through porous media over flat surfaces are of great theoretical as well as practical interest in view of their applications in various fields such as aerodynamics, extraction of plastic sheets, cooling of infinite metallic plates in a cool bath, liquid film condensation process and in major fields of glass and polymer industries. The interaction of convection and radiation in absorbing-emitting media occurs in many practical cases. Radiative convective flows are encountered in countless industrial and environment processes e.g. heating and cooling chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, astrophysical flows, and solar power technology and space vehicle re-entry. Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of the surrounding fluid is rather high, radiation effects play an important role and this situation does exist in space technology.

In view of its wide applications, Hasimoto [1] initiated the boundary layer growth on a flat plate with suction or injection. V.M.Soundalgekar [2] studied the viscous dissipation effect on unsteady free convection flow past an infinite, vertical porous plate with constant suction. V.M.Soundalgekar [3] studied the viscous dissipation effect on unsteady free convection flow past an infinite, vertical porous plate with constant suction. The unsteady free convection flow past an infinite plate with constant suction and heat sources has been studied by Pop et.al. [4].Soundalgekar and Wavre [5] studied unsteady free convection flow past an infinite vertical plate with variable suction and mass transfer.

Viscous dissipation effects on the unsteady free convection flow of an elastic-viscous fluid past an infinite vertical plate with constant suction have been studied by V.M. Soundalgekar and G.A.Desai [6]. The two dimensional unsteady free convective and mass transfer flow of an incompressible viscous dissipative and electrically conducting fluid past an infinite vertical porous plate was examined by Gregantopoulos et. al [7]. Raptisand Kafousias [8] studied the influence of a magnetic field upon the steady free convection flow through a porous medium bounded by an infinite vertical plate with a constant suction velocity and when the plate temperature is also constant. Vajravelu [9] studied the exact solution for hydrodynamic boundary layer flow and heat transfer over a continuous, moving horizontal flat surface with uniform suction and internal heat generation/absorption. Vajravelu and A. Hadjinicolaou [10] studied the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or friction heating and internal heat generation. Kim [11] presented the unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Kinyanjui et al.[12] solved the problem of MHD free convection heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with Hall current and radiation absorption by using a finite difference scheme. Muthucumaraswamy [13] presented heat and mass transfer effects on a continuously moving isothermal vertical surface with uniform suction by taking into account the homogeneous chemical reaction of first order. The effect of the viscous dissipation term along with temperature dependence heat source/ sink on momentum, heat and mass transfer in a visco-elastic fluid flow over an accelerating surface were studied by Sonth et al. [14]. Cookey et. al, [15] investigated the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous media with time dependent suction. The study of unsteady hydro magnetic free convection flow of viscous incompressible and electrically conducting fluid pass an infinite vertical porous plate in the Presence of constant suction and heat absorbing, Sinks has been study by Sahoo et al. [16].The combined effect of internal heat generation and magnetic field on free convective mass transfer micro polar fluid flow over a vertical infinite surface with constant suction is investigated by El-Amin [17]. Sarangi and Jose [18] studied the unsteady MHD free convection flow and mass transfer through porous medium with variable suction but with constant heat flux. Aissa and Mohammadein [19] have analyzed the effects of the magnetic parameter, Joule heating, viscous dissipation and heat generation on the MHD micro polar fluids that passed through a stretching sheet. The effects of chemical reaction, thermophoresis and variable viscosity on a study hydromagnetic flow with heat and mass transfer over a flat plate in the presence of heat generation/absorption was examined by Seddeek [20].The effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection was studied by Kandasamy et al.[21]. Salem [22] investigated the simultaneous effects of coupled heat and mass transfer in Darcy-Forchheimer mixed convection from a vertical flat plat embedded in a fluid-saturated porous medium under the effects of radiation and viscous dissipation. Zueco [23] used network simulation method (NSM) to study the effects of viscous dissipation and radiation on unsteady MHD free convection flow past a vertical porous plate. [24] Sharma P. R.Singh G discussed the unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Ibrahim [25] studied the effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction. Prasad VR and Reddy NB [26] investigated Radiation and mass transfer effects on an unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with viscous dissipation. The effect of viscous and joules dissipation on MHD flow, heat and mass transfer past a stretching porous surface embedded in porous medium was studied by Anjali Devi and B. Ganga [27].

In this paper an attempt is made to study the effects of aligned magnetic field, radiation absorption and viscous dissipation on the unsteady convective heat and mass transfer flow along a vertical porous flat surface embedded in a porous medium with constant suction and heat source/sink.

II. MATHEMATICAL FORMULATION

Consider the two-dimensional unsteady free convective flow of a laminar, viscous, incompressible electrically conducting and heat (radiation) absorbing fluid past an infinite vertical porous plate embedded in a uniform porous medium under the action of align magnetic fieldB_0 in the presence of constant suction, heat source or sink with thermal and concentration buoyancy effects. Let *x*-axis be taken in vertically upward direction along the plate and *y*-axis normal to it.

By applying Boussinesq's approximation the governing equations of the flow field are given by:

Continuity equation:

$$\frac{\partial V'}{\partial y'} = 0 \Rightarrow v' = -v_o' (\text{Constant}) \tag{1}$$

Momentum equation:

$$\frac{\partial u'}{\partial t'} + V' \frac{\partial u'}{\partial y'} = \upsilon \frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T_\infty') + g\beta^*(C' - C_\infty') - \frac{\sigma B_0^2 Sin^2\phi}{\rho} u' - \frac{\upsilon}{K'} u' \tag{2}$$

Energy equation:

$$\frac{\partial T'}{\partial t'} + V' \frac{\partial T'}{\partial y'} = K \frac{\partial^2 T'}{\partial y'^2} + \frac{\upsilon}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 + Q_0\left(T - T_\infty'\right) + Q_1'\left(C - C_\infty'\right) \tag{3}$$

Concentration equation:

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

The initial and boundary conditions are

$$u' = 0, V' = -V_0', T' = T_w' + \varepsilon\left(T_w' - T_\infty'\right)e^{i\omega' t'},\ C' = C_w' + \varepsilon\left(C_w' - C_\infty'\right)e^{i\omega' t'}\ at\ y' = 0,$$

$$u' \to 0, T' \to T_\infty', C' \to C_\infty'\ as\ y' \to \infty \tag{5}$$

introducing the following non-dimensional variables and parameters.

$$y = \frac{y' v_0'}{\upsilon}, t = \frac{t' v_0'^2}{4\upsilon}, \omega = \frac{4\upsilon\omega'}{v_0'^2}, u = \frac{u'}{v_0'}, \upsilon = \frac{\eta_0}{\rho}, \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'}, C = \frac{C' - C_\infty'}{C_w' - C_\infty'}, M = \left(\frac{\sigma B_0^2}{\rho}\right)\frac{\upsilon}{V_0'^2}$$

$$k = \frac{V_0^2 K'}{\upsilon^2}, \Pr = \frac{\upsilon}{K}, Gr = \frac{\upsilon g\beta(T_w' - T_\infty')}{V_0'^3}, Gm = \frac{\upsilon g\beta^*(C_w' - C_\infty')}{V_0'^3}, Ec = \frac{V_0'^2}{C_p(T_w' - T_\infty')},$$

$$Q = \frac{4Q_0\upsilon}{V_0'^2}, Q_1 = \frac{\upsilon Q_1'(C_w' - C_\infty')}{(T_w' - T_\infty')V_0'^2} \tag{6}$$

In equations (2), (3) and (4) under boundary condition (5) we get:

$$\frac{1}{4}\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\theta+GmC-\left(MSin^2\phi+\frac{1}{k}\right)u \quad (7)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t}-\frac{\partial \theta}{\partial y}=\frac{1}{pr}\frac{\partial^2 \theta}{\partial y^2}+Ec\left(\frac{\partial u}{\partial y}\right)^2+\frac{1}{4}Q\theta+\frac{1}{4}Q_1C \quad (8)$$

$$\frac{1}{4}\frac{\partial C}{\partial t}=\frac{1}{SC}\frac{\partial^2 C}{\partial y^2} \quad (9)$$

The corresponding boundary conditions are:

$$u=0,\theta=1+\varepsilon e^{i\omega t},C=1+\varepsilon e^{i\omega t}\ at\ y=0$$
$$u\to 0,\theta\to 0,C\to 0\ as\ y\to\infty \quad (10)$$

where g is the acceleration due to gravity, ρ is the density, σ is the electrical conductivity, β is the volumetric coefficient of expansion for heat transfer, β *is the volumetric coefficient of expansion for mass transfer, ν is the coefficient of kinematic viscosity, ω is the angular frequency, η_0 is the coefficient of viscosity, K is the thermal diffusivity, T is the temperature, Tw is the temperature at the plate, T∞ is the temperature at infinity, Cp is the specific heat at constant pressure, Pr is the Prandtl number, Sc is the Schmidt number, M is the magnetic field parameter, k is the permeability parameter, Pr is the Prandtl number, Gr is the Grashof number for heat transfer, Gm is the Grashof number for mass transfer, Q is the heat source/sink parameter, Q_1 is the radiation absorption coefficient , ϕ is an align angle and Ec is the Viscous dissipation or Eckert number.

III. METHOD OF SOLUTION

In order to solve equations (7), (8) and (9) we assume ε to be very small and the concentration, temperature and velocityof the flow field in the neighborhood of the plate as

$$C(y,t)=C_0(y)+\varepsilon e^{i\omega t}C_1(y) \quad (11)$$
$$\theta(y,t)=\theta_0(y)+\varepsilon e^{i\omega t}\theta_1(y) \quad (12)$$
$$u(y,t)=u_0(y)+\varepsilon e^{i\omega t}u_1(y) \quad (13)$$

Substituting equations (11), (12) and (13) in to equations (7), (8) and (9) respectively and equating the harmonic and non-harmonic terms and neglecting the coefficients of ε^2, we get

Zeroth- order equations:

$$C_0^{11}=0 \quad (14)$$

$$\theta_0^{11}+\Pr\theta_0^1+\frac{\Pr Q\theta_0}{4}=\frac{-\Pr Q_1C_0}{4}-\Pr Ec\,u_0^{1^2} \quad (15)$$

$$u_0^{11}+u_0^1-(M\ Sin^2\phi+\frac{1}{k})u_0=-Gr\theta_0-GmC_0 \quad (16)$$

First orderequations:

$$C_1^{11} - \frac{Sci\omega}{4} C_1 = 0 \tag{17}$$

$$\theta_1^{11} + \Pr\theta_1^1 + \left(\frac{Q - i\omega}{4}\right)\Pr\theta_1 = \frac{-\Pr Q_1 C_1}{4} - 2\Pr Ec\, u_0^1 u_1^1 \tag{18}$$

$$u_1^{11} + u_1^1 - (M\ Sin^2\phi + \frac{1}{k} + \frac{i\omega}{4})u_1 = -Gr\theta_1 - GmC_1 \tag{19}$$

The corresponding boundary conditions are

$$y = 0:\ u_0 = 0, \theta_0 = 1, C_0 = 1, u_1 = 0, \theta_1 = 1, C_1 = 1$$

$$y \to \infty : u_0 = 0, \theta_0 = 0, C_0 = 0, u_1 = 0, \theta_1 = 0, C_1 = 0 \tag{20}$$

Using multi parameter perturbation technique and choosing Ec<<1, we get

$$C_0 = C_{00} + Ec\, C_{01} \tag{21}$$

$$\theta_0 = \theta_{00} + Ec\, \theta_{01} \tag{22}$$

$$u_0 = u_{00} + Ec\, u_{01} \tag{23}$$

$$C_1 = C_{10} + Ec\, C_{11} \tag{24}$$

$$u_1 = u_{10} + Ec\, u_{11} \tag{25}$$

$$\theta_1 = \theta_{10} + Ec\, \theta_{11} \tag{26}$$

Now substituting the equations (21) – (26) in to equations (14) – (19) and equating the coefficients of like powers of *Ec* neglecting those of Ec^2 because, Eckert number *Ec* is very small for incompressible fluid flows. we get the following set of differential equations.

Zeroth-order equations:

$$C_{00}^{11} = 0 \tag{27}$$

$$C_{10}^{11} - \frac{SCi\omega}{4} C_{10} = 0 \tag{28}$$

$$\theta_{00}^{11} + \Pr\theta_{00}^1 + \frac{\Pr Q}{4}\theta_{00} = \frac{-\Pr Q_1}{4} C_{00} \tag{29}$$

$$\theta_{10}^{11} + \Pr\theta_{10}^1 + (Q - i\omega)\frac{\Pr}{4}\theta_{10} = \frac{-\Pr Q_1}{4} C_{10} \tag{30}$$

$$u_{00}^{11} + u_{00}^1 - \left(M\ Sin^2\phi + \frac{1}{k}\right)u_{00} = -Gr\,\theta_{00} - Gm\,C_{00} \tag{31}$$

$$u_{10}^{11} + u_{10}^1 - \left(M\ Sin^2\phi + \frac{1}{k} + \frac{i\omega}{4}\right)u_{10} = -Gr\,\theta_{10} - Gm\,C_{10} \tag{32}$$

The corresponding boundary conditions are

$$y = 0 : u_{00} = 0, \theta_{00} = 1, C_{00} = 1, u_{10} = 0, \theta_{10} = 1, C_{10} = 1$$

$$y \to \infty : u_{00} = 0, \theta_{00} = 0, C_{00} = 0, u_{10} = 0, \theta_{10} = 0, C_{10} = 0 \tag{33}$$

First order equations:

$$C_{01}^{11} = 0 \tag{34}$$

$$C_{11}^{11} - \frac{Sci\omega}{4} C_{11} = 0 \tag{35}$$

$$\theta_{01}^{11} + \Pr\theta_{01}^{1} + \frac{\Pr Q}{4}\theta_{01} = \frac{-\Pr Q_1}{4} C_{01} - \Pr u_{00}^{1^2} \tag{36}$$

$$\theta_{11}^{11} + \Pr\theta_{11}^{1} + (Q - i\omega)\frac{\Pr}{4}\theta_{11} = \frac{-\Pr Q_1}{4} C_{11} - 2\Pr u_{00}^{1} u_{10}^{1} \tag{37}$$

$$u_{01}^{11} + u_{01}^{1} - \left(M\, Sin^2\phi + \frac{1}{k} \right) u_{01} = -Gr\,\theta_{01} - Gm\,C_{01} \tag{38}$$

$$u_{11}^{11} + u_{11}^{1} - \left(M\, Sin^2\phi + \frac{1}{k} + \frac{i\omega}{4} \right) u_{11} = -Gr\,\theta_{11} - Gm\,C_{11} \tag{39}$$

The corresponding boundary conditions are

$$y = 0 : u_{01} = 0, \theta_{01} = 0, C_{01} = 0, u_{11} = 0, \theta_{11} = 0, C_{11} = 0$$

$$y \to \infty : u_{01} = 0, \theta_{01} = 0, C_{01} = 0, u_{11} = 0, \theta_{11} = 0, C_{11} = 0 \tag{40}$$

The ordinary differential equations (27) - (32) and (34) –(39) subject to the boundary conditions (33) and (40) respectively then substituting these values in to equations (21) –(26), we obtained the exact solutions as follows,

$$C_0 = 1 \tag{41}$$

$$\theta_0 = (A_4 e^{-m_3 y} - A_3) + Ec(A_{28}\, e^{-2m_5 y} + A_{29}\, e^{-2m_3 y} + A_{30}\, e^{-(m_3+m_5)y} + A_{31}\, e^{-m_3 y}) \tag{42}$$

$$u_0 = (A_{10} e^{-m_3 y} + A_{13} + A_{14}\, e^{-m_5 y}) + Ec(A_{40}\, e^{-2m_5 y} + A_{41}\, e^{-2m_3 y} + A_{42}\, e^{-(m_3+m_5)y} + A_{43}\, e^{-m_3 y} + A_{44}\, e^{-m_5 y}) \tag{43}$$

First ordersolution:

$$C_1 = e^{-m_1 y} \tag{44}$$

$$\theta_1 = (A_2\, e^{-m_2 y} - A_1 e^{-m_1 y}) + Ec(A_{21}\, e^{-(m_4+m_5)y} - A_{22} e^{-(m_3+m_4)y} + A_{23} e^{-(m_2+m_5)y} + A_{24}\, e^{-(m_2+m_3)y} + A_{25} e^{-(m_1+m_5)y} + A_{26}\, e^{-(m_1+m_3)y} + A_{27}\, e^{-m_2 y}) \tag{45}$$

$$u_1 = (A_5\, e^{-m_2 y} + A_8\, e^{-m_1 y} + A_9\, e^{-m_4 y}) + Ec(A_{32}\, e^{-(m_4+m_5)y} + A_{33}\, e^{-(m_3+m_4)y} + A_{34}\, e^{-(m_2+m_5)y} + A_{35}\, e^{-(m_2+m_3)y} + A_{36}\, e^{-(m_1+m_5)y} + A_{37}\, e^{-(m_1+m_3)y} + A_{38} e^{-m_2 y} + A_{39}\, e^{-m_4 y}) \tag{46}$$

Substitute eq. 41-46 in to eq. 11-13, we obtained the solutions for concentration, temperature and velocity which can be expressed as

$$C(y,t)=1+\varepsilon e^{i\omega t}\,e^{-m_1 y} \tag{47}$$

$$\begin{aligned}\theta(y,t)=&[(A_4 e^{-m_3 y}-A_3)+Ec(A_{28}\,e^{-2m_5 y}+A_{29}\,e^{-2m_3 y}+A_{30}\,e^{-(m_3+m_5)y}+A_{31}\,e^{-m_3 y})]+\\ &\varepsilon e^{i\omega t}[(A_2\,e^{-m_2 y}-A_1 e^{-m_1 y})+Ec(A_{21}\,e^{-(m_4+m_5)y}+A_{22}\,e^{-(m_3+m_4)y}+A_{23}\,e^{-(m_2+m_5)y}+\\ &A_{24}\,e^{-(m_2+m_3)y}+A_{25}\,e^{-(m_1+m_5)y}+A_{26}\,e^{-(m_1+m_3)y}+A_{27}\,e^{-m_2 y}]\end{aligned} \tag{48}$$

$$\begin{aligned}u(y,t)=&[(A_{10}\,e^{-m_3 y}+A_{13}+A_{14}\,e^{-m_5 y})+Ec(A_{40}\,e^{-2m_5 y}+A_{41}\,e^{-2m_3 y}+A_{42}\,e^{-(m_3+m_5)y}+A_{43}\,e^{-m_3 y}+A_{44}\,e^{-m_5 y})]\\ &+\varepsilon e^{i\omega t}[(A_5\,e^{-m_2 y}+A_8 e^{-m_1 y}+A_9\,e^{-m_4 y})+Ec(A_{32}\,e^{-(m_4+m_5)y}+A_{33}\,e^{-(m_3+m_4)y}+A_{34}\,e^{-(m_2+m_5)y}+\\ &A_{35}\,e^{-(m_2+m_3)y}+A_{36}\,e^{-(m_1+m_5)y}+A_{37}\,e^{-(m_1+m_3)y}+A_{38}\,e^{-m_2 y}+A_{39}\,e^{-m_4 y})]\end{aligned} \tag{49}$$

Skin friction

$$\begin{aligned}\tau=&\left[\frac{\partial u}{\partial y}\right]_{y=0}\\ =&[(-m_3 A_{10}-m_5 A_{14})+Ec(-2m_5 A_{40}-2m_3 A_{41}-(m_3+m_5)A_{42}-m_3 A_{43}-m_5 A_{44})]+\\ &\varepsilon\, e^{i\omega t}[(-m_1 A_8-m_2 A_5-m_4 A_9)+Ec(-(m_4+m_5)A_{32}-(m_3+m_4)A_{33}-(m_2+m_5)A_{34}-\\ &(m_2+m_3)A_{35}-(m_1+m_5)A_{36}-(m_1+m_3)A_{37}-m_2 A_{38}-m_4 A_{39})]\end{aligned} \tag{50}$$

Nusselt number

$$\begin{aligned}Nu=&\left[\frac{\partial\theta}{\partial y}\right]_{y=0}\\ =&[-m_3 A_4+Ec(-2m_5 A_{28}-2m_3 A_{29}-(m_3+m_5)A_{30}-m_3 A_{31})]+\\ &\varepsilon\, e^{i\omega t}[(m_1 A_1-m_2 A_2)+Ec(-(m_4+m_5)A_{21}-(m_3+m_4)A_{22}-(m_2+m_5)A_{23}-\\ &(m_2+m_3)A_{24}-(m_1+m_5)A_{25}-(m_1+m_3)A_{26}-m_2 A_{27})]\end{aligned} \tag{51}$$

Sherwood number

Knowing the concentration field, the rate of mass transfer at the wall can be obtained, which in non – dimensional form, in terms of the Sherwood number, is given by

$$\begin{aligned}Sh=&\left[\frac{\partial c}{\partial y}\right]_{y=0}\\ =&-m_1\varepsilon\, e^{i\omega t}\end{aligned} \tag{52}$$

IV. RESULTS AND DISCUSSION

In order to get an insight in the physical situation of the problem, the numerical values of the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number at the plate are obtained for different values of the physical parameters like thermal Grashof number (Gr), mass Grashof number (Gm), Prandtl number (Pr), Schmidt number (Sc),Viscous dissipation or Eckert number(Ec),magnetic field parameter(M), permeability parameter(K),heat source /sink parameter(Q) , radiation absorption coefficient (Q_1), angular frequency(ω), epsilon parameter (ε)and angle ϕ involved on the flow field are analyzed and discussed with the help of figures from 1-25 and Tables 1-3.The value of the Schmidt number Sc is taken to be 0.66 which corresponds to water-vapor. The value of Pr is taken to be 0.71 which corresponds to air at $25^0 C$ temperature. The values of the other physical parameters are chosen arbitrarily.

For different values of the Schmidt number Sc, the concentration profile is plotted in figure1. We notice that the effect of increasing values of Sc is to decrease the concentration in the flow field. Figure 2 displays the effect of angular frequency ω on concentration profile. It is seen that the concentration distributions decrease with increasing the angular frequency parameter.Figure3 represents the concentration profile for different values of epsilon parameter (ε).It is observed that an increasing in epsilon parameter(ε)leads to a rise in the values of concentration.

The variation of the temperature distributions are presented in figures 4-14.As Gr increases, temperature increases for both heat source parameter (Q>0) and heat sink parameter (Q<0). Figures 5a and 5b shows the effect of increasing the Grashof number for mass transfer Gc on temperature field for Q>0 and Q<0.The analytic results shows that an increasing values of Grashof number for mass transfer Gc, results to an increase in the temperature in both the cases . Figure 6a and 6b reveals that the temperature profile for different values of Schmidt number with respect to heat source and heat sink parameters. It is noticed that the temperature of the flow field increasing, as the values of Schmidt number is increasing. Fig.7a and Fig.7b shows the variation of the temperature profiles with the viscous dissipation Ec. These figures show that as viscous dissipation Ec increases, the temperature increases.

Fig. 8a and Fig.8b gives the effect of Prandtl number Pr on the temperature distribution. From these figures we see that temperature decrease with an increasing of Pr. Fig.9a and Fig. 9b shows the variation of temperature profiles for different values of magnetic field parameter M. It is observed from these figures that temperature decrease with an increasing of M.

The temperature profiles are calculated for different values of permeability parameter K and these are shown in Fig10a and Fig10b.It is seen that, temperature increases with increase in permeability parameter.

Figs. 11a−25a indicate the variations of the non-dimensional velocity corresponding to heat source parameter (i.e. Q>0) and figures 11b-25b corresponding to heat sink parameter (i.e. Q<0) with different flow parameters respectively.

In Fig.11a and Fig.11b, the velocity profile is plotted for various values of thermal Grashof number Gr. It is observed that the mainstream velocity increases in both the cases with an increase in the Gr. Fig.12a and Fig.12b shows the velocity distributions for different values of mass Grashof number Gm. It can be seen that the velocity increases with the increase of Gm, for both Q>0 and Q<0.

Fig13a and Fig.13b reveal the velocity variations with Schmidt number Sc. The velocity decreases with an increase in Schmidt number.

The variation of the velocity profile is shown on Fig.14a and Fig.14b with different varying values of viscous dissipation Ec. The velocity increases with increasing the value of Ec.

In Fig15a and Fig.15b, we discuss the effect of Prandtl number Pr on the velocity field. It is found that for the increase of Pr, the velocity decreases.

Table1 presents the variation of skin friction for various values of physical parameters encountering in the flow field corresponding to heat source and heat sink parameters. The results show that the skin friction coefficient increases due to the increase of Gr, Gm, k,Ec, Sc, ω and ε while it decreases with increasing M, Q, Pr and ϕ in both the cases.

Table 2 show that the coefficient of rate of heat transfer for different flow parameters on the fluid flow. It is noticed that the rate of heat transfer coefficient falls with the increase of M, Pr, Sc and ϕ where as it increases with the increase of Gr, Gm, k, Ec, ω and ε in both the cases. It is interesting to note here that the skin friction and rate of heat transfer coefficient decreases as Q_1 increases in the case of heat source parameter where as an opposite behavior occurs in the case of heat sink parameter . It is also observed from the Table 3 that Sherwood number increases with an increase of Sc, ω and ε . The tabular values are not provided as they are space consuming.

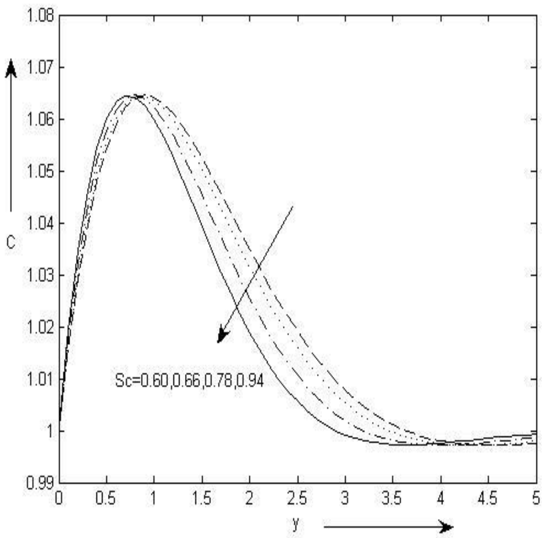

Fig 1 Effect of Sc on Concentration profile when ω =5.0, ε =0.2

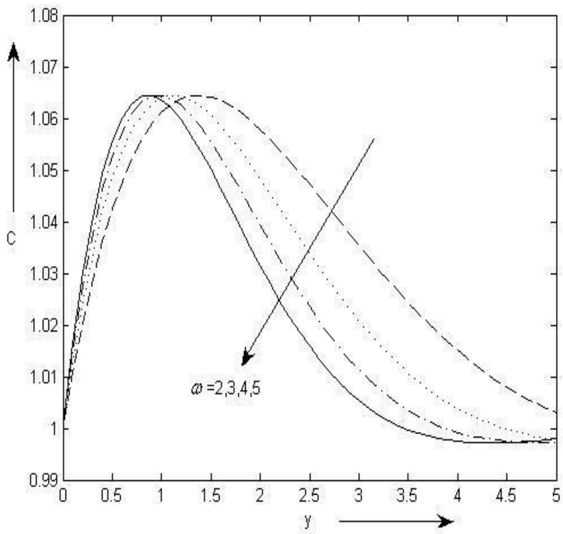

Fig 2 Effect of ω on Concentration profile when Sc=0.66 , ε =0.2

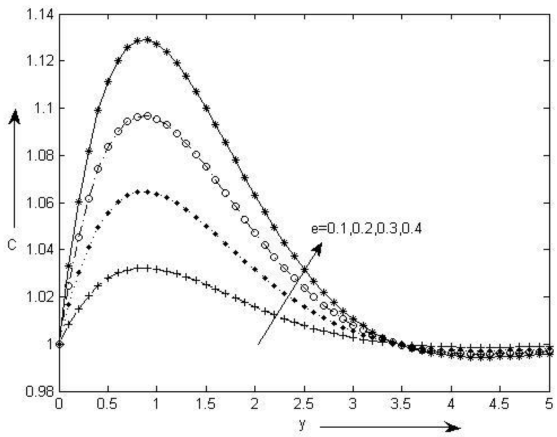

Fig 3 Effect of ε on Concentration profile When Sc=0.66, ω =5.0

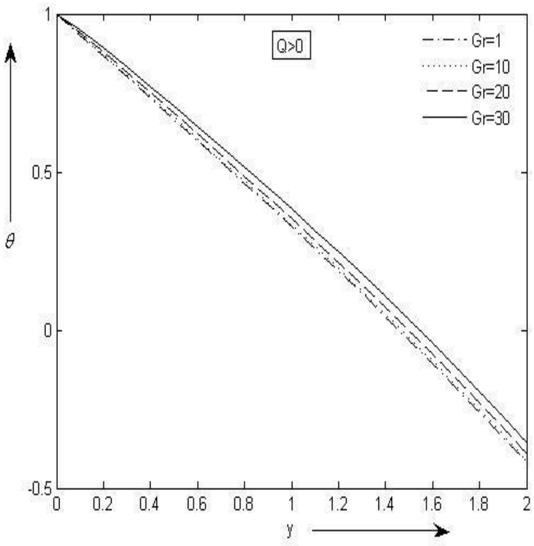

Fig 4a Effect of Gr on Temperature profile
When Gm=1, Ec=0.002, M=1, K=1, Q=1 ,
ε =0.2, ω =1.0

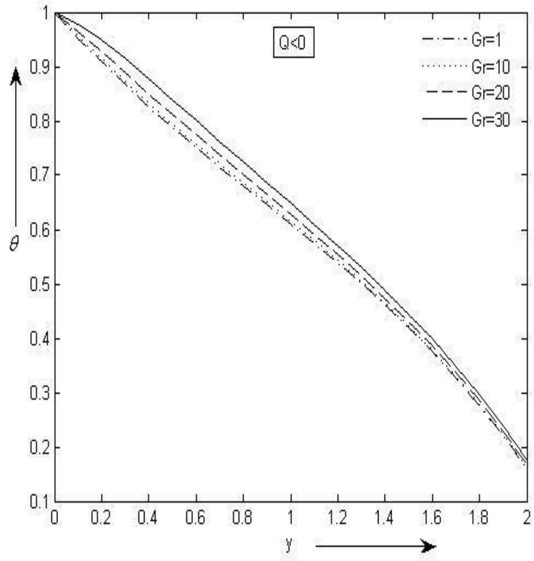

Fig 4b Effect of Gr on Temperature profile
When Gm=1, Ec=0.002, M=1, K=1, Q=-1, Q_1=0.5,
Q_1=0.5 ε =0.2, ω =1.0

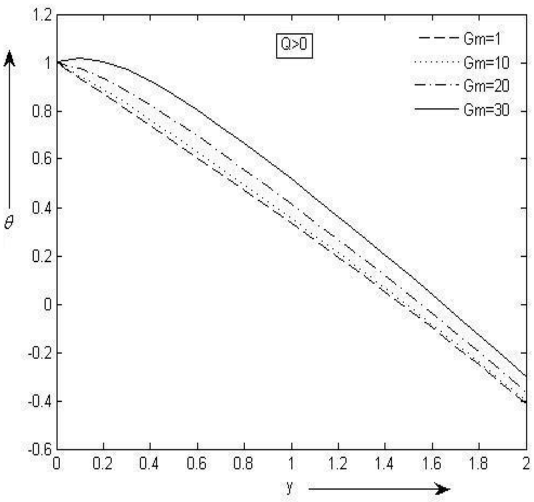

Fig 5a Effect of Gm on Temperature profile
When Gr=10, Ec=0.002, M=1, K=1, Q=1 ,
ε =0.2, ω =1.0

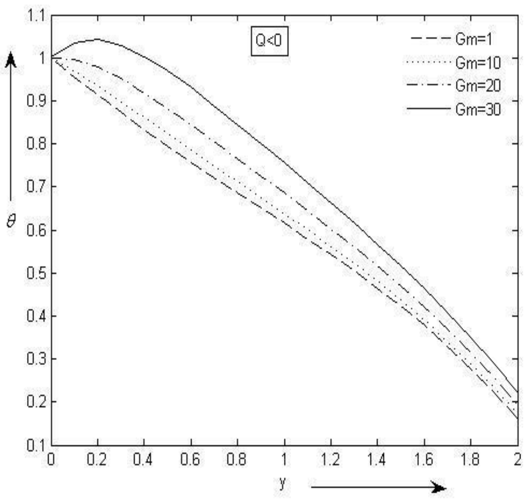

Fig 5b Effect of Gm on Temperature profile
When Gr=10, Ec=0.002, M=1, K=1, Q=-1, Q_1=0.5,
Q_1=0.5 ε =0.2, ω =1.0

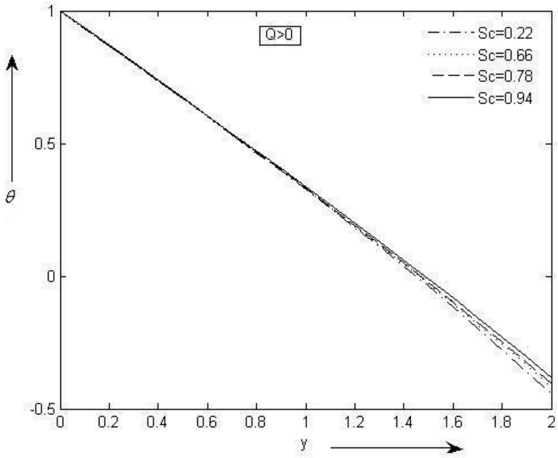

Fig 6a Effect of Sc on Temperature profile
When Gr=5, Gm=1, Ec=0.002, M=1, K=1, Q=1, ε =0.2, ω =1.0

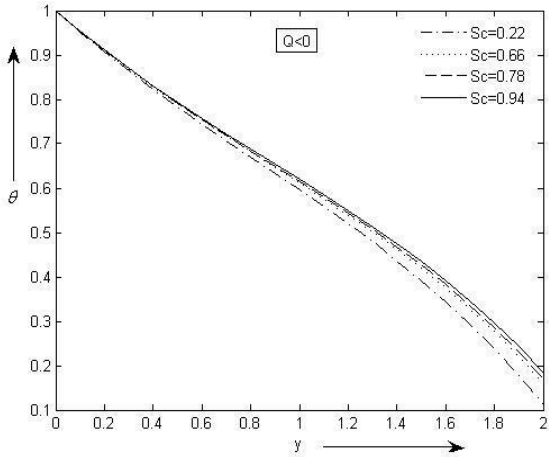

Fig 6b Effect of Sc on Temperature profile
When Gr=5, Gm=1, Ec=0.002, M=1, K=1, Q_1=0.5, Q=-1,Q_1=0.5 ε =0.2, ω =1.0

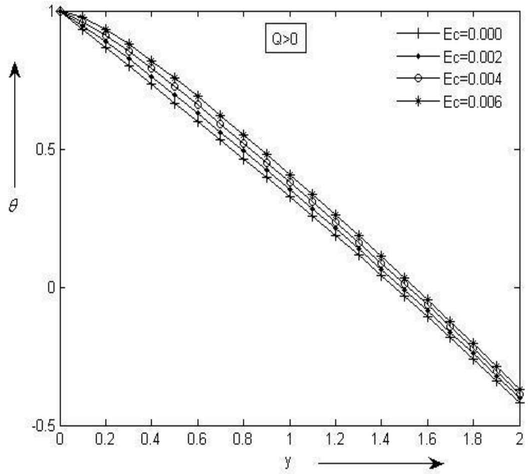

Fig 7a Effect of Ec on Temperature profile
When Gr=10, Gm=10,M=1, K=1, Q=1, =0.2, ω =1.0

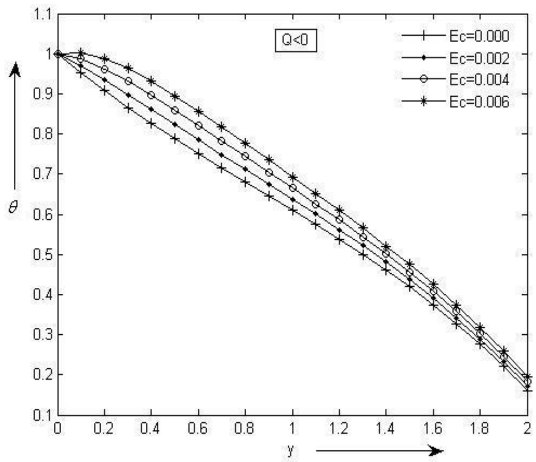

Fig 7b Effect of Ec on Temperature profile,
When Gr=10, Gm=10, M=1, K=1, Q=-1, Q_1=0.5, ε Q_1=0.5 ε =0.2, ω =1.0

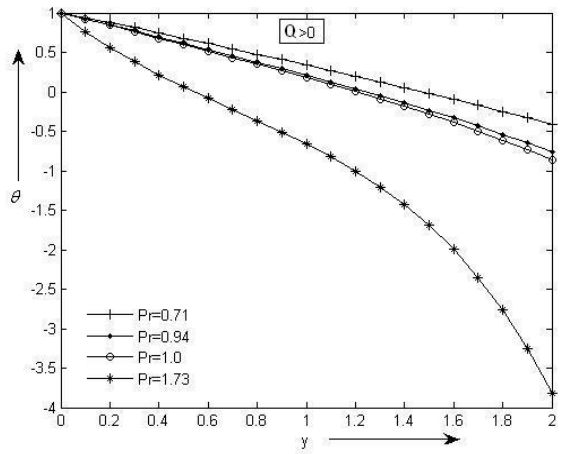

Fig 8a Effect of Pr on Temperature profile
When Gr=5,Gm=5, M=1, Ec=0.002, K=2, Q=1, Q_1=0.5, ε =0.2, ω =1.0

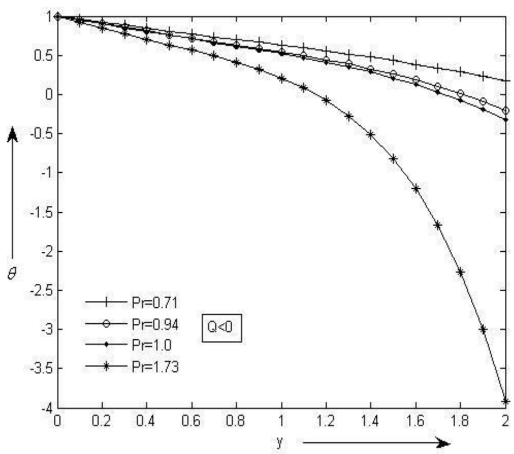

Fig 8b Effect of Pr on Temperature profile
When Gr=5, Gm=5, M=1, Ec=0.002, K=2, Q=-1, , Q_1=0.5 ε =0.2, ω =1.0

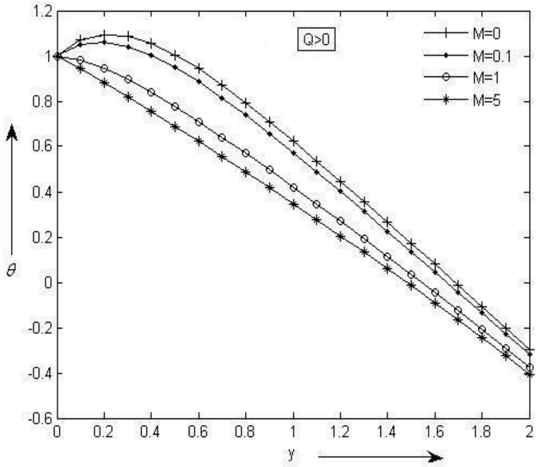

Fig 9a Effect of M on Temperature profile When Gr=10,Gm=10, Ec=0.002, K=5, Q=1, ε =0.2, ω =1.0

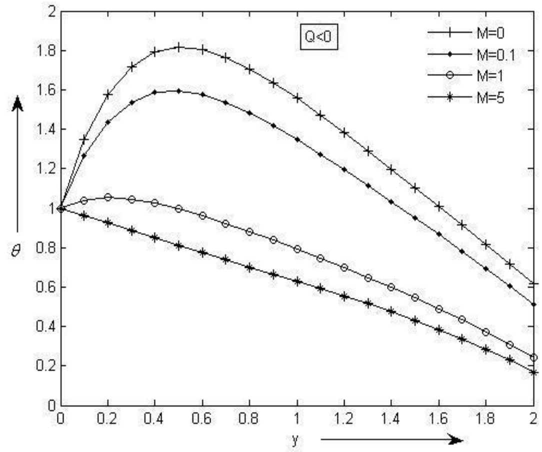

Fig 9b Effect of M on Temperature profile When Gr=10, Gm=10, Ec=0.002, K=5, Q=-1, Q_1=0.5, Q_1=0.5 ε =0.2, ω =1.0

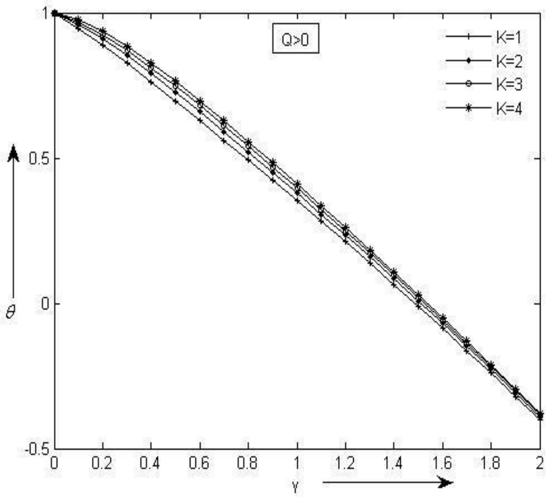

Fig 10a Effect of K on Temperature profile,when Gr=10,Gm=10, Ec=0.002, M=1, Q=1, Q_1=0.5, ε =0.2, ω =1.0

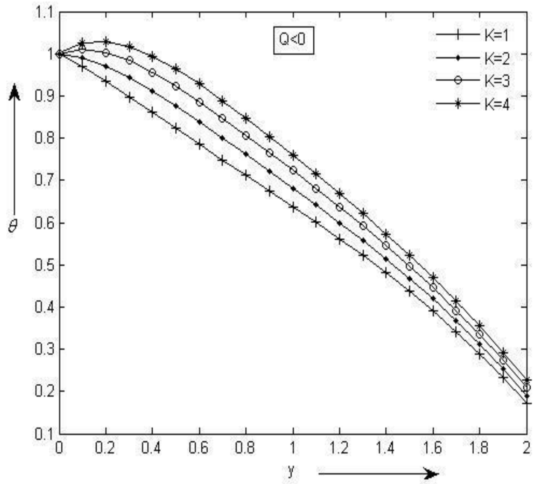

Fig 10b Effect of K on Temperature profile, when Gr=10, Gm=10, Ec=0.002, M=1, Q=-1, Q_1=0.5 ε =0.2, ω =1.0

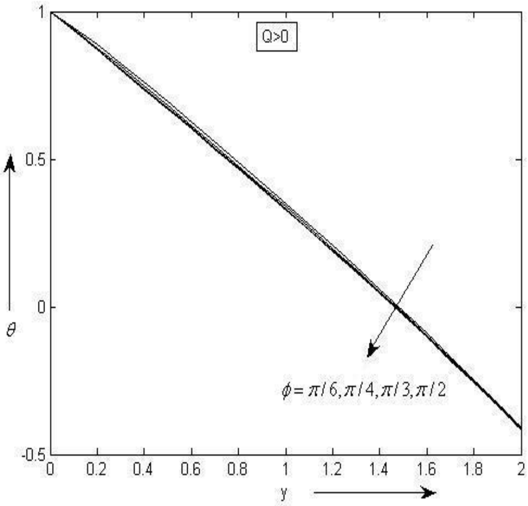

Fig 11a Effect of ϕ on Temperature profile
When Gr=5, Gm=5, Ec=0.002, K=5, Q=1,
ε =0.2, ω =1.0, M=1

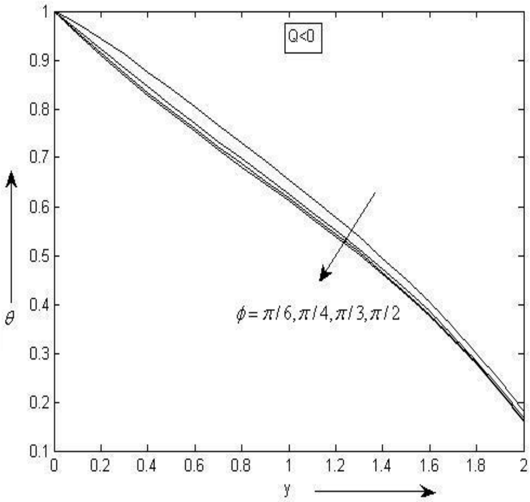

Fig 11b Effect of ϕ on Temperature profile
When Gr=5, Gm=5, Ec=0.002, K=5, Q=-1,Q_1=0.5,
Q_1=0.5 ε =0.2, ω =1.0 , M=1

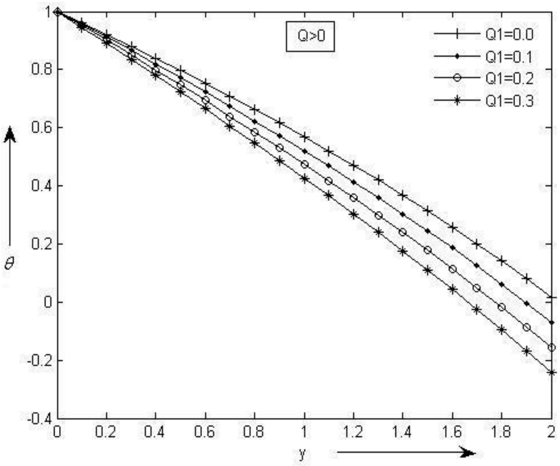

Fig 12a Effect of Q_1 on Temperature profile,
when Gr=5,Gm=5, Ec=0.002, K=5, Q=1,
=0.2, ω =1.0, M=1

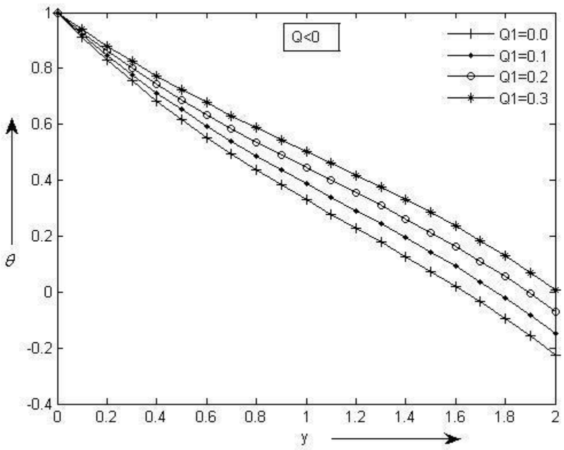

Fig12b. Effect of Q_1 on Temperature profile,
When Gr=5, Gm=5, Ec=0.002, K=5, Q=-1, ε
ε =0.2, ω =1.0 , M=1

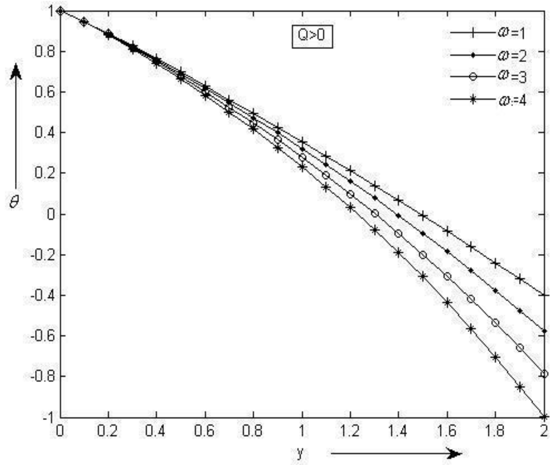

Fig 13a Effect of ω on Temperature profile When Gr=10,Gm=10, Ec=0.002, K=1, Q_1=0.5, ε =0.2, M=1

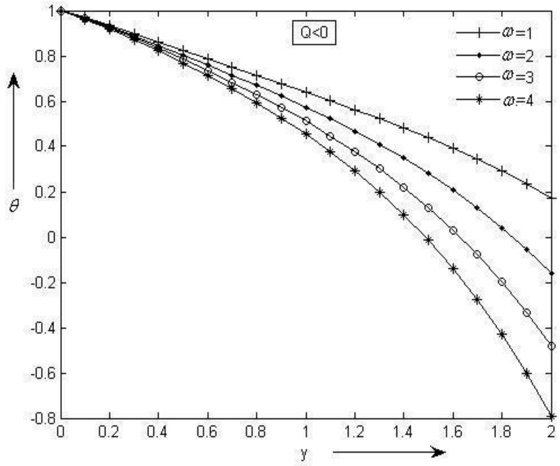

Fig 13b Effect of ω on Temperature profile When Gr=10, Gm=10, Ec=0.002, K=1, Q=-1, Q=1, Q_1=0.5, ε =0.2, M=1

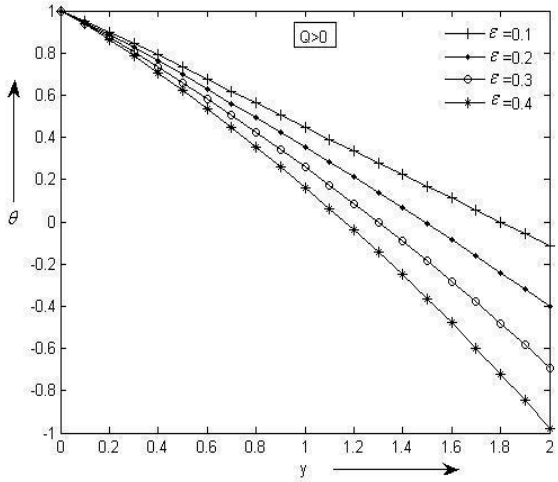

Fig 14a Effect of ε on Temperature profile When Gr=10,Gm=10, Ec=0.002, K=1, Q_1=0.5, ω =1, M=1

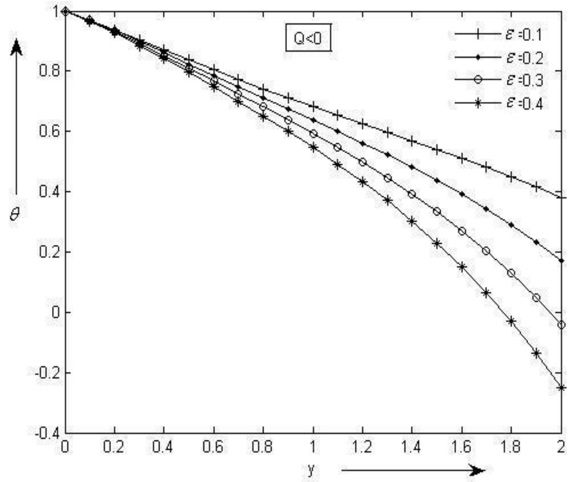

Fig 14b Effect of ε on Temperature profile When Gr=10, Gm=10, Ec=0.002, K=1, Q=-1, Q=1, Q_1=0.5, ω =1, M=1

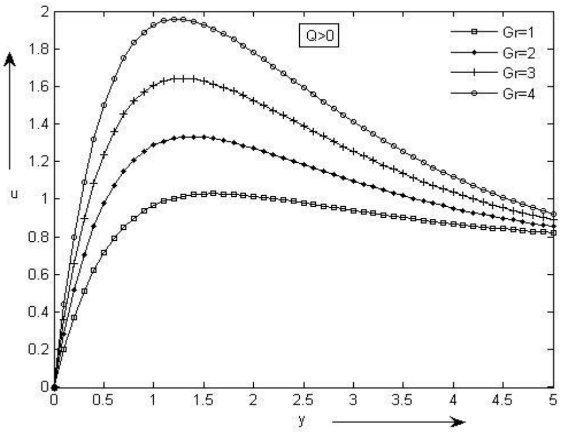

Fig 15a Effect of Gr on velocity profile
When Gm=1, Ec=0.002, M=1, K=1, Q=1, Q_1=0.01, ε =0.01, ω =1.0

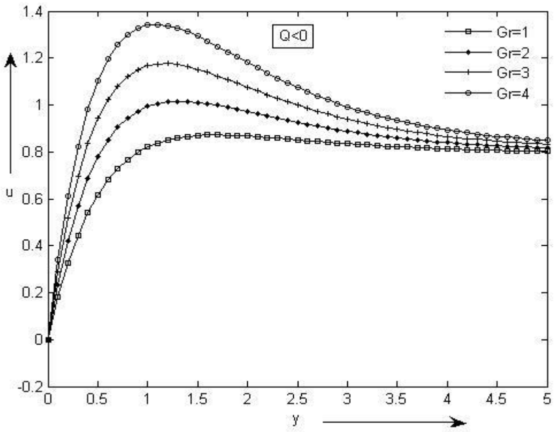

Fig 15b Effect of Gr on Velocity profile
When Gm=1, Ec=0.002, M=1, K=1, Q=-1, Q_1=0.01, ε =0.01, ω =1.0

Table 1: Values of the coefficient of Skinfriction at the wall for various values of physical parameters, where $\omega t = \pi/2$

Gr	*Gm*	*Sc*	*Pr*	*Ec*	*M*	*K*	*Q*	Q_1	ω	ε	ϕ	τ *for heat source parameter Q>0*	τ *for heat sink parameter Q<0*
3	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	3.9977	3.8383
4	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	4.8765	4.4574
5	2	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	7.1253	5.8243
5	3	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	8.4963	7.1922
5	4	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	9.8690	8.5612
5	1	0.30	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	5.7560	4.4574
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	5.7561	4.4574
5	1	0.78	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	5.7561	4.4574
5	1	0.94	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/6$	5.7562	4.4574
5	1	0.66	1	0.002	1	1	1	0.01	1	0.01	$\pi/6$	5.4169	3.9878
5	1	0.66	2	0.002	1	1	1	0.01	1	0.01	$\pi/6$	3.3710	3.1083
5	1	0.66	7	0.002	1	1	1	0.01	1	0.01	$\pi/6$	1.9737	2.0547
5	1	0.66	0.71	0.01	1	1	1	0.01	1	0.01	$\pi/6$	5.7812	4.4688
5	1	0.66	0.71	0.05	1	1	1	0.01	1	0.01	$\pi/6$	5.9069	4.5258
5	1	0.66	0.71	0.10	1	1	1	0.01	1	0.01	$\pi/6$	6.0639	4.5971
5	1	0.66	0.71	0.002	0	1	1	0.01	1	0.01	$\pi/6$	6.4851	4.9608
5	1	0.66	0.71	0.002	2	1	1	0.01	1	0.01	$\pi/6$	5.2222	4.0907
5	1	0.66	0.71	0.002	3	1	1	0.01	1	0.01	$\pi/6$	4.8099	3.8069
5	1	0.66	0.71	0.002	1	2	1	0.01	1	0.01	$\pi/6$	7.3377	5.5597
5	1	0.66	0.71	0.002	1	3	1	0.01	1	0.01	$\pi/6$	8.2276	6.2041
5	1	0.66	0.71	0.002	1	4	1	0.01	1	0.01	$\pi/6$	8.8109	6.6407
5	1	0.66	0.71	0.002	1	1	1.5	0.01	1	0.01	$\pi/6$	5.4642	4.3108
5	1	0.66	0.71	0.002	1	1	2	0.01	1	0.01	$\pi/6$	5.2094	4.1942
5	1	0.66	0.71	0.002	1	1	2.5	0.01	1	0.01	$\pi/6$	4.9847	4.0968

Table: 1. Continued on next page…

5	1	0.66	0.71	0.002	1	1	1	0.00	1	0.01	$\pi/6$	5.7802	4.4197
5	1	0.66	0.71	0.002	1	1	1	0.02	1	0.01	$\pi/6$	5.7320	4.4951
5	1	0.66	0.71	0.002	1	1	1	0.04	1	0.01	$\pi/6$	5.6838	4.5706
5	1	0.66	0.71	0.002	1	1	1	0.01	2	0.01	$\pi/6$	5.7578	4.4608
5	1	0.66	0.71	0.002	1	1	1	0.01	3	0.01	$\pi/6$	5.7583	4.4624
5	1	0.66	0.71	0.002	1	1	1	0.01	4	0.01	$\pi/6$	5.7582	4.4632
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.02	$\pi/6$	5.7697	4.4651
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.03	$\pi/6$	5.7834	4.4728
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.04	$\pi/6$	5.7970	4.4805
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/4$	5.1097	4.0133
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/3$	4.4793	3.5783
5	1	0.66	0.71	0.002	1	1	1	0.01	1	0.01	$\pi/2$	3.4593	2.8597

Table 2: Values of the coefficient of Nusselt number at the wall for various values of physical parameters, where $\omega t = \pi/2$

Gr	*Gm*	*Sc*	*Pr*	*Ec*	*M*	*K*	*Q*	Q_1	ϕ	ω	ε	*Nu for heat source parameter Q>0*	*Nu for heat sink parameter Q<0*
1	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4395	-0.4066
10	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.3940	-0.3544
15	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.3398	-0.2967
5	2	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4218	-0.3820
5	3	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4139	-0.3703
5	1	0.60	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4267	-0.3911
5	1	0.78	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4290	-0.3925
5	1	0.94	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4306	-0.3934
5	1	0.66	0.71	0.002	0	5	1	0.5	π/6	1	0.2	-0.4058	0.0031
5	1	0.66	0.71	0.002	0.1	5	1	0.5	π/6	1	0.2	-0.4079	-0.0836
5	1	0.66	0.71	0.002	5	5	1	0.5	π/6	1	0.2	-0.4303	-0.3965
5	1	0.66	0.71	0.002	1	2	1	0.5	π/6	1	0.2	-0.4200	-0.3699
5	1	0.66	0.71	0.002	1	3	1	0.5	π/6	1	0.2	-0.4164	-0.3506
5	1	0.66	0.94	0.002	1	2	1	0.5	π/6	1	0.2	-0.5587	-0.4700
5	1	0.66	1	0.002	1	2	1	0.5	π/6	1	0.2	-0.5810	-0.4955
5	1	0.66	0.71	0.000	1	1	1	0.5	π/6	1	0.2	-0.4380	-0.4045
5	1	0.66	0.71	0.004	1	1	1	0.5	π/6	1	0.2	-0.4170	-0.3786
5	1	0.66	0.71	0.006	1	1	1	0.5	π/6	1	0.2	-0.4066	-0.3657
5	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.3	-0.3792	-0.3669
5	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.4	-0.3309	-0.3423
5	1	0.66	0.71	0.002	1	1	1	0.5	π/6	2	0.2	-0.4160	-0.3698
5	1	0.66	0.71	0.002	1	1	1	0.5	π/6	3	0.2	-0.4026	-0.3509
5	1	0.66	0.71	0.002	1	1	1	0.0	π/6	1	0.2	-0.2738	-0.8725
5	1	0.66	0.71	0.002	1	1	1	0.1	π/6	1	0.2	-0.3049	-0.7770
5	1	0.66	0.71	0.002	1	1	1	0.2	π/6	1	0.2	-0.3358	-0.6812
5	1	0.66	0.71	0.002	1	5	1	0.5	π/6	1	0.2	-0.4208	-0.3732
5	1	0.66	0.71	0.002	1	5	1	0.5	π/6	1	0.2	-0.4277	-0.3921
5	1	0.66	0.71	0.002	1	5	1	0.5	π/6	1	0.2	-0.4355	-0.4037
5	1	0.66	0.71	0.002	1	1	1	0.5	π/6	1	0.2	-0.4275	-0.3916
5	1	0.66	0.71	0.002	1	1	1.5	0.5	π/6	1	0.2	-0.3580	-0.6042
5	1	0.66	0.71	0.002	1	1	2	0.5	π/6	1	0.2	-0.3168	-0.7439
5	1	0.66	0.71	0.002	1	1	2.5	0.5	π/6	1	0.2	-0.2878	-0.8508

Table 3: Values of the coefficient of Sherwood number at the wall for various values of physical parameters, where $\omega t = \pi/2$

Sc	ω	ε	ωt	*Sherwood Number(Sh)*
0.60	5	0.2	$\pi/2$	0.1225
0.78	5	0.2	$\pi/2$	0.1396
0.94	5	0.2	$\pi/2$	0.1533
0.66	2	0.2	$\pi/2$	0.0812
0.66	3	0.2	$\pi/2$	0.0995
0.66	4	0.2	$\pi/2$	0.1149
0.66	5	0.1	$\pi/2$	0.0642
0.66	5	0.3	$\pi/2$	0.1927
0.66	5	0.4	$\pi/2$	0.2569

V. CONCLUSION

The above study brings out the following results of physical interest on the velocity, temperature, concentration, skin friction , rate of heat transfer and rate of mass transfer at the wall of the flow field corresponding to heat source parameter(i.e. Q>0) and heat sink parameter (i.e. Q<0).

Increasing the Schmidt number, induces reduction in the distribution of concentration, velocity and the rate of heat transfer. On the other hand the effect of increasing the Schmidt number leads to increase in the temperature and Skin friction coefficient for Q>0 and Q<0. An increase in the Grashof number for heat transfer, Grashof number for mass transfer , permeability parameter and viscous dissipation Ec causes an increase in the velocity , temperature, concentration, skin friction and the rate of heat transfer for both Q>0 and Q<0. The velocity, temperature, concentration, skin friction and the rate of heat transfer decreases with increasing the magnetic field parameter, Prandtl number and angle ϕ in both the cases of heat source parameter and heat sink parameter. Increasing the material parameter epsilon increases the velocity, concentration, skin friction and the rate of heat transfer and decreases the Temperature For Q>0 And Q<0.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Statement: The authors declare that they have followed ethical responsibilities.

REFERENCES

[1] Hasimoto(1957).Boundary layer growth on a flat plate with suction or injection. J. Phys. Soc. Japan 12, 68-72,

[2] Soundalgekar VM (1972).Viscous dissipation effects on unsteady free convective flow past an infinite vertical porous plate with constant suction. International Journal of H. M. T., 15, pp.1253-1261

[3] V.M. Soundalgekar,(1974), Viscous dissipation effect on unsteady free convection flow past an infinite, vertical porous plate with variable suction, Int J. Heat and Mass Transfer, 17, 85-92

[4] Pop, I., Soundalgekar V M (1974), The unsteady free-convection flow past an infinite plate with constant suction and heat sources, Int. J. Heat Mass Transfer, 17, 85-91.

[5] Soundalgekar, V. M. and Wavre, P. D(1977). "Unsteady Free Convection Flow Past an Infinite Vertical Plate with Variable Suction and Mass Transfer," Int. J. Heat MassTransfer, Vol. 20, pp. 1375-1380.

[6] V.M. Soundalgekar and G.A Desai(1979), Viscous dissipation effects on the unsteady free convective flow of an elastico-viscous fluid past an infinite vertical plate with constant suction, Indian J. pure Appl. Math., 10 (11), 1397-1404.

[7]Gregantopoulos GA, Koullias J, Goudas CL and Courogenis C (1981). Free convection and mass transfer effects on the hydromagnetic oscillatory flow past an infinite vertical porous plate. Astrophysics and space science 74 pp. 357-389..

[8] Raptis, A. A and Kafousias (1982), N. Heat transfer in flow through a porous medium bounded by an infinite vertical plate under the action of a magnetic field. Inter. J. Energy Research, 6(1982), 241- 245.
[9] Vajravelu, K(1986), "Hydrodynamic Flow and Heat Transfer over Continuous, Moving Porous, Flat Surface", Acta Mech.,64, 179-185.
[10] Vajravelu, K. and A. Hadjinicolaou (1997), Convective heat transfer in an electrically conducting fluid at a stretching surface with uniform free stream, Int. J. Engg. Sci., 35(12-13): 1237-1244.
[11] Kim Y. J(2000). Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Int. J. Engng. Sci. 38, 833-845.
[12] Kinyanjui M, Kwanza JK, Uppal SM (2001) Magnetohydrodynamic free convection heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with Hall current and radiation absorption. Energy Conversion Management 42:917-931.
[13] Muthecumaraswamy R (2002), Effects of a chemical reaction on a moving isothermal surface with suction. ActaMechanica 155, pp.65-72.
[14] R. M. Sonth, S. K. Khan, M.S. Abel, K.V.Prasad (2002), Heat and mass transfer in a visco-elastic fluid over an accelerating surface with heat source /sink and viscous dissipation, HMT, 38, 213-220.
[15] Cookey, C. A., Ogolu, A. and Omubopepple, V. B(2003)., Influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction, International journal of heat and mass transfer, vol.13; pp. 2305-2311.
[16] Sahoo,P.K., N. Datta and S. Biswal (2003), "MHD unsteady free convection flow past an infinite vertical plate with constant suction and heat sink," IJPAM, 34,145-55.
[17] El-Amin, M.F(2004)., "Combined effect of internal heat generation and magnetic field on free convection and mass transfer flow in a micropolar fluid with constant suction", Journal of Magnetism and Magnetic Materials, Vol. 270, pp. 130-135.
[18] Sarangi, K. C. and Jose, C. B(2004)., "Unsteady MHD Free Convection Flow and Mass Transfer through Porous Medium with Variable Suction and Constant Heat Flux," J. Indian Acad. Math., Vol. 26,115-126.
[19] Aissa, W.A. &Mohammadein, A.A (2005). "Joule Heating Effects on a Micropolar Fluid Past a Stretching Sheet with Variable Electric Conductivity". Jounal of Computational and Applied Mechanics.Vol. 6.No. 1, pp. 3-13.
[20] Seddek MA (2005). Finite-element Method for the Effects of Chemical Reaction,Variable Viscosity, Thermophoresis and Heat Generation/Absorption on a Boundary-layer Hydro Magnetic Flow with Heat and Mass Transfer Over a Heat Surface. ActaMech 177, pp. 1-18,
[21] Kandasamy R, Wahib B, Md Raj and Azme B Khamis (2006)., Effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in presence of suction or injection. Theatrical Applied Mechanics Belgrade, 33(2), pp. 123-148.
[22] Salem, A. M (2006), Coupled Heat and Mass Transfer in Darcy-Forchheimer Mixed Convection from a Ver-tical Flat Plate Embedded in a Fluid-Saturated Porous Medium under the Effects of Radiation and Visc-ous Dissipation, J. of the Korean Physical Society, 48, 3, pp. 409-413.
[23] Zueco, J (2007). "Network simulation method applied to radiation and viscous dissipation effect on porous plate". Applied mathematical Modeling, Vol. 31, and Pp.2019-2033.
[24] Sharma P. R., Singh G (2008). Unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Int. J. Appl. Math. Mech. 4, 5, pp1-8.
[25] Ibrahim FS., Elaiw AM., Bakr AA(2008)., Effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction. Communications in Nonlinear Science and Numerical Simulation Vol 13 pp.1056-1066..
[26] Prasad VR and Reddy NB (2008)., Radiation and mass transfer effects on an unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with viscous dissipation. Indian J. of Pure & Appl. Phys., 46, pp. 81-92.
[27]. S.P. Anajali Devi and B. Ganga (2009), Effects of Viscous and Joules dissipation on MHD flow,haet and mass transfer past a stretching porous surface embedded in a porous medium., Nonlinear Analysis: Modelling and Control , 14(3), 303-314.
[28] Okedoye, A. M., and Lamidi, O. T (2009), Analytical solution of an unsteady flow past an Accelerated Vertical Porous plate with solution. Journal of Nigerian Mathematical Physics.Vol. 15; pp. 501-512.

[30] Das S. S., Satapathy A., Das J. K., Panda J. P (2009). Mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Int. J. Heat Mass Trans. 52, 5962-5969.
[31] HemantPoonia_ R.C.Chaudhary (2010). MHD free convection and mass transfer flow over an infinite vertical porous plate with viscous dissipation Theoret. Appl. Mech., Vol.37, No.4, pp. 263–287.
[32] BalaSiddulu Malga and NaikotiKishan(2011). Viscous Dissipation Effects on Unsteady free convection and MassTransfer Flow past an Accelerated Vertical Porous Plate with Suction, Advances in Applied Science Research, 2 (6):460-469.

APPENDIX

$$M_1 = MSin^2\phi + \frac{1}{k}, M_2 = MSin^2\phi + \frac{1}{k} + \frac{i\omega}{4},\ M_3 = (Q - i\omega)\frac{\Pr}{4}, M_4 = \frac{\Pr Q}{4}$$

$$m_1 = \sqrt{\frac{Sc\, i\omega}{4}}, m_2 = \frac{\Pr + \sqrt{\Pr^2 - 4M_3}}{2},\ m_3 = \frac{\Pr + \sqrt{\Pr^2 - 4M_4}}{2}, m_4 = \frac{1 + \sqrt{1 + 4M_2}}{2}, m_5 = \frac{1 + \sqrt{1 + 4M_1}}{2}$$

$$A_1 = \frac{\Pr Q_1}{4(m_1^2 - \Pr m_1 + M_3)}, A_2 = 1 + A_1, A_3 = \frac{Q_1}{Q}, A_4 = 1 + A_3, A_5 = \frac{-Gr\, A_2}{m_2^2 - m_2 - M_2}, A_6 = \frac{Gr\, A_1}{m_1^2 - m_1 - M_2},$$

$$A_7 = \frac{Gm}{m_1^2 - m_1 - M_2}, A_8 = A_6 - A_7, A_9 = -(A_5 + A_8), A_{10} = \frac{-Gr\, A_4}{m_3^2 - m_3 - M_1}, A_{11} = \frac{Gr\, A}{M_1}, A_{12} = \frac{Gm}{M_1},$$

$$A_{13} = A_{12} - A_{11},\ A_{14} = -(A_9 + A_{10}),\ A_{15} = A_9 A_{14} m_4 m_5, A_{16} = A_9 A_{10} m_3 m_4, A_{17} = A_5 A_{14} m_2 m_5, A_{18} = A_5 A_{10} m_2 m_3,$$

$$A_{19} = A_8 A_{14} m_1 m_5,\ A_{20} = A_8 A_{10} m_1 m_3, A_{21} = \frac{-2\Pr A_{15}}{(m_4 + m_5)^2 - \Pr(m_4 + m_5) + M_3},$$

$$A_{22} = \frac{-2\Pr A_{16}}{(m_3 + m_4)^2 - \Pr(m_3 + m_4) + M_3}, A_{23} = \frac{-2\Pr A_{17}}{(m_2 + m_5)^2 - \Pr(m_2 + m_5) + M_3},$$

$$A_{24} = \frac{-2\Pr A_{18}}{(m_2 + m_3)^2 - \Pr(m_2 + m_3) + M_3},\ A_{25} = \frac{-2\Pr A_{19}}{(m_1 + m_4)^2 - \Pr(m_1 + m_5) + M_3},$$

$$A_{26} = \frac{-2\Pr A_{20}}{(m_1 + m_3)^2 - \Pr(m_1 + m_3) + M_3}, A_{27} = -(A_{21} + A_{22} + A_{23} + A_{24} + A_{25} + A_{26}),$$

$$A_{28} = \frac{-\Pr m_5^2 A_{14}^2}{4m_5^2 - 2m_5 \Pr + M_4},\ A_{29} = \frac{-\Pr m_3^2 A_{10}^2}{4m_3^2 - 2m_3 \Pr + M_4}, A_{30} = \frac{-2\Pr m_3 m_5 A_{10} A_{14}}{(m_3 + m_5)^2 - \Pr(m_3 + m_5) + M_4},$$

$$A_{31} = -(A_{28} + A_{29} + A_{30}),\ A_{32} = \frac{-Gr\, A_{24}}{(m_2 + m_3)^2 - (m_2 + m_3) - M_2},\ A_{33} = \frac{-Gr\, A_{25}}{(m_1 + m_5)^2 - (m_1 + m_5) - M_2},$$

$$A_{34} = \frac{-Gr\, A_{26}}{(m_1 + m_3)^2 - (m_1 + m_3) - M_2}, A_{35} = \frac{A_{27}}{m_2^2 - m_2 - M_2}, A_{36} = \frac{-Gr\, A_{21}}{(m_4 + m_5)^2 - (m_4 + m_5) - M_2},$$

$$A_{37} = \frac{-Gr\, A_{22}}{(m_3 + m_4)^2 - (m_3 + m_4) - M_2},\ A_{38} = \frac{-Gr\, A_{23}}{(m_2 + m_5)^2 - (m_2 + m_5) - M_2},$$

$$A_{39} = -(A_{32} + A_{33} + A_{34} + A_{35} + A_{36} + A_{37} + A_{38}),\ A_{40} = \frac{-Gr\, A_{28}}{4 m_5^2 - 2m_5 - M_1},\ A_{41} = \frac{-Gr\, A_{29}}{4m_3^2 - 2m_3 - M_1},$$

$$A_{42} = \frac{-Gr\, A_{30}}{(m_3 + m_5)^2 - (m_3 + m_5) - M_1},\ A_{43} = \frac{-Gr\, A_{31}}{m_3^2 - m_3 - M_1},\ A_{44} = -(A_{40} + A_{41} + A_{42} + A_{43})$$