Influence of Thermal Radiation and Chemical Reaction on MHD Convective Flow over a Moving Porous Plate

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ABSTRACT

Analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generation/absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and the mass flux are considered. The plate is assumed to move with a constant velocity in the direction of fluid flow. A uniform magnetic field acts perpendicular to the porous surface, which absorbs the fluid with a suction velocity varying with time. The dimensionless governing equations are solved analytically using two-term perturbation technique method. The results of the velocity, temperature and concentration profiles are shown in graphically and discussed qualitatively.

Keywords: Radiation, MHD, Porous medium, heat and mass transfer, skin-friction.

I. INRTODUCTION

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects. The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast Growth of electronic technology, effective cooling of electronic equipment has become warranted and cooling of electronic equipment ranges from individual transistors to main frame computers and from energy suppliers to telephone switch boards and thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight.

Chambre and Young [1] have presented a first order chemical reaction in the neighborhood of a horizontal plate. . D. DastagiriBabu et al.[2] studied heat and mass transfer on unsteady MHD free convection rotating flow through a porous medium over an infinite vertical plate with hall effects. Dekha et al. [3] investigated the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past a vertical plate with a constant heat and mass transfer. Dulal Pal et al [4] studied Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Recently, Ramana Reddy et al [5] have studied the mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption. Gregantopoulos et al. [6] studied two-dimensional unsteady free convection and mass transfer flow of an incompressible viscous dissipative and electrically conducting fluid past an infinite vertical porous plate. Gribben [7] presented the boundary layer flow over a semi-infinite plate with an aligned magnetic field in the presence of pressure gradient. He obtained solutions for large and small magnetic Prandtl number using the method of matched asymptotic expansion. For some industrial applications such as glass production and furnace design, and in space technology applications such as cosmical flight aerodynamics rocket, propulsion systems, plasma physics and spacecraft re-entry aerothermodynamics which operate at higher temperatures, radiation effects can be significant. Helmy [8] presented an unsteady two-dimensional laminar free convection flow of an incompressible, electrically conducting (Newtonian or polar) fluid through a porous medium bounded by infinite vertical plane surface of constant temperature. In view of this, Hossain and Takhar [9] analyzed the effect of radiation on mixed convection along a vertical plate with uniform surface temperature. K. Rajasekhar et al. [10] studied unsteady MHD free convective flow past a semi-infinite vertical porous plate. K. Jhansi Rani et al. [11] studied heat and mass transfer effects on MHD free convection flow over an inclined plate embedded in a porous medium. K.V.B.Rajakumar et al.[12] studied chemical reaction and viscous dissipation effects on MHD free convective flow past a semi-infinite moving vertical porous plate with

radiation absorption. Kim and Fedorov [13] analyzed transient mixed radiative convective flow of a micropolar fluid past a moving semi-infinite vertical porous plate. M. V. Ramana Murthy et al. [14] studied the heat and mass transfer effects on MHD natural convective flow past an infinite vertical porous plate with thermal radiation and hall current. Double-Diffusive Convection-Radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects was studied by Mohamed [15]. Mohamed et al.[16] studied heat and mass transfer of unsteady hydromagnetic free convection flow through porous medium past a vertical plate with uniform surface heat flux. Muthucumaraswamy [17] 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. Muthucumaraswamy and Meenakshisundaram[18] investigated theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Muthuraj and Srinivas [19] studied the fully developed MHD flow of a micropolar and viscous fluid in a vertical porous space using HAM.

There has been a renewed interest in studying magnetohydrodynamic (MHD) flow and heat transfer in porous and non-porous media due to the effect of magnetic fields on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. Patil and Kulkarni [20] studied the effects of chemical reaction on free convective flow of a polar fluid through porous medium in the presence of internal heat generation. Radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium was studied by Ramachandraprasad et al. [21]. Raptis et al. [22] analyzed hydromagnetic free convection flow through a porous medium between two parallel plates. Satyanarayana et al [23] studied Hall current effect on magneto hydrodynamics free-convection flow past a semi-infinite vertical porous plate with mass transfer.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Possible heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electric chips and semiconductor wafers. Seddeek [24] studied the effects of chemical reaction, thermophoresis and variable viscosity on steady hydromagnetic flow with heat and mass transfer over a flat plate in the presence of heat generation/absorption. Effects of the chemical reaction and radiation absorption on free convection flow through porous medium with variable suction in the presence of uniform magnetic field were studied by Sudheer Babu and Satyanarayana [25]. Venkata Ramana Reddy et al. [26] studied MHD free convection fluid flow past a semi-infinite vertical porous plate with heat absorption and chemical reaction.

In spite of all the previous studies, the unsteady MHD free convection heat and mass transfer for a heat generation/absorption with radiation absorption in the presence of a reacting species over an infinite permeable plate has received little attention. Hence, the main objective of this chapter is to investigate the effects of thermal radiation, chemical reaction, and heat source/sink parameter of an electrically conducting fluid past an infinite vertical porous plate subjected to variable suction. The plate is assumed to be embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. It is also assumed that temperature over which are superimposed an exponentially varying with time. The Equations of continuity, linear momentum, energy and diffusion, which govern the flow field, are solved by using a regular perturbation method. The behavior of the velocity, temperature, concentration, skin-friction, Nusselt number and Sherwood number has been discussed for variations in the governing parameters.

II. MATHEMATICAL FORMULATION

We consider unsteady two-dimensional flow of a laminar, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects. It is assumed that there is no applied voltage which implies the absence of an electrical field. The fluid properties are assumed to be constant except that the influence of density variation with temperature has been considered only in the body-force term. The concentration of diffusing species is very small in comparison to other chemical species, the concentration of species far from the wall, C_∞, is infinitesimally small (Dekha [3]) and hence the Soret and Dufour effects are neglected. The chemical reactions are taking place in the flow and all thermophysical properties are assumed to be constant of the linear momentum Equation which is approximated according to the Boussinesq approximation. Due to the semi-infinite plane surface assumption, the flow variables are functions of y' and the time t' only. Under these assumptions, the governing Equations for the problem considered in this chapter are based on the balances of mass, linear momentum, energy and concentration species. These Equations are as given below:

Continuity Equation:

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

Momentum Equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{\partial p'}{\partial x'} + g\beta\left(T'-T'_\infty\right) + g\beta^*\left(C'-C'_\infty\right) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{K'}u' - \frac{\sigma B_0^2}{\rho}u' \tag{2}$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{1}{\rho C_p}\left[k\frac{\partial^2 T'}{\partial y'^2} - Q_0\left(T'-T'_\infty\right)\right] + Q'_l\left(C'-C'_\infty\right) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \tag{3}$$

Mass diffusion Equation:

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_r\left(C'-C'_\infty\right) \tag{4}$$

where x', y' are the dimensional distance along and perpendicular to the plate, respectively. u' and v' are the velocity components in the x', y' directions respectively, g is the gravitational acceleration, ρ is the fluid density, β and β^* are the thermal and concentration expansion coefficients respectively, K' is the Darcy permeability, B_0 is the magnetic induction, T' is the thermal temperature inside the thermal boundary layer and C' is the corresponding concentration, σ is the electric conductivity, C_p is the specific heat at constant pressure, D is the diffusion coefficient, q_r is the heat flux, Q_0 is the dimensional heat absorption coefficient, Q'_l is the coefficient of proportionality of the radiation and K'_r is the chemical reaction parameter.

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

$$\begin{aligned} &u' = u'_p, \quad T' = T'_\infty + \varepsilon\left(T'_W - T'_\infty\right)e^{n't'}, \; C' = C'_\infty + \varepsilon\left(C'_W - C'_\infty\right)e^{n't'} \quad \text{at} \quad y' = 0 \\ &u' = U'_\infty = U_0 + \varepsilon\left(1+e^{n't'}\right), \qquad T' \to T'_\infty, \qquad C' \to C'_\infty, \quad \text{as} \quad y' \to \infty \end{aligned} \tag{5}$$

where u'_p is the velocity, T'_w and C'_w the temperature and concentration of the wall respectively, U'_∞ - the free stream velocity, and U_0, n' - the constants. From Equation (1), it is clear that the suction velocity at the plate is either a constant and or a function of time. Hence the suction velocity normal to the plate is assumed in the form

$$v' = -v_0(1+\varepsilon A e^{n't'}) \tag{6}$$

where A is a real positive constant, ε and εA is small values less than unity, and v_0 is scale of suction velocity which is non zero positive constant. The negative sign indicates that the suction is towards the plate.
Outside the boundary layer, Equation (2) gives

$$-\frac{1}{\rho}\frac{\partial p'}{\partial x'} = \frac{dU'_\infty}{dt'} + \frac{\nu}{K'}U'_\infty - \frac{\sigma B_0^2}{\rho}U'_\infty \tag{7}$$

By using the Rosseland diffusion approximation and following among other researchers, the radiative heat flux, q_r is given by

$$q_r = -\frac{4\sigma^*}{3K_s}\frac{\partial T'^4}{\partial y'} \tag{8}$$

Where σ^* and K_s are the Stefan- Boltzmann constant and the Roseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature.

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \tag{9}$$

Using (8) and (9) in the last term of Equation (3) we obtain

$$\frac{\partial q_r}{\partial y'} = -\frac{16\sigma^* T_\infty^3}{3K_s}\frac{\partial^2 T'}{\partial y'^2} \tag{10}$$

In order to write the governing Equations and the boundary conditions in dimensional following non-dimensional Quantities are introduced.

$$y = \frac{v_0 y'}{\nu},\ u = \frac{u'}{U_0},\ v = \frac{v'}{v_0}, t = \frac{t' v_0^2}{\nu}, U_\infty = \frac{U'_\infty}{U_0}, U_p = \frac{u'_p}{U_0}\ \ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},$$

$$Gr = \frac{g\beta\nu(T'_w - T'_\infty)}{v_0^3}, Gm = \frac{g\beta^*\nu(C'_w - C'_\infty)}{v_0^3}, Sc = \frac{\nu}{D},\ Q = \frac{\nu Q_0}{\rho C_p v_0^2}, Q_l = \frac{\nu Q'_l\left(C'_w - C'_\infty\right)}{\left(T'_w - T'_\infty\right)v_0^2}$$

$$n = \frac{\nu n'}{v_0^2}\ M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}\ K = \frac{K' v_0^2}{\nu^2}, K_r = \frac{K'_r \nu}{v_0^2},\ R = \frac{4\sigma^* T_\infty^3}{K_s}, \Pr = \frac{\nu\rho C_p}{k} \tag{11}$$

In view of Equations (6) – (11), Equations (2)-(4) reduce to the following dimensional form.

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + Gr\theta + GmC + \frac{\partial^2 u}{\partial y^2} + N\left(U_\infty - u\right) \tag{12}$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1 + \frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} - Q\theta + Q_l C \tag{13}$$

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - K_r C \tag{14}$$

where $N = M + \frac{1}{K}, Gr, Gm, \Pr, K_r, Sc, Q, Q_l$ and R are the magnetic field parameter, permeability parameter, thermal Grashof number, Solutal Grashof number, Prandtl number, Chemical reaction number, Schmidt number, heat absorption parameter, absorption of radiation parameter and thermal radiation parameter.

The corresponding boundary conditions for $t > 0$ are transformed to:

$$\begin{aligned} &u = U_p,\ \theta = 1 + \varepsilon e^{nt},\ C = 1 + \varepsilon e^{nt} \quad \text{at} \quad y = 0 \\ &u \to U_\infty = 1 + \varepsilon e^{nt},\ \theta \to 0,\ C \to 0 \ \text{ as } \ y \to \infty \end{aligned} \tag{15}$$

III. SOLUTION OF THE PROBLEM

Equations (12) – (14) are coupled, non – linear partial differential Equations and these cannot be solved in closed form. However, these Equations can be reduced to a set of ordinary differential Equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} u(y,t) &= u_0(y) + \varepsilon e^{nt} u_1(y) + o\left(\varepsilon^2\right) + \ldots\ldots\ldots \\ \theta(y,t) &= \theta_0(y) + \varepsilon e^{nt}\theta_1(y) + o\left(\varepsilon^2\right) + \ldots\ldots\ldots \\ C(y,t) &= C_0(y) + \varepsilon e^{nt} C_1(y) + o\left(\varepsilon^2\right) + \ldots\ldots\ldots \end{aligned} \tag{16}$$

Substituting (16) in Equations (12) – (14) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $o\left(\varepsilon^2\right)$, we obtain

$$u_0'' + u_0' - Nu_0 = -N - Gr\theta_0 - GmC_0 \tag{17}$$

$$u_1'' + u_1' - (N+n)u_0 = -(N+n) - Gr\theta_1 - GmC_1 - Au_0' \tag{18}$$

$$\left(1+\frac{4R}{3}\right)\theta_0'' + \Pr\theta_0' - \Pr Q\theta_0 = -\Pr Q_l C_0 \tag{19}$$

$$\left(1+\frac{4R}{3}\right)\theta_1'' + \Pr\theta_1' - \Pr(Q+n)\theta_1 = -A\Pr\theta_0' - \Pr Q_l C_1 \tag{20}$$

$$C_0'' + ScC_0' - ScK_r C_0 = 0 \tag{21}$$

$$C_1'' + ScC_1' - Sc(K_r+n)C_1 = -AScC_0' \tag{22}$$

where prime denotes ordinary differentiation with respect to y.

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \quad \text{at} \quad y = 0 \\ &u_0 \to 1, u_1 \to 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \ \text{ as } \ y \to \infty \end{aligned} \tag{23}$$

Solving Equations (17) – (22) under the boundary condition (23) we obtain the velocity, temperature and concentration distribution in the boundary layer as

$$\begin{aligned} u(y,t) = {} & 1 + A_{14}\exp(-m_5 y) - A_{12}\exp(-m_1 y) - A_{13}\exp(-m_3 y) + \\ & \varepsilon\exp(nt)\begin{bmatrix} 1 + A_{25}\exp(-m_6 y) + A_{20}\exp(-m_1 y) - A_{21}\exp(-m_2 y) \\ -A_{22}\exp(-m_3 y) - A_{23}\exp(-m_4 y) + A_{24}\exp(-m_5 y) \end{bmatrix} \end{aligned}$$

$$\theta(y,t) = A_3\exp(-m_1 y) + A_4\exp(-m_3 y) + \varepsilon\exp(nt)\begin{bmatrix} A_8\exp(-m_1 y) - A_9\exp(-m_2 y) \\ +A_{10}\exp(-m_3 y) + A_{11}\exp(-m_4 y) \end{bmatrix}$$

$$C(y,t) = \exp(-m_1 y) + \varepsilon\exp(nt)\left[A_1\exp(-m_1 y) + A_2\exp(-m_2 y)\right]$$

where

$$N = M + 1/K,$$

$$m_1 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4KSc}\right],\ m_2 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4Sc(n+K)}\right],\ m_3 = \frac{1}{2}\left[\Pr + \sqrt{\Pr^2 + 4F\Pr}\right]$$

$$m_4 = \frac{1}{2}\left[1 + \sqrt{1+4N}\right],\ m_5 = \frac{1}{2}\left[\Pr + \sqrt{\Pr^2 + 4\Pr(F+n)}\right],\ m_6 = \frac{1}{2}\left[1 + \sqrt{1+4(N+n)}\right]$$

$$A_1 = AScm_1/\left(m_1^2 + Scm_1 - (n+K)Sc\right),\ A_2 = 1 + A_1,\ A_3 = \Pr Q_l/\left(m_1^2 + \Pr m_1 - \Pr F\right)$$

$$A_4 = 1 - A_3,\ A_5 = GrA_4/\left(m_3^2 - m_3 - N\right),\ A_6 = GrA_3/\left(m_1^2 - m_1 - N\right),\ A_7 = Gm/\left(m_1^2 - m_1 - N\right)$$

$$A_8 = Up - 1 - A_5 - A_6 - A_7,\ A_9 = A\Pr m_3 A_4/\left(m_3^2 + \Pr m_3 - \Pr(n+F)\right),$$

$$A_{10} = A\Pr m_1 A_3/\left(m_1^2 + \Pr m_1 - \Pr(n+F)\right),\ A_{11} = \Pr Q_l A_2/\left(m_2^2 + \Pr m_2 - \Pr(n+F)\right),$$

$$A_{12} = \Pr Q_l A_1/\left(m_1^2 + \Pr m_1 - \Pr(n+F)\right),\ A_{13} = 1 - \left(A_9 + A_{10} + A_{11} + A_{12}\right),$$

$$A_{14} = GrA_{13} / \left(m_5^2 + m_5 - \left(N + n\right)\right), A_{15} = GrA_9 / \left(m_3^2 + m_3 - \left(N + n\right)\right),$$
$$A_{16} = GrA_{10} / \left(m_1^2 + m_1 - \left(N + n\right)\right), A_{17} = GrA_{11} / \left(m_2^2 + m_2 - \left(N + n\right)\right),$$
$$A_{18} = GrA_{12} / \left(m_1^2 + m_1 - \left(N + n\right)\right), A_{19} = GmA_2 / \left(m_3^2 + m_3 - \left(N + n\right)\right),$$
$$A_{20} = -GrA_1 / \left(m_1^2 + m_1 - \left(N + n\right)\right), A_{21} = Am_4A_8 / \left(m_4^2 + m_4 - \left(N + n\right)\right),$$
$$A_{22} = Am_3A_5 / \left(m_3^2 + m_3 - \left(N + n\right)\right), A_{23} = Am_1A_6 / \left(m_1^2 + m_1 - \left(N + n\right)\right),$$
$$A_{24} = Am_1A_7 / \left(m_1^2 + m_1 - \left(N + n\right)\right),$$
$$A_{25} = 1 + A_{14} + A_{15} + A_{16} + A_{17} + A_{18} + A_{19} + A_{20} + A_{21} + A_{22} + A_{23} + A_{24}.$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

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

$$C_f = \frac{\tau'_w}{\rho U_0 v_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$C_f = -\left[-m5A_{14} + m_1A_{12} + A_{12}m_3 + \varepsilon e^{nt}\begin{pmatrix} -m_6A_{25} - m_1A_{20} + A_{21}m_2 \\ +A_{22}m_3 + m_4A_{23} - A_{24}m_5 \end{pmatrix}\right]$$

Nusselt number

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

$$N_u = -x\frac{\left(\frac{\partial T'}{\partial y'}\right)_{y'=0}}{\left(T'_w - T'_\infty\right)} \Rightarrow N_u \,\mathrm{Re}_x^{-1} = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$N_u \,\mathrm{Re}_x^{-1} = -m_1A_3 - A_4m_3 + \varepsilon e^{nt}\left[-m_1A_8 + m_2A_9 - m_3A_{10} - m_4A_{11}\right]$$

where $\mathrm{Re}_x = \frac{v_0 x}{\nu}$ is the local Reynolds number.

Sherwood number

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

$$S_h = -x\frac{\left(\frac{\partial C'}{\partial y'}\right)_{y'=0}}{\left(C'_w - C'_\infty\right)} \Rightarrow S_h \,\mathrm{Re}_x^{-1} = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$S_h \,\mathrm{Re}_x^{-1} = -\left[-m_1 + \varepsilon\, \mathrm{e}^{nt}\left(-m_1A_1 - m_2A_2\right)\right]$$

IV. RESULT AND DISCUSSION

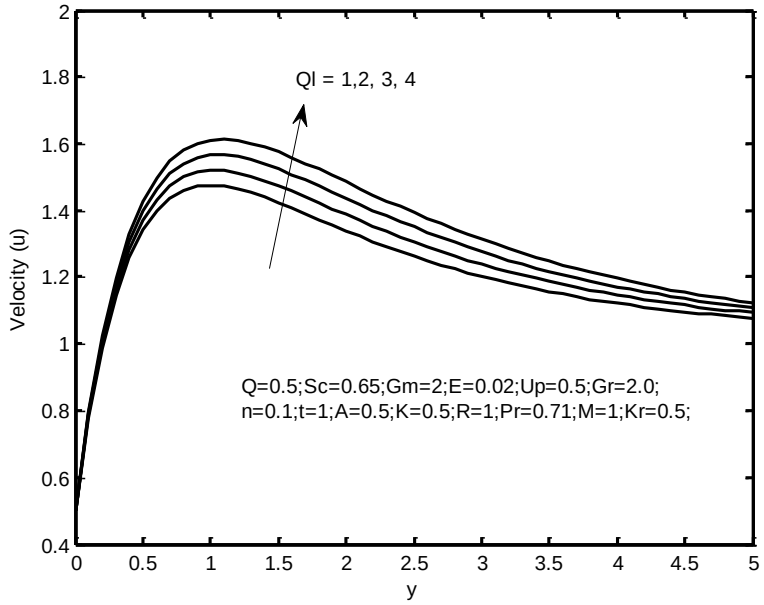

Fig.1. Effects of Ql on velocity profiles.

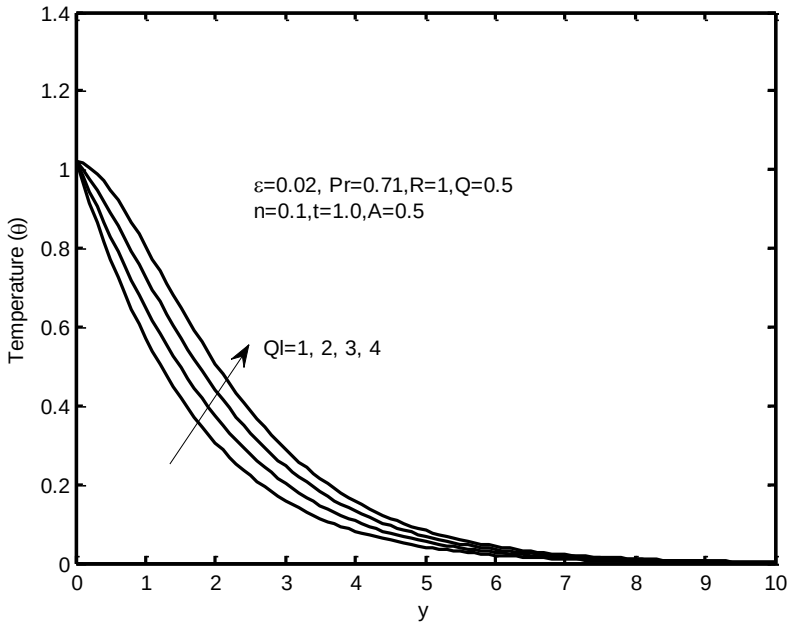

Fig.2. Effects of Ql on temperature profiles.

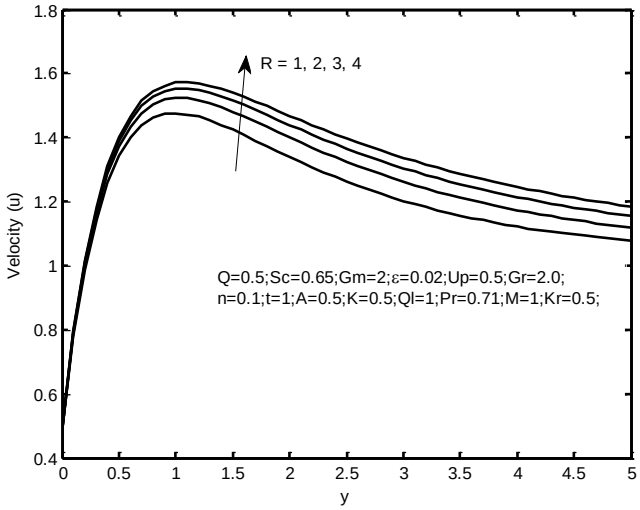

Fig.3. Effects of R on velocity profiles.

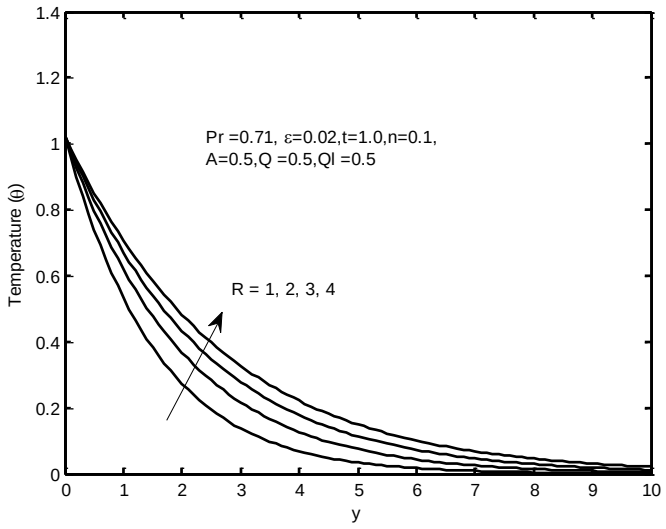

Fig.4. Effects of R on temperature profiles.

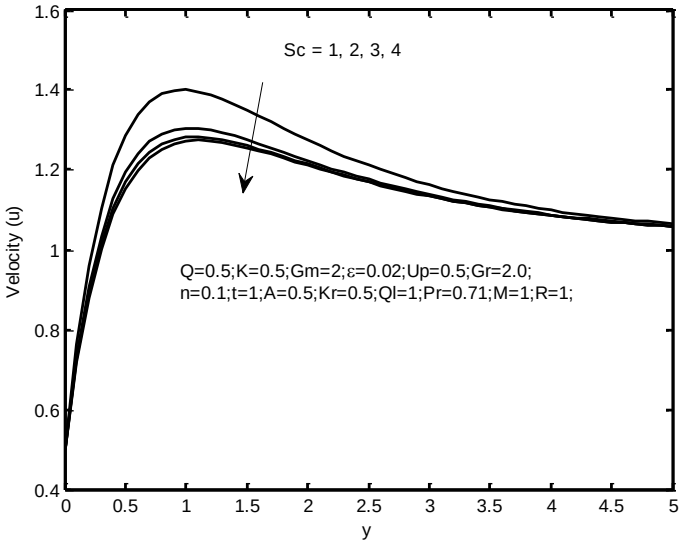

Fig.5.Effects of Sc on velocity profiles

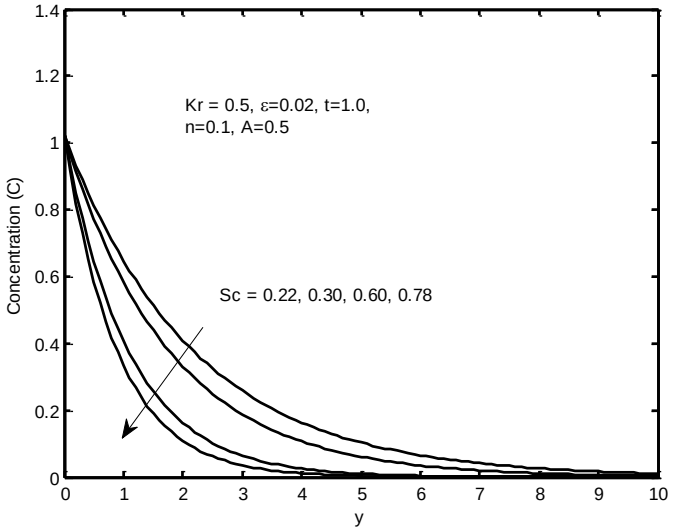

Fig.6. Effects of Sc on concentration profiles

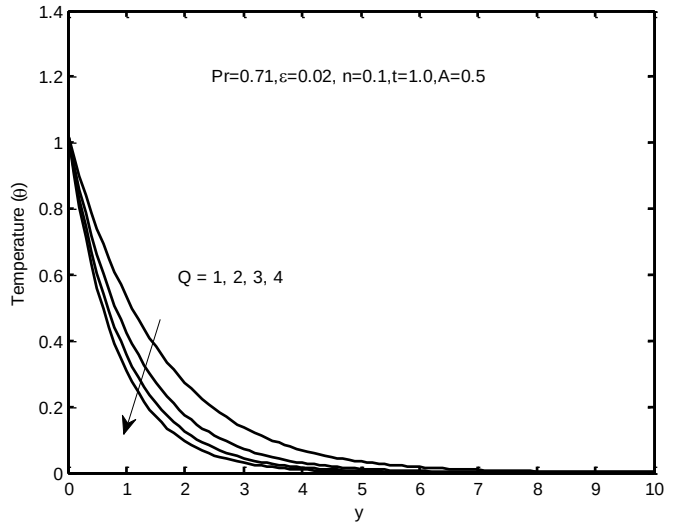

Fig.7. Effects of Q on temperature profiles

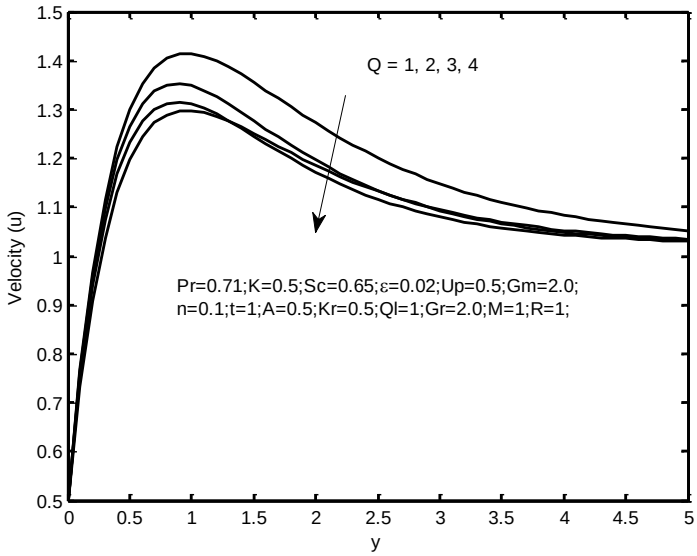

Fig.8.Effects of Q on velocity profiles

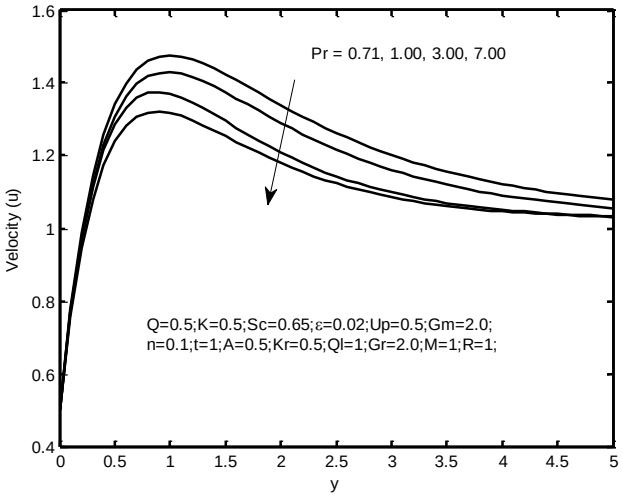

Fig.9.Effects of Pr on velocity profiles

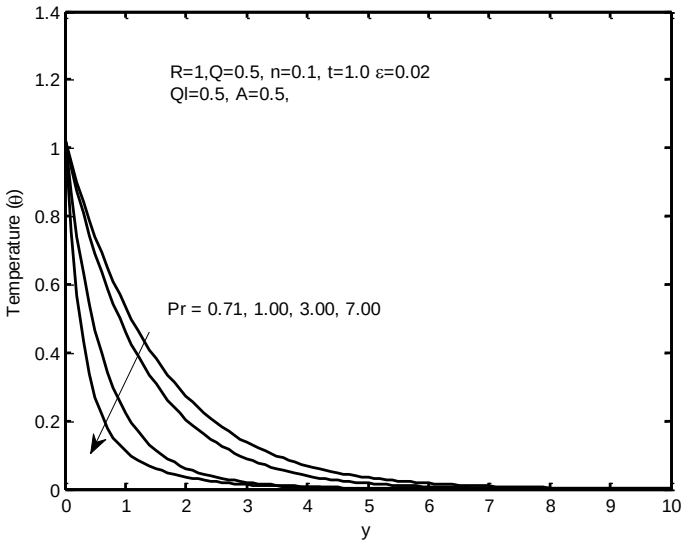

Fig.10. Effects of Pr on temperature profiles.

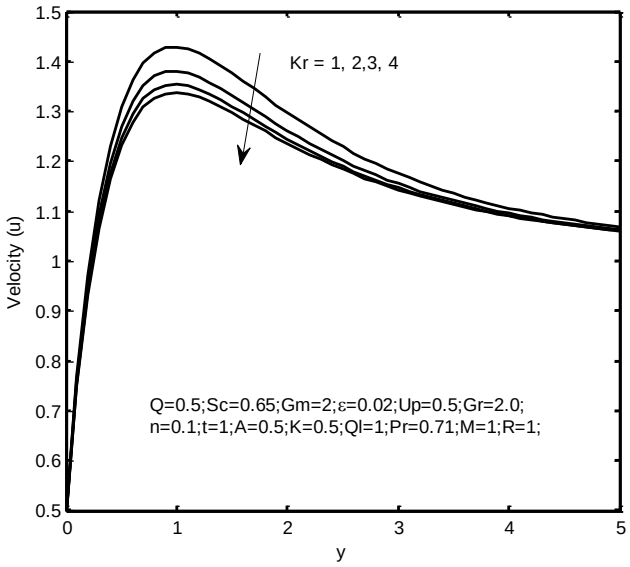

Fig.11.Effects of chemical reaction parameter on velocity profiles.

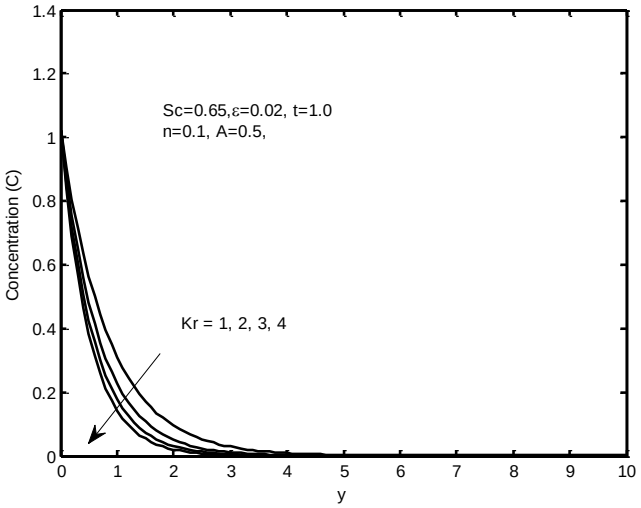

Fig.12. Effects of Kr on concentration profiles.

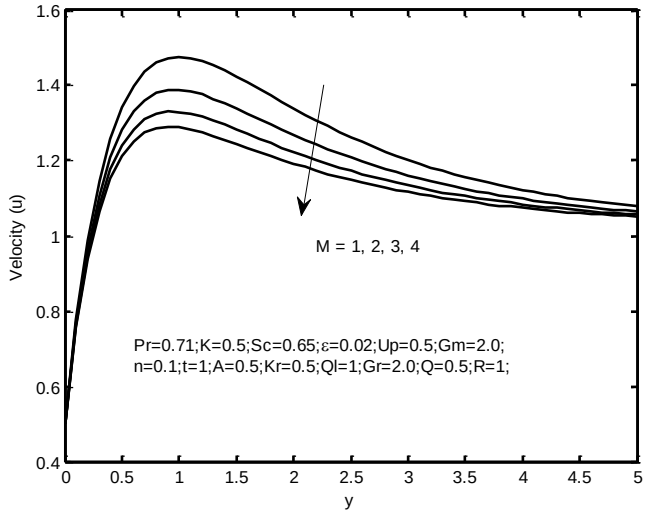

Fig.13.Effects of magnetic field on velocity profiles.

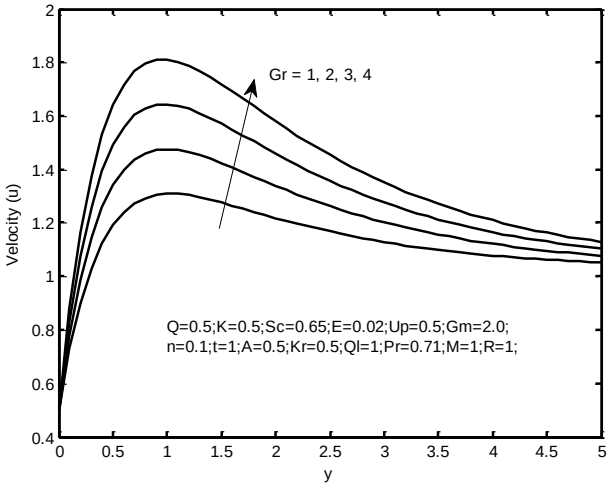

Fig.14.Effects of Gr on velocity profiles.

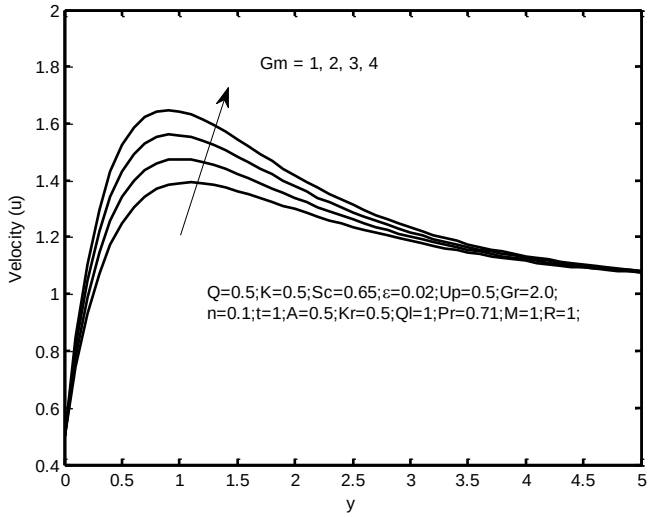

Fig.15.Effects of Gm on velocity profiles

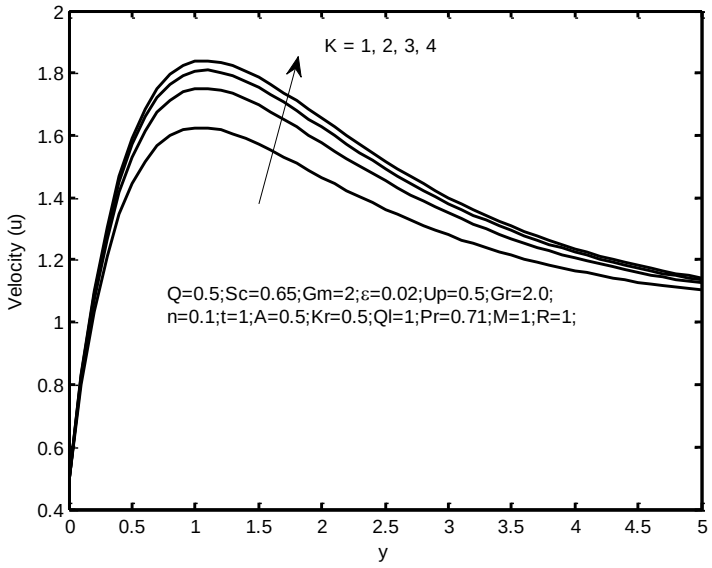

Fig.16.Effects of K on velocity profiles

The effect of magnetic field on velocity profiles in the boundary layer is depicted in the effect of increasing the value of the absorption parameter ***Ql*** on the velocity is shown Figure (1). We observe in this figure that increasing the value of the absorption of the radiation parameter due to increase in the buoyancy force accelerates the flow rate. The effect of absorption of radiation parameter on the temperature profile is shown on Figure (2). It is seen from this figure that the effect of absorption of radiation is to increase temperature in the boundary layer as the radiated heat is absorbed by the fluid which in turn increases the temperature of the fluid very close to the porous boundary layer and its effect diminishes far away from the boundary layer. Figure (3) shows the velocity profiles for different values of the radiation parameter ***R***, clearly as ***R*** increases the peak values of the velocity tends to increase. Figure (4) shows the temperature profiles for different values of the radiation parameter ***R***, clearly as ***R*** increases the peak values of the temperature tends to increase. Figure (5) display the effects of Schmidt number Sc on velocity profiles. As the Schmidt number increases the velocity filed decreases. This causes the velocity buoyancy effects to decreases yielding a reduction in the fluid velocity. The reductions and the velocity profiles are accompanied by simultaneous reductions in the velocity boundary layers. Figure (6) display the effects of Schmidt number ***Sc*** on the concentration profiles respectively. As the Schmidt number increases the concentration decreases. Figure (7) has been plotted to depict the variation of temperature profiles against **y** for different values of heat source parameter ***Q*** by fixing other physical parameters. From this Graph we observe that temperature decrease with increase in the heat source parameter ***Q*** because when heat is absorbed, the buoyancy force decreases the temperature profiles. The effect of increasing the value of the heat source parameter is to decrease the boundary layer as shown in Figure (8), which is as

expected due to the fact that when heat is absorbed the buoyancy force decreases which retards the flow rate and there are by giving rise to decrease in the velocity profiles. Figure (9) illustrate the velocity profiles for different values of Prandtl number ***Pr***. The numerical results show that the effect of increasing values of Prandtl number result in decreasing velocity. Figure (10) illustrate the temperature profiles for different values of Prandtl number ***Pr***. It is observed that the temperature decrease as an increasing the Prandtl number. The reason is that smaller values of ***Pr*** are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of ***Pr***. Hence in the case of smaller Prandtl number the thermal boundary layer is thicker and the rate of heat transfer is reduced. Figure (13). From this figure it is seen that the velocity starts from minimum value at the surface and increase till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is to decrease the value of the velocity profiles throughout the boundary layer. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. This type of resisting force slows down the fluid velocity as shown in this figure. Figure (11) and (12) shows the velocity and concentration distribution ***u*** against ***y*** for different values of ***Kr***. we noticed that the velocity and concentration are decrease with increases ***Kr***. For the case of different values of thermal Grashof number ***Gr***, the velocity profiles in the boundary layer are shown in Figure (14). As expected, it is observed that an increase in ***Gr*** leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of ***Gr*** correspond to cooling of the surface. Figure (15) presents typical velocity profiles in the boundary layer for various values of the Solutal Grashof number ***Gm***, while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value more distinctive due to increase in the concentration buoyancy effects represented by ***Gm***. This is evident in the increase in the value of ***u*** as ***Gm*** increases in Figure (15). Figure (16) shows the velocity profiles for different values of the permeability parameter ***K***, clearly as ***K*** increases the peak values of the velocity tends to increase

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