EFFECTS OF CHEMICAL REACTION ON UNSTEADY MHD HEAT AND MASS TRANSFER FLOW PAST A SEMI INFINITE VERTICAL POROUS MOVING PLATE IN THE PRESENCE OF VISCOUS DISPATION

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ABSTRACT

This paper deals with the effects of inclined magnetic field and heat and mass transfer on unsteady two dimensional laminar flow of a viscous incompressible electrically conducting fluid past a semi infinite moving vertical porous plate under the influence of a uniform transverse magnetic field with temperature dependent heat generation, viscous dissipation and homogeneous first order chemical reaction. The analytical expressions for the velocity, temperature and mass concentration are obtained. The effects of inclined magnetic field and material parameters like Grashof number for heat transfer, Grashof number for mass transfer, Prandtl number, Magnetic parameter, permeability parameter, Schmidt number and chemical reaction parameter on velocity, temperature and mass concentration are discussed through graphs. In addition, the expressions for skin friction and rate of heat and mass transfer coefficients are derived and discussed numerically.

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1. INTRODUCTION

The study of flow and heat transfer for an electrically conducting fluid past a porous plate under the influence of a magnetic field has attracted the interest of many investigators in view of plasma studies, nuclear reactors, geothermal energy extractions and the boundary layer control in the field of aerodynamics. A great number of Darcian porous MHD studies have been performed examining the effects of magnetic field on hydrodynamic flow without heat transfer in various configurations, e.g., in channels and past plates, wedges, etc.

Gribben [14] has considered the MHD boundary layer flow over a semi-infinite plate with an aligned magnetic field in the presence of a pressure gradient. He has obtained solutions for large and small magnetic Prandtl numbers using the method of matched asymptotic expansion. Takhar and Ram [10] have studied the effects of Hall currents on hydromagnetic free convection boundary layer flow of a porous medium past a plate, using harmonic analysis. Takhar and Ram [11] also studied the MHD free porous convection heat transfer of water at 4^0C through a porous medium. Soundalegkar [16] obtained approximate solutions for the two-dimensional flow of an incompressible, viscous fluid past an infinite porous vertical plate with constant suction velocity normal to the plate, the difference between the temperature of the plate and the free stream is moderately large causing the free convection currents. Raptis and Kafousias [1] have studied the influence of a magnetic field upon the steady free convection flow through a porous medium bounded by an infinite vertical plate with constant suction velocity, and when the plate temperature is also constant. Raptis [2] has studied mathematically the case of time-varying two-dimensional natural convective heat transfer of an incompressible, electrically-conducting viscous fluid via a highly porous medium bounded by an infinite vertical porous plate. The effect of free convection on steady MHD flow past a vertical porous plate has been studied by Soundalgekar [17] and its unsteady part by Gulab and Mishra [9]. Georgantopoulos et al. [8] estimated the effect of free convection and mass transfer on the hydro-magnetic oscillatory flow past an infinite vertical porous plate. Singh and his associates [15] discussed the unsteady MHD free convective flow through a porous medium between two infinite vertical parallel oscillating porous plates with different amplitude. Chamkha [5] studied the hydromagnetic three-dimensional free convection flow on a vertical stretching surface with heat generation/absorption. Choudhury and Das [13] analyzed the magneto hydrodynamic boundary layer flow of non-Newtonian fluid past a flat plate. The 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. The effect of a chemical reaction depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an interface or a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of the order n, if the reaction rate is proportional to the n power of concentration. In particular, a reaction is said to be first order, if the rate of reaction is directly proportional to concentration itself. Chambre and Young [4] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Apelblat [3] studied analytical solution for mass with a chemical reaction of first order. Das et al. [6] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Again mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al. [7]. Most of previous works assumed that the semi-infinite plate is to be rest. In the present work we have considered the case of a semi-infinite moving porous plate in a porous medium with the presence of pressure gradient and constant velocity in the flow direction when the magnetic field is imposed transverse to the plate. We also consider the free stream to consist of a mean velocity and temperature over which are superimposed an exponentially varying with time.

This paper deals with the influence of inclined magnetic field and heat and mass transfer on unsteady two dimensional laminar flow of a viscous incompressible electrically conducting fluid past a semi infinite moving vertical porous plate under the influence of a uniform transverse magnetic field with temperature dependent heat generation, viscous dissipation and homogeneous first order chemical reaction. The analytical expressions for the velocity, temperature and mass concentration are obtained. The effects of material parameters on velocity, temperature and mass concentration are discussed through graphs. Also the expressions for skin friction and rate of heat and mass transfer coefficients are derived and discussed numerically.

2. FORMULAION OF THE PROBLEM

Consider a two-dimensional unsteady flow of a laminar, incompressible electrically conducting and heat generating/absorbing fluid with viscous dissipation and mass transfer, past a semi-infinite vertical porous moving plate in the presence of chemical reaction. A uniform transverse magnetic field is applied perpendicular to the plate (see Fig.1). In the presence of strong magnetic field a current is inclined in direction normal to the magnetic field. The inclined magnetic field gives rise to secondary flow transverse to plate. The x-axis is taken along the plate in the upward direction and the y-axis is taken normal to it. The fluid properties are assumed constant except for influence of density in the body force term.We made the following assumptions:

(i) The transversely applied magnetic field and magnetic Reynolds number are very small and hence the induced magnetic field is negligible [1].

(ii) Viscous and Darcy's resistance terms are taken into account with constant permeability of the porous medium.

(iii) The MHD term is derived from an order-of-magnitude analysis of the full Navier- Stokes equations.

(iv) The porous plate moves with constant velocity in the direction of fluid flow, and the free stream velocity follows the exponentially increasing small perturbation law.

(v) We also assume the plate temperature, concentration and free stream velocity are exponentially varying with time.

Under the above assumptions, the governing equations, i.e., the mass, momentum, energy and concentration can be written in a Cartesian frame of reference, as follows

Continuity equation

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Momentum equation

$$\frac{\partial u^*}{\partial t} + v^* \frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P^*}{\partial x^*} + \vartheta \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T - T_\infty)$$

$$+g\beta^*(c-c_\infty)-\vartheta\frac{u^*}{K^*}-\frac{\sigma}{\rho}B_0^2(Sin^2\alpha)u^* \quad (2)$$

The third term on the RHS of the momentum equation (2) denotes buoyancy effects, the fifth is the bulk matrix linear resistance, i.e. Darcy term, and the sixth is the MHD term.

Energy equation

$$\frac{\partial T}{\partial t^*}+v^*\frac{\partial T}{\partial y^*}=\frac{K}{\rho C_P}\frac{\partial^2 T}{\partial y^{*2}}+Q(T-T_\infty)+\frac{\mu}{\rho C_P}\left(\frac{\partial u^*}{\partial y^*}\right)^2 \quad (3)$$

Concentration equation

$$\frac{\partial C}{\partial t^*}+v^*\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^{*2}}-K_1^*(c-c_\infty) \quad (4)$$

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

$$u^*=U_p^*, T=T_w+\in(T_w-T_\infty)e^{n^*t^*}, c=c_w+\in(c_w-c_\infty)e^{n^*t^*} \; at\; y=0 \quad (5)$$

$$u^*\to U_\infty^*=U_0\left(1+\in e^{n^*t^*}\right),\quad T\to T_\infty,\quad c\to c_\infty \quad as\; y\to\infty \quad (6)$$

From the continuity equation (1), it is clear that the suction velocity normal to the plate is a function of time only and we shall take it in the form

$$v^*=V_0\left(1+\in Ae^{n^*t^*}\right) \quad (7)$$

Where A is a real positive constant, ε and εA are small less than unity, and V_0 is a scale of suction velocity which has non-zero positive constant. Outside the boundary layer, equation (2) gives

$$-\frac{1}{\rho}\frac{\partial P^*}{\partial x^*}=\frac{\partial U_\infty^*}{\partial t^*}+\frac{\vartheta}{K^*}U_\infty^*+\frac{\sigma}{\rho}B_0^2\,(Sin^2\alpha\,)U_\infty^* \quad (8)$$

3. NON-DIMENSIONALISATION

We introduce the following non-dimensional variables, as follows

$$\left.\begin{array}{l} u=\frac{u^*}{U_0}, v=\frac{v^*}{V_0}, y=\frac{V_0 y^*}{\vartheta}, U_\infty=\frac{U_\infty^*}{U_0}, U_P=\frac{U_P^*}{U_0} \\ t=\frac{t^*V_0^*}{\vartheta}, \theta=\frac{T-T_\infty}{T_w-T_\infty}, C=\frac{c-c_\infty}{c_w-c_\infty}, n=\frac{n^*\vartheta}{V_0^2} \end{array}\right\} \quad (9)$$

$K = \frac{K^* V_0^2}{\vartheta^2}$, $S = \frac{Q\,\vartheta}{V_0^2}$ (*Heat Soyrce Parameter*), $P_r = \frac{\vartheta\,\rho\,C_P}{K}$

$G_r = \frac{\vartheta\, g\, \beta\,(T_w - T_\infty)}{U_0 V_0^2}$, $M = \frac{\sigma B_0^2 \vartheta \rho}{\rho V_0^2}$, $G_c = \frac{\vartheta\, g\, B^*\,(c_w - c_\infty)}{U_0 V_0^2}$. $S_c = \frac{\vartheta}{D}$

$K_1 = \frac{\vartheta\, K_1^*}{V_0^2}$, $N = \left(M Sin^2\alpha + \frac{1}{K}\right)$ (Dimensionless material parameter)

K=Permeability of Porous Media . $E_c = \frac{V_0^2}{C_P(T_w - T_\infty)}$ (*Ecart Number*)

C_P = Specific heat of constant pressure

After non-dimensionalisation in view of equations (7) to (9), the governing equations (2), (3) and (4) reduce to the following non-dimensional form

$$\frac{\partial u}{\partial t} - (1{+}\epsilon\, Ae^{nt})\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_c C + N(U_\infty - U) \quad (10)$$

$$\frac{\partial \theta}{\partial t} - (1{+}\epsilon\, Ae^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} + S\theta + J_n\left(\frac{\partial u}{\partial y}\right)^2 \quad (11)$$

$$\frac{\partial C}{\partial t} - (1{+}\epsilon\, Ae^{nt})\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K_1 C \quad (12)$$

The boundary conditions (5) and (6) are then given by the following dimensionless form

$$\left.\begin{array}{l} u = U_P\,, \theta = 1{+}\epsilon\, e^{nt}\,, C = 1{+}\epsilon\, e^{nt} \;\; at\; y = 0 \\ u \to U_\infty = 1{+}\epsilon\, e^{nt}, \theta \to 0\,, C \to 0 \;\; as\; y \to \infty \end{array}\right\} \quad (13)$$

4. SOLUTION OF THE PROBLEM

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we may represent the velocity, temperature and concentration as

$$u = u_0(y) {+}\epsilon\, e^{nt} u_1(y) + O(\epsilon^2) + \;\ldots\ldots\ldots\ldots\ldots \quad (14)$$

$$\theta = \theta_0(y) {+}\epsilon\, e^{nt} \theta_1(y) + O(\epsilon^2) + \;\ldots\ldots\ldots\ldots\ldots \quad (15)$$

$$C = C_0(y) {+}\epsilon\, e^{nt} C_1(y) + O(\epsilon^2) + \;\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Substituting these equations (14), (15) and (16) into equations (10), (11) and (12). And equating the harmonic and non-harmonic terms, neglecting the coefficient of $O(\epsilon^2)$ we get the fol-lowing equations

$$u_0'' + u_0' - N u_0 = -N - G_r \theta_0 - G_c C_0 \quad (17)$$

$$u_1'' + u_1' - N_1 u_1 = -N_1 - A u_0' - G_r \theta_1 - G_c C_1 \quad (18)$$

$$\theta_0'' + P_r \theta_0' + P_r S \theta_0 = -P_r E_C U_0'^2 \quad (19)$$

$$\theta_1'' + P_r \theta_1' + P_r S_1 \theta_1 = -P_r A \theta_0' - 2 P_r E_C u_0' u_1' \quad (20)$$

$$C_0'' + S_C C_0' - K_1 S_C C_0 = 0 \quad (21)$$

$$C_1'' + S_C C_1' - K_2 S_C C_1 = -A S_C C_0' \quad (22)$$

Where $K_2 = K_1 + n$, $N_1 = N + n$, $S_1 = S - n$

The corresponding boundary conditions can be written as

$$\left.\begin{aligned} &u_0 = U_p , u_1 = 0, \theta_0 = 1 , \theta_1 = 1 , c_0 = 1 , c_1 = 1 \ \ as\ y = 0 \\ &u_0 \to 1 , u_1 \to 1 , \theta_0 \to 0 , \theta_1 \to 0 , c_0 \to 0, c_1 \to 0 \ \ as\ y \to \infty \end{aligned}\right\} \quad (23)$$

The equations (17) to (22) are still coupled equations for the variables $u_0 , u_1 , \theta_0 , \theta_1 , C_0 and\ C_1$. To solve them, it is to be noted that $E_C < 1$ for all incompressible fluids and assumes that

$$f(y) = f_0(y) + E_C f_1(y) + O(E_C^2)$$

Where f stands for any $u_0 , u_1 , \theta_0 , \theta_1 , c_0\ or\ c_1$.

Assume that,

$$\left.\begin{aligned} u_0(y) &= E_0(y) + E_C E_1(y) + O(E_C^2) \\ u_1(y) &= F_0(y) + E_C F_1(y) + O(E_C^2) \\ \theta_0(y) &= G_0(y) + E_C G_1(y) + O(E_C^2) \\ \theta_1(y) &= H_0(y) + E_C H_1(y) + O(E_C^2) \\ C_0(y) &= \emptyset_0(y) + E_C \emptyset_1(y) + O(E_C^2) \\ C_1(y) &= \psi H_0(y) + E_C \psi_1(y) + O(E_C^2) \end{aligned}\right\} \quad (24)$$

Substituting these equations (24), into equations (17) - (22) and equating the harmonic and non-harmonic terms, neglecting the coefficient of $O(\epsilon^2)$ we get the following equations

$$E_0'' + E_0' - N E_0 = -N - G_r G_0 - G_C \phi_0 \quad (25)$$

$$E_1'' + E_1' - N E_1 = -G_r G_1 - G_C \phi_1 \quad (26)$$

$$F_0'' + F_0' - N_1 F_0 = -N - AE_0' - G_r H_0 - G_C \psi_0 \quad (27)$$

$$F_1'' + F_1' - N_1 F_1 = -AE_1' - G_r H_1 - G_C \psi_1 \quad (28)$$

$$G_0'' + P_r G_0' + P_r\, S\, G_0 = 0 \quad (29)$$

$$G_1'' + P_r G_1' + P_r\, S\, G_1 = -P_r\, E_0'^2 \quad (30)$$

$$H_0'' + P_r H_0' + P_r\, S_1\, H_0 = -P_r\, A\, G_0' \quad (31)$$

$$H_1'' + P_r H_1' + P_r\, S_1\, H_1 = -P_r\, A\, G_1' - 2\, P_r\, E_0'\, F_0' \quad (32)$$

$$\phi_0'' + S_C \phi_0' - K_1\, S_1\, \phi_0 = 0 \quad (33)$$

$$\phi_1'' + S_C \phi_1' - K_1\, S_1\, \phi_1 = 0 \quad (34)$$

$$\psi_0'' + S_C \psi_0' - K_2 S_C\, \psi_0 = -A\, S_C \phi_0' \quad (35)$$

$$\psi_1'' + S_C \psi_1' - K_2 S_C\, \psi_1 = -A\, S_C \phi_1' \quad (36)$$

Boundary conditions

$$\left.\begin{aligned} &E_0 = U_P\,, E_1 = 0\,, F_0 = 0\,, F_1 = 0\,, G_0 = 1\,, G_1 = 0 \\ &H_0 = 1\,, H_1 = 0\,, \phi_0 = 1\,, \phi_1 = 0\,, \psi_0 = 1\,, \psi_1 = 0 \end{aligned}\right\} \text{as } y \to 0 \quad (37)$$

$$\left.\begin{aligned} &E_0 = 1\,, E_1 = 0\,, F_0 = 1\,, F_1 = 0\,, G_0 = 0\,, G_1 = 0 \\ &H_0 = 0\,, H_1 = 0\,, \phi_0 = 0\,, \phi_1 = 0\,, \psi_0 = 0\,, \psi_1 = 0 \end{aligned}\right\} \text{as } y \to \infty \quad (38)$$

The solutions of equations (25) to (36) with satisfying boundary conditions (37) and (38) are given by

$$\phi_1(y) = \phi_0(y) = e^{-m_1 y} \quad (39)$$

$$\psi_1(y) = \psi_0(y) = A_1\, e^{-m_1 y} + A_2\, e^{-m_2 y} \quad (40)$$

$$G_0(y) = e^{-m_3 y} \quad (41)$$

$$H_0(y) = A_3\, e^{-m_3 y} + A_4\, e^{-m_4 y} \quad (42)$$

$$E_0(y) = 1 - A_5\, e^{-m_1 y} - A_6\, e^{-m_3 y} + A_7\, e^{-m_5 y} \quad (43)$$

$$G_1(y) = A_8\, e^{-m_8 y} - A_9\, e^{-m_7 y} + A_{10}\, e^{-m_6 y} - A_{11} e^{-2m_1 y} - A_{12}\, e^{-2m_3 y} - A_{13}\, e^{-2m_5 y} + A_{14}\, e^{-m_3 y} \quad (44)$$

$$E_1(y) = A_{21}\, e^{-m_5 y} - A_6\, A_{14} e^{-m_3 y} + A_{20}\, e^{-2m_5 y} + A_{18} e^{-2m_1 y} - A_{17}\, e^{-m_6 y} + A_{16}\, e^{-m_7 y} - A_{15}\, e^{-2m_8 y} - A_5 e^{-m_1 y} \quad (45)$$

$$F_0(y) = 1 + A_{31}\, e^{-m_9 y} + A_{30} e^{-m_5 y} - A_{29}\, e^{-m_4 y} - A_{28} e^{-m_3 y} - A_{25}\, e^{-m_2 y} - A_{24}\, e^{-m_1 y} \quad (46)$$

$$H_1(y) = A_{61}\, e^{-m_4 y} + A_3\, A_{14} e^{-m_3 y} - A_{60}\, e^{-m_1 y} - A_{59} e^{-2m_1 y} - A_{58}\, e^{-2m_3 y} - A_{55}\, e^{-2m_5 y} + A_{52}\, e^{-m_6 y} - A_{48} e^{-m_7 y} + A_{44}\, e^{-m_8 y} + A_{40} e^{-m_{10} y} + A_{39}\, e^{-m_{11} y} + A_{38} e^{-m_{12} y} - A_{37}\, e^{-m_{13} y} - A_{35}\, e^{-m_{15} y} - A_{34}\, e^{-m_{16} y} - A_{33} e^{-m_{17} y} - A_{32} e^{-m_{18} y} \quad (47)$$

$$F_1(y) = A_{97}\, e^{-m_9 y} + A_{96} e^{-2m_5 y} + A_{93}\, e^{-2m_3 y} + A_{90} e^{-2m_1 y} + A_{87}\, e^{-m_1 y} - A_{84}\, e^{-m_3 y} - A_{81}\, e^{-m_4 y} + A_{80} e^{-m_5 y} - A_{79}\, e^{-m_6 y} + A_{76} e^{-m_7 y} - A_{73}\, e^{-m_8 y} - A_{70} e^{-m_{10} y} - A_{69}\, e^{-m_{11} y} - A_{68}\, e^{-m_{12} y} + A_{67}\, e^{-m_{13} y} + A_{66} e^{-m_{14} y} + A_{65} e^{-m_{15} y} + A_{64}\, e^{-m_{16} y} + A_{63} e^{-m_{17} y} + A_{62} e^{-m_{18} y} \quad (48)$$

The various constants used above are given in the Appendix.

By virtue of equations (14), (15), (16) and form the equation (24) we get the velocity, temperature and concentration expressions.

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

Skin-friction at the wall

Given the velocity field in the boundary layer, we can now calculated the skin friction at the wall of the plate is given by

$$\tau_w = \frac{\tau_w^*}{\rho U_0 V_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = (u_0{}' + \varepsilon\, e^{nt}\, u_1')_{y=0} \quad (49)$$

We calculate the heat transfer coefficient in terms of Nusselt number and mass transfer coefficient in terms of Sherwood number as follows

Nusselt number

$$N_u = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\theta_0{}' + \varepsilon\, e^{nt}\, \theta_1'\right)_{y=0} \quad (50)$$

Sherwood number

$$S_h = \left(\frac{\partial C}{\partial y}\right)_{y=0} = (C_0{}' + \varepsilon\, e^{nt} C_1')_{y=0} \quad (51)$$

5. RESULTS AND DISCUSSIONS

The formulation of the effects of inclined magnetic field and suction velocity varying exponentially with time about a non-zero constant mean value on the flow and heat transfer of an incompressible fluid along a semi-infinite vertical porous moving plate with heat generation and viscous dissipation has been carried out in the preceding sections. This enables us to carry out the numerical computations for the velocity, temperature and concentration for various values of the material parameters. In the present study the boundary condition for $y \rightarrow \propto$ is replaced by a sufficiently large value of y where the velocity profile u can be approached to the relevant free stream velocity. A span wise step distance Δy of 0.001 is used with max $y_{max} = 6$.

In order to assess the accuracy of our method, we have compared our results with accepted data sets for the velocity, temperature and concentration profiles for a stationary vertical porous plate corresponding to the case computed by Helmy [15]. The results of this comparison are found to be in very good agreement.

Figure 1 shows the velocity profiles against span wise direction for different values of the dimensionless exponential index n. It is observed that an increase in the value of n leads to an increase in the velocity distribution across the boundary layer. Also, it is noticed that the velocity increases for 0 < y < 1 attains maximum at y =1.0 and decreases for y >1.0.

Figure 2 illustrates the variation of velocity profiles with span wise coordinate y for several values of M. It is observed the an increase in the value of M leads to decrees in the velocity distribution across the boundary layer.

Figure 3 shows the velocity profiles for different values of the Prandtl number Pr. The velocity increases for 0 < y < 1.0, attains maximum at y = 1.0 and decreases for y > 1.0. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing velocity.

The velocity profiles for different values of Grashof number Gr are described in Figure 4. It is observed that an increase in Gr leads to a rise in the values of velocity. In addition, the curves show that the peak value of velocity increases rapidly near the wall of the plate as Grashof number increases.

Figure 5 shows the velocity profiles for different values of the permeability parameter K. Clearly as K increases the peak value of velocity tends to increase. Also it is observed that the maximum velocity occurs near y =1.0 is shifted slightly decreases towards the right for y >1.0.

Figure 6 shows the velocity profiles for different values of the Chemical reaction parameter K1. Clearly as K1 increases the peak value of velocity tends to decrease. Also it is observed that the maximum velocity occurs near y = 1.0.

The velocity profiles for different values of Grashof number Gc are described in Figure 7. It is observed that an increase in Gc leads to a rise in the values of velocity. In addition, the curves show that the peak value of velocity increases rapidly near the wall of the plate as Grashof number increases.

Figure 8 shows the velocity profiles for different values of α. The numerical results show that the effect of increasing values of α results in a decreasing velocity.

Figure 9 depicts the temperature profiles with span wise coordinate y for different values of the dimensionless exponential index n .Having with different initial surface temperatures, the profiles of temperature distribution across the boundary layer represent slight difference near the moving porous plate That is an increase in the value of n leads to an increase in the temperature distribution across the boundary layer.

Figure 10 shows the temperature profiles for different values of the Prandtl number Pr. Clearly as Pr increases the peak value of temperature tends to decrease.

The temperature profiles for different values of the Chemical reaction parameter K1 are shown in Fig.11. It is clear that there is no effect on temperature for increasing K1 values.

Figure 12 shows the temperature profiles for different values of the Ec . The numerical results show that the effect of increasing values of Ec results in a decreasing temperature.

Figure 13 display the concentration profiles for different values of the dimensionless exponential index n. Having with different initial surface concentrations, the profiles of concentration distribution across the boundary layer represent slight difference near the moving porous plate. It is noticed that an increase in the value of n leads to an increase in the concentration distribution across the boundary layer.

For the case of different values of Schmidt number Sc the concentration profiles are plotted in Figure 14. It is noticed that the concentration decreases when increasing values of Schmidt number Sc.

Also the figure shows that an increase in Schmidt number *Sc* results in a decreasing the concentration distribution, because the smaller values of Sc are equivalent to increasing the chemical molecular diffusivity.

Figure 15 represents the concentration profiles for different values of the Chemical reaction parameter K1. It is observed that the concentration decreases when increasing K1 values.

The effects of Pr, M, Gr, Gc, Sc, S, A, K1, K, α and Ec on the surface skin friction (τ_p) and on rate of heat transfer (Nu) are numerically shown in Table 1 and Table 2 respectively. Also the effects of Sc, A, K1, and Ec on the rate of mass transfer (Sh) are numerically shown in Table 3.

From Table 1 we observe that an increase in Pr, M, Sc, K1 and α results in a decrease in the surface skin friction while an increase in Gr, Gc, S, A, K, and Ec results in an increase in the surface skin friction.

From Table 2 we observe that an increase in Pr, M, and α leads to an increase in the rate of heat transfer expressed in terms of Nusselt number while reverse effect is noted for an increase in Gr, Gc, Sc, S, A, K1, K, and Ec.

From Table 3, an increase in Sc, K1 and Ec leads to an increase in the rate of Mass transfer expressed in terms of Sherwood number while reverse effect is noted for an increase in A.

In the absence of chemical reaction, heat source and concentration parameters these results are in agreement with the results of Youn J. Kim [18].

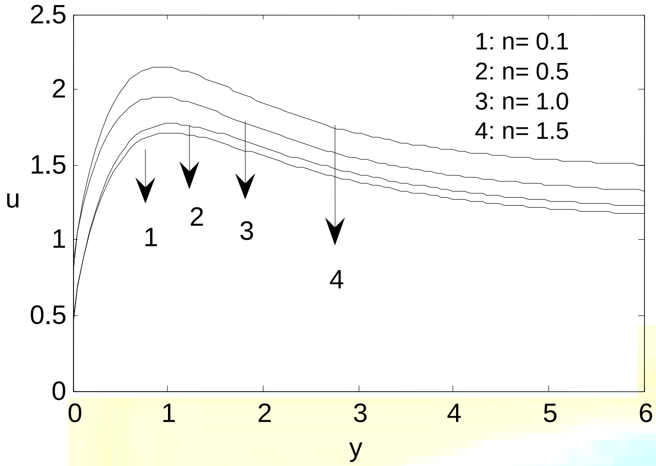

Fig. 1: Velocity profile for different values of n

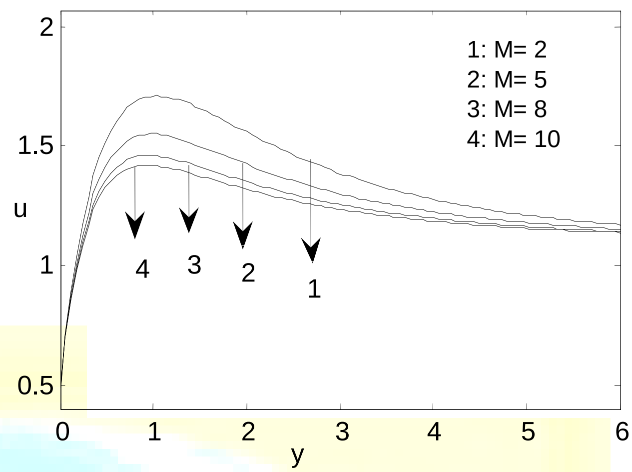

Fig. 2 Velocity profile for different values of M

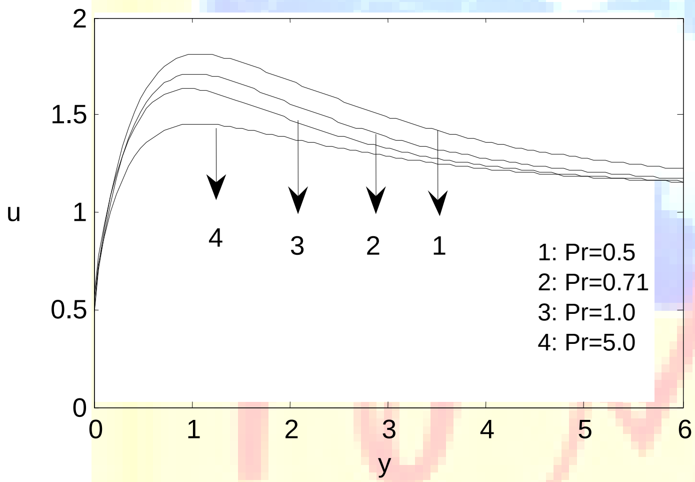

Fig. 3: Velocity profile for different values of Pr

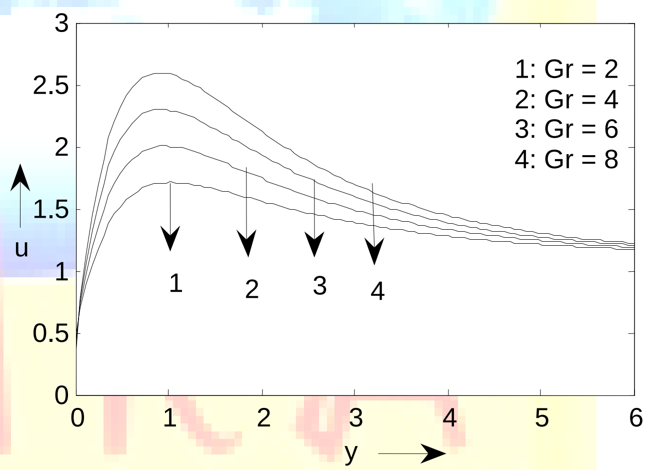

Fig. 4: Velocity Profile for different values of Gr

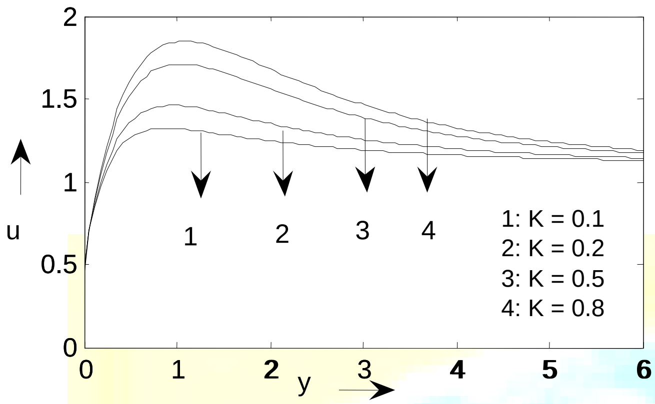

Fig. 5: Velocity Profile for different values of K

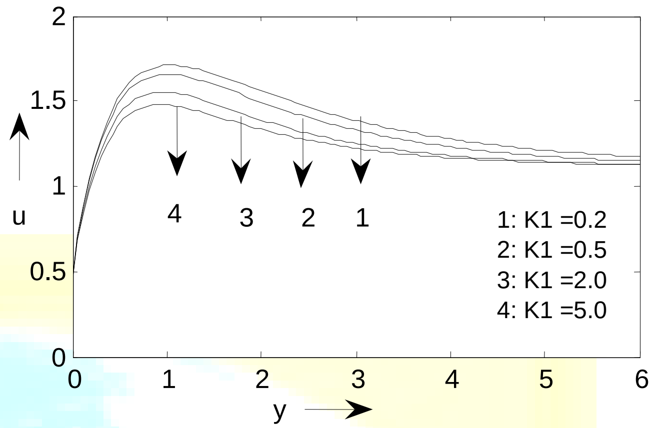

Fig. 6: Velocity Profile for Different values of K1

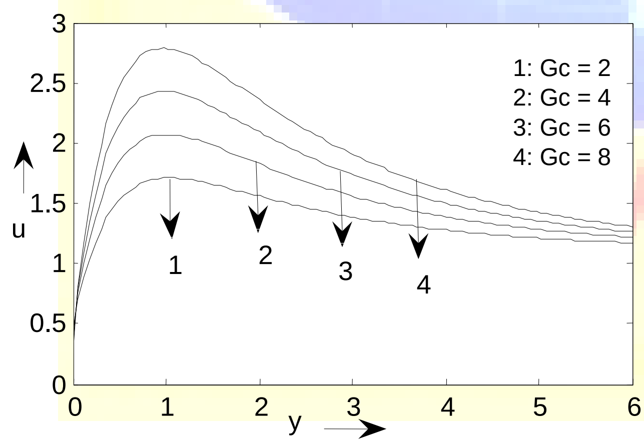

Fig. 7: Velocity profile for different values of Gc

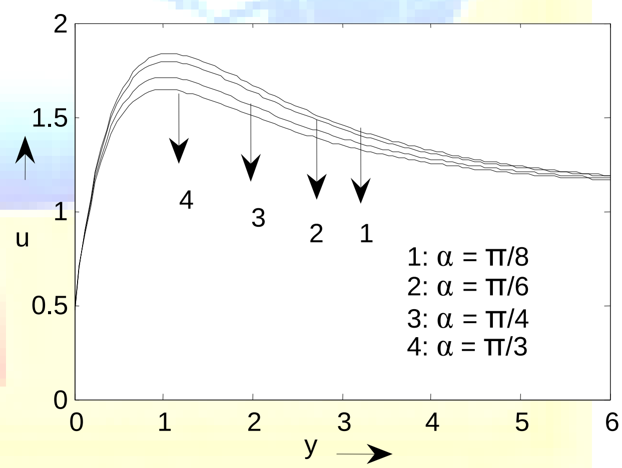

Fig. 8: Velocity profile for Different values of α

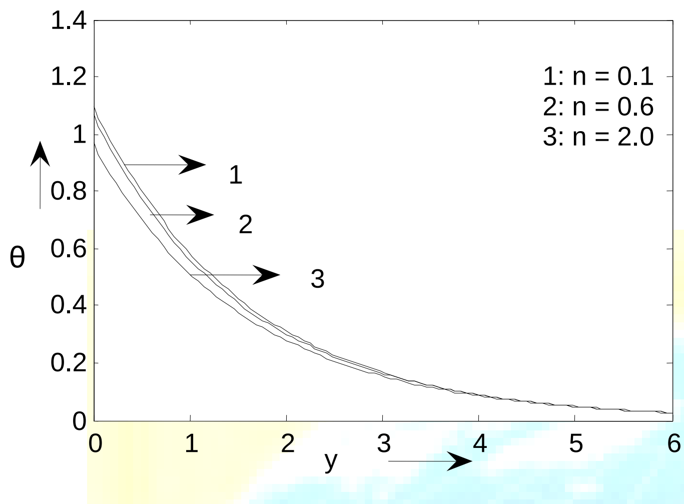

Fig. 9 : Temperature profile for different values of **n**

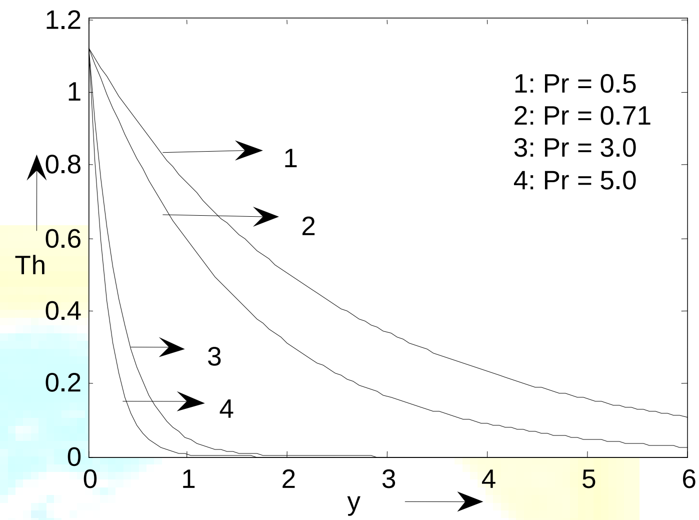

Fig.10: Temperature profile for different values of Pr

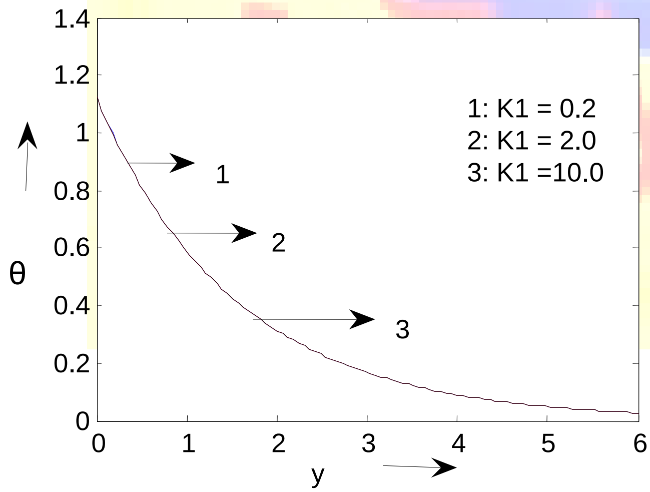

Fig.11: Temperature profile for different values of K1

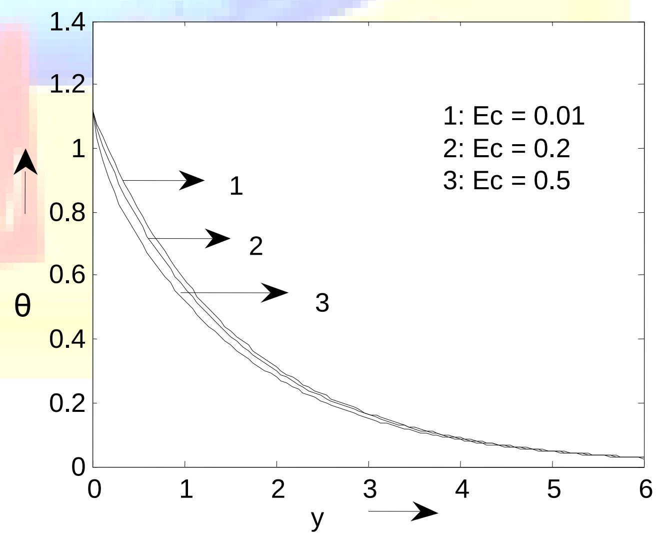

Fig. 12: Temperature profile for different values of Ec

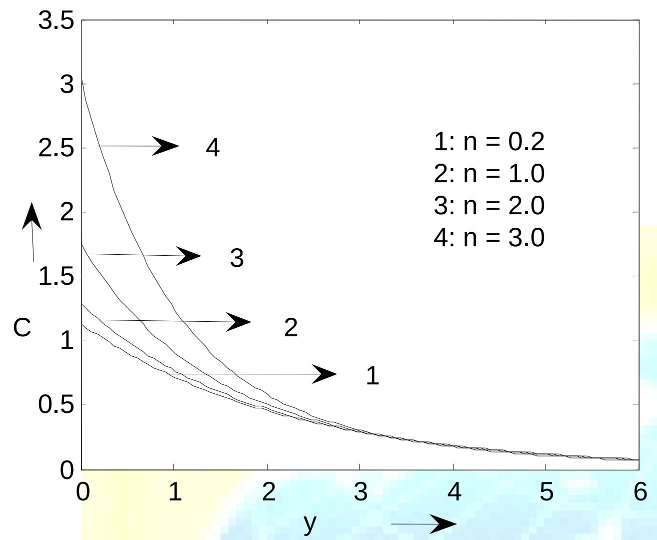

Fig. 13 Concentration profile for different values of n

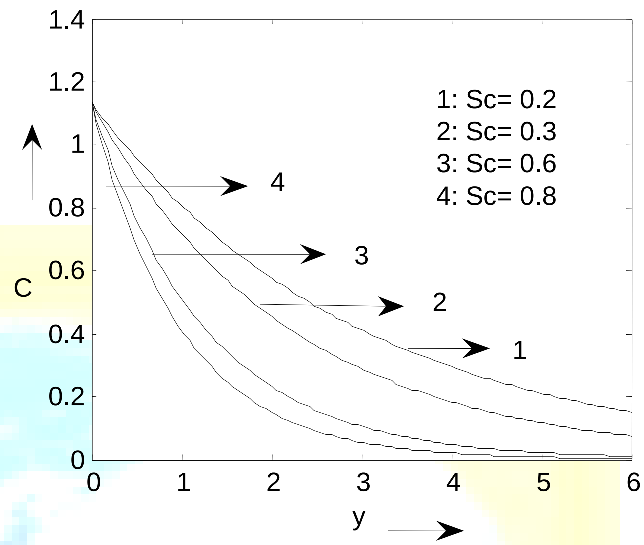

Fig. 14: Concentration profile for different values of Sc

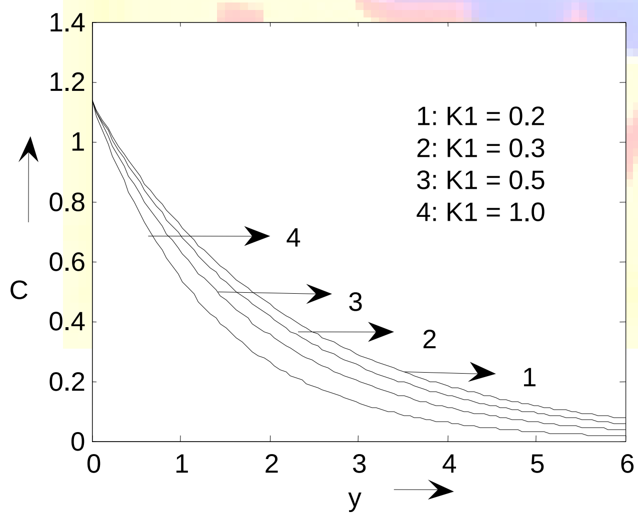

Fig. 15: Concentration profile for different values of K1

Table 1 : Numerical values of Skin-friction coefficient τ_p

Pr	M	Gr	Gc	Sc	S	A	K_1	K	A_p	E_c	τ_p
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	3.9177
5.00	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	2.9101
0.71	**5.0**	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	3.7303
0.71	2.0	**5.0**	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	5.6991
0.71	2.0	2.0	**5.0**	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	5.8901
0.71	2.0	2.0	2.0	**0.9**	0.1	0.5	0.2	0.5	0.7854	0.01	3.5527
0.71	2.0	2.0	2.0	0.3	**0.3**	0.5	0.2	0.5	0.7854	0.01	4.0295
0.71	2.0	2.0	2.0	0.3	0.1	**2.5**	0.2	0.5	0.7854	0.01	3.9445
0.71	2.0	2.0	2.0	0.3	0.1	0.5	**2.5**	0.5	0.7854	0.01	3.5838
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	**2.5**	0.7854	0.01	4.5677
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	**1.0472**	0.01	3.8327
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	**0.02**	3.9466

Table 2 : Numerical values of Nusselt number Nu

Pr	M	Gr	Gc	Sc	S	A	K_1	K	A_p	E_c	Nu
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	0.7207
5.00	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	31.8532
0.71	**5.0**	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	0.7310
0.71	2.0	**5.0**	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	0.5648
0.71	2.0	2.0	**5.0**	0.3	0.1	0.5	0.2	0.5	0.7854	0.01	0.7197
0.71	2.0	2.0	2.0	**0.9**	0.1	0.5	0.2	0.5	0.7854	0.01	0.7072
0.71	2.0	2.0	2.0	0.3	**0.3**	0.5	0.2	0.5	0.7854	0.01	0.4893
0.71	2.0	2.0	2.0	0.3	0.1	**2.5**	0.2	0.5	0.7854	0.01	0.6596
0.71	2.0	2.0	2.0	0.3	0.1	0.5	**2.5**	0.5	0.7854	0.01	0.7076
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	**2.5**	0.7854	0.01	0.6048
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	**1.0472**	0.01	0.7259
0.71	2.0	2.0	2.0	0.3	0.1	0.5	0.2	0.5	0.7854	**0.02**	0.7165

Table 3: Numerical values of Sherwood number **Sh**

Sc	A	K_1	Ec	Sh
0.3	0.5	0.2	0.01	0.3644
0.9	0.5	0.2	0.01	0.8878
0.3	**2.5**	0.2	0.01	0.3157
0.3	0.5	**2.5**	0.01	0.8975
0.3	0.5	0.2	**0.02**	0.3680

NOMENCLATURE

A : Suction velocity parameter ,

B_0 : Magnetic flux density

C_f : Skin friction coefficient,

C_p : Specific heat at constant pressure

Gr : Grashof number,

Gc : Concentration parameter

g : Acceleration due to gravity,

K : Permeability of the porous medium

K1: Chemical reaction parameter, k : Thermal conductivity

M : Magnetic field parameter, N: Dimensionless material parameter

n : Dimensionless exponential index, Nu : Nusselt number

Pr : Prandtl number, Sc : Schmidt number

T : Temperature, t : Dimensionless time

U_0 : Scale of free stream velocity, V_0 : scale of suction velocity

u, v : Components of velocities along and perpendicular to the plate, respectively

α : Angle of inclination,

x, y : distances along and perpendicular to the plate, respectively.

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APPENDIX

$m_1 = \frac{1}{2}\left[S_c + \sqrt{S_c^2 + 4K_1\ S_c}\ \right]$ $m_2 = \frac{1}{2}\left[S_c + \sqrt{S_c^2 + 4K_2\ S_c}\ \right]$

$m_3 = \frac{1}{2}\left[P_r + \sqrt{P_r^2 - 4P_r\ S}\ \right]$ $m_4 = \frac{1}{2}\left[P_r + \sqrt{P_r^2 - 4P_r\ S_1}\ \right]$

$K_2 = K_1 + n$ $m_5 = \frac{1}{2}\left[1 + \sqrt{1 + 4\,N}\ \right]$ etc.

To save the paper, unable to present the remaining constants.

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