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The effect of chemical reaction on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction

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Abstract: *The effect of chemical reaction on an unsteady magneto hydrodynamic flow past an infinite vertical porous plate with variable suction and heat convective mass transfer, where the plate temperature oscillates with the same frequency as that of variable suction velocity. The non – linear partial differential equations governing the flow have been solved numerically using finite difference method. The flow phenomenon has been characterized with the help of flow parameters such as velocity, temperature and concentration profiles for different parameters such as thermal Grashof number (Grashof number for heat transfer)* (Gr), *solutal Grashof number (Grashof number for mass transfer)* (Gc), *Prandtl number* $(\Pr)$, *Schmidt number* (Sc), *Hartmann number* (M), *Permeability parameter* (K) *and Chemical reaction parameter* (k_r), *The velocity, temperature and concentration profiles are shown through graphically and Skin – friction, Nusselt number and Schmidt number are shown through tabular forms.*

Key Words: *Chemical reaction, Unsteady, MHD, Free convection flow, Porous medium, Infinite vertical porous plate, Finite difference method.*

Nomenclature

A	Variable suction parameter
B_o	Magnetic field component along $y'-$ axis
C_p	Specific heat at constant pressure
Gr	Grashof number
Gc	Modified Grashof number
g	Acceleration of gravity
K'	The permeability of medium
K	The permeability parameter
M	Hartmann number
$\Pr$	Prandtl number
Sc	Schmidt number
k_r	Chemical reaction parameter
D	Chemical molecular diffusivity
T'	Temperature of fluid near the plate
T'_w	Temperature of the fluid far away of the fluid from the plate
T'_∞	Temperature of the fluid at infinity
C	Concentration of the fluid
C'	Concentration of fluid near the plate
C'_w	Concentration of the fluid far away of the fluid from the plate
C'_∞	Concentration of the fluid at infinity
t'	Time in x', y' coordinate system
t	Time in dimensionless co – ordinates
u'	Velocity component in $x'-$ direction
v'	Velocity component in $y'-$ direction
u	Dimensionless velocity component in $x'-$ direction
Nu	Nusselt number

Sh Sherwood number
R_{e_x} Reynold's number
x', y' Co – ordinate system
x, y Dimensionless coordinates
v_o Mean suction velocity

Greek symbols
β Coefficient of volume expansion for heat transfer
β^* Coefficient of volume expansion for mass transfer
ε Smallest positive constant
K_T Thermal conductivity of the fluid
σ Electrical conductivity of the fluid
ν Kinematic viscosity
θ Non – dimensional temperature
ρ Density of the fluid
τ Skin – friction
μ Viscosity, Ns/m^2

I. Introduction

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. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. There are two types of reactions, homogeneous reaction and heterogeneous reaction. A homogeneous reaction is one that occurs uniformly throughout a given phase. The species generation in a homogeneous reaction is analogous to internal source of heat generation. In contrast, a heterogeneous reaction takes place in a restricted region or within the boundary of a phase. It can therefore be treated as a boundary condition similar to the constant heat flux condition in heat transfer. The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. The flow of a fluid past a wedge is of fundamental importance since this type of flow constitutes a general and wide class of flows in which the free stream velocity is proportional to a power of the length coordinate measured from the stagnation point. In many transport processes in nature and in industrial applications in which heat and mass transfer is a consequence of buoyancy effects caused by diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production and food processing. In nature, the presence of pure air or water is impossible. Some foreign mass may be present either naturally or mixed with the air or water. The present trend in the field of chemical reaction with viscosity analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular, the study of chemical reaction, heat and mass transfer is of considerable importance in chemical and hydrometallurgical industries. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction.

Both free and forced convection boundary layer flows with Soret and Dufour have been addressed by Abreu *et al.* [1]. Afify [2] carried out an analysis to study free convective heat and mass transfer of an incompressible, electrically conducting fluid over a stretching sheet in the presence of suction and injection with thermal diffusion and diffusion thermo effects. Beg *et al.* [3] have also analyzed the chemical reaction rate effects on steady buoyancy – driven dissipative micropolar free convective heat and mass transfer in a Darcian porous regime. Beg *et al.* [4] have also studied numerically both viscous heating and Joule (Ohmic) dissipation effects on transient Hartmann – Couette convective flow in a Darcian porous medium channel also including Hall current and ion – slip effects. Chaudhary *et al.* [5] studied the effect of free convection effects on magnetohydrodynamic flow past an infinite vertical accelerated plate embedded in porous media with constant heat flux by using Laplace transform technique for finding the analytical solutions. Chin *et al*. [6] obtained numerical results for the steady mixed convection boundary layer flow over a vertical impermeable surface embedded in a porous medium when the viscosity of the fluid varies inversely as a linear function of the temperature. Das and Mitra [7] discussed the unsteady mixed convective MHD flow and mass transfer past an accelerated infinite vertical plate with suction. Recently, Das and his co – workers [8] analyzed the effect of mass transfer on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Das *et al.* [9] investigated numerically the unsteady free convective MHD flow past an accelerated vertical plate with suction and heat flux. Das and his associates [10] estimated the mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction employing finite difference analysis. Gireesh kumar *et al.* [11] investigated effects of chemical reaction and mass transfer on MHD unsteady free convection flow past an infinite vertical plate with constant suction and heat sink.

Hayat *et al*. [12] analyzed a mathematical model in order to study the heat and mass transfer characteristics in mixed convection boundary layer flow about a linearly stretching vertical surface in a porous medium filled with a visco – elastic fluid, by taking into account the diffusion thermo and thermal diffusion effects. Ibrahim *et al.* [13] studied the effects of chemical reaction and radiation absorption on transient hydromagnetic natural convection flow with wall transpiration and heat source. The unsteady free convective MHD flow with heat transfer past a semi – infinite vertical porous moving plate with variable suction has been studied by Kim [14]. Effects of chemical reaction on free convection flow of a polar fluid through a porous medium in the presence of internal heat generation are examined by Patil and Kulkarni [15]. Several studies have also described thermal radiation effects on convection flows in porous media. MHD convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption was studied by Rahman and Sattar [16]. Sarangi and Jose [17] studied the unsteady free convective MHD flow and mass transfer past a vertical porous plate with variable temperature. The effect of temperature dependent viscosity and thermal conductivity on unsteady MHD convective heat transfer past a semi – infinite vertical porous plate has studied Seddek and Salama [18]. Seddeek *et al.* [19] more recently reported on the effect of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through a Darcian porous media in the presence of radiation and magnetic field. Seethamahalakshmi *et al.* [20] discussed the effects of Soret on an unsteady magnetohydrodynamic free convection flow past an infinite vertical porous plate with variable suction. The unsteady free convection flow of a viscous incompressible fluid past an infinite vertical plate with constant heat flux is considered on taking into account viscous dissipative heat, under the influence of a transverse magnetic field studied by Srihari *et al* [21].

The object of the present paper is to analyze the chemical reaction effect on an unsteady magneto hydrodynamic free convection flow past an infinite vertical plate by taking variable suction into account. The governing equations are transformed by using unsteady similarity transformation and the resultant dimensionless equations are solved by using the finite difference method. The effects of various governing parameters on the velocity, temperature, concentration, skin – friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and discussed in detail. From computational point of view it is identified and proved beyond all doubts that the finite difference method is more economical in arriving at the solution and the results obtained are good agreement with the results of Seethamahalakshmi *et al*. [20] in some special cases.

II. Mathematical Analysis

Consider the unsteady magneto hydrodynamic flow past an infinite vertical porous plate with variable suction and heat convective mass transfer, where the plate temperature oscillates with the same frequency as that of variable suction velocity in presence of chemical reaction.

We made the following assumptions.

1. In Cartesian coordinate system, let $x'-$axis is taken to be along the plate and the $y'-$axis normal to the plate. Since the plate is considered infinite in $x'-$direction, hence all physical quantities will be independent of $x'-$direction.
2. The wall is maintained at constant temperature (T'_w) and concentration (C'_w) higher than the ambient temperature (T'_∞) and concentration (C'_∞) respectively.
3. Let the components of velocity along x' and y' axes be u' and v' which are chosen in the upward direction along the plate and normal to the plate respectively.
4. A uniform magnetic field of magnitude B_o is applied normal to the plate. The transverse applied magnetic field and magnetic Reynold's number are assumed to be very small, so that the induced magnetic field is negligible.
5. The polarization effects are assumed to be negligible and hence the electric field is also negligible.
6. The homogeneous chemical reaction of first order with rate constant between the diffusing species and the fluid is assumed.
7. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species, which are present and hence Soret and Dufour effects are negligible.
8. The Hall Effect of magneto hydrodynamics and magnetic dissipation (Joule heating of the fluid) are neglected.

Hence the governing equations of the problem are:

$$\frac{\partial \rho'}{\partial t'} + \frac{\partial(\rho' u')}{\partial x'} + \frac{\partial(\rho' u')}{\partial y'} = 0 \tag{1}$$

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

$$\rho' C_p' \left(\frac{\partial T'}{\partial t'} + u' \frac{\partial T'}{\partial x'} + v' \frac{\partial T'}{\partial y'} \right) = K_T \left(\frac{\partial^2 T'}{\partial x'^2} + \frac{\partial^2 T'}{\partial y'^2} \right) \quad (3$$

$$\rho' \left(\frac{\partial C'}{\partial t'} + u' \frac{\partial C'}{\partial x'} + v' \frac{\partial C'}{\partial y'} \right) = \rho' D \left(\frac{\partial^2 C'}{\partial x'^2} + \frac{\partial^2 C'}{\partial y'^2} \right) - K_r \left(C' - C'_\infty \right) \quad (4)$$

Here, the status of an equation of state is that of equation $\rho' =$ constant. This means that the density variations produced by the pressure, temperature and concentration variations are sufficiently small to be unimportant. Variations of all fluid properties other than the variations of density except in so far as they give rise to a body force, are ignored completely (Boussinesq approximation). All the physical variables are functions of y' and t' only as the plate are infinite. It is also assumed that the variation of expansion coefficient is negligibly small and the pressure and influence of the pressure on the density are negligible. Within the framework of above assumptions the governing equations reduce to Continuity Equation:

$$\frac{\partial v'}{\partial y'} = 0 \quad (5)$$

Momentum Equation:

$$\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} = g\beta \left(T' - T'_\infty \right) + g\beta^* \left(C' - C'_\infty \right) + \nu \frac{\partial^2 u'}{\partial y'^2} - \left(\frac{\sigma B_o^2}{\rho} + \frac{\nu}{K'} \right) u' \quad (6)$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'} = \frac{K_T}{\rho' C_p'} \frac{\partial^2 T'}{\partial y'^2} \quad (7)$$

Species Diffusion Equation:

$$\frac{\partial C'}{\partial t'} + v' \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} - K_r \left(C' - C'_\infty \right) \quad (8)$$

And the corresponding boundary conditions are

$$\left. \begin{array}{l} t' \le 0 : u' = 0,\ T' = T'_\infty,\ C' = C'_\infty \quad for\ all\ \ y' \\ t' > 0 : \begin{cases} u' = 0,\ T' = T'_w = 1 + \varepsilon e^{i\omega' t'},\ C' = C'_w \quad at\ y' = 0 \\ u' \to 0,\ T' \to T'_\infty,\ C' \to C'_\infty \quad as\ \ y' \to \infty \end{cases} \end{array} \right\} \quad (9)$$

From the continuity equation, it can be seen that v' is either a constant or a function of time. So, assuming suction velocity to be oscillatory about a non – zero constant mean, one can write $v' = -v_o \left(1 + \varepsilon A e^{i\omega' t'} \right)$

(10)

Where ε, A are small such that $\varepsilon A << 1$. The negative sign indicates that the suction velocity is directed towards the plate. In order to write the governing equations and the boundary conditions in dimensional following non – dimensional quantities are introduced.

$$\left. \begin{array}{l} y = \frac{y' v_o}{\nu},\ t = \frac{t' v_o}{\nu},\ u = \frac{u'}{v_o},\ v = \frac{v'}{v_o},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ Gr = \frac{g\beta\nu \left(T'_w - T'_\infty \right)}{v_o^3},\ Sc = \frac{\nu}{D}, \\ Gc = \frac{g\beta^* \nu \left(C'_w - C'_\infty \right)}{v_o^3},\ \Pr = \frac{\mu C_p}{K_T},\ M = \left(\frac{\sigma B_o^2}{\rho} \right) \frac{\nu}{v_o^2},\ K = \frac{K' v_o^2}{\nu^2},\ k_r = \frac{K_r \nu}{v_o^2},\ \omega = \frac{4\nu\omega'}{v_o'^2} \end{array} \right\}$$

(11)

Hence, using the above non – dimensional quantities, the equations (6) – (9) in the non – dimensional form can be written as

$$\frac{1}{4} \frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t} \right) \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + (Gr)\theta + (Gc)C - \left(M + \frac{1}{K} \right) u \quad (12)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} \tag{13}$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-k_r C \tag{14}$$

And the corresponding boundary conditions are

$$\left.\begin{array}{l} t\le 0:\ u=0,\ \theta=0,\ C=0\ \ for\ \ all\ \ y \\ t>0:\begin{cases} u=0,\ \theta=1+\varepsilon e^{i\omega t}, C=1\ \ at\ \ y=0 \\ u\to 0,\ \ \theta\to 0,\ \ C\to 0\ \ \ as\ \ y\to\infty \end{cases} \end{array}\right\} \tag{15}$$

All the physical parameters are defined in the nomenclature.

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, the local surface heat and mass flux. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin – friction) is given by and in dimensionless form, we obtain Knowing the temperature field, it is interesting to study the effect of the free convection and radiation on the rate of heat transfer. This is given by which is written in dimensionless form as

$$\tau=\frac{\tau_w}{\rho u_w^2},\ \tau_w=\left[\mu\frac{\partial u}{\partial y}\right]_{y'=0}=\rho v_o^2 u'(0)=\left[\frac{\partial u}{\partial y}\right]_{y=0} \tag{16}$$

The dimensionless local surface heat flux (i.e., Nusselt number) is obtained as

$$N_u(x')=-\left[\frac{x'}{(T'_w-T'_\infty)}\frac{\partial T'}{\partial y'}\right]_{y'=0}\quad \text{Then}\ \ Nu=\frac{N_u(x')}{R_{e_x}}=-\left[\frac{\partial \theta}{\partial y}\right]_{y=0} \tag{17}$$

The definition of the local mass flux and the local Sherwood number are respectively given by with the help of these equations, one can write

$$S_h(x')=-\left[\frac{x'}{(C'_w-C'_\infty)}\frac{\partial C'}{\partial y'}\right]_{y'=0}\quad \text{Then}\ \ Sh=\frac{S_h(x')}{R_{e_x}}=-\left[\frac{\partial C}{\partial y}\right]_{y=0} \tag{18}$$

Where $R_{e_x}=-\frac{v_o x'}{\nu}$ the Reynold is's number.

III. Method of solution

Equations (12) – (14) are coupled non – linear partial differential equations and are solved by using initial and boundary conditions (15). However, exact or approximate solutions are not possible for this set of equations. And hence we solve these equations by an implicit finite difference method of Crank – Nicolson type for a numerical solution. The equivalent finite difference scheme of equations (12) – (14) is as follows:

$$\frac{1}{4}\left(\frac{u_{i,\,j+1}-u_{i,\,j}}{\Delta t}\right)-B\left(\frac{u_{i+1,\,j}-u_{i,\,j}}{\Delta y}\right)=\frac{1}{2}\left(\frac{u_{i-1,\,j+1}-2u_{i,\,j+1}+u_{i+1,\,j+1}}{(\Delta y)^2}+\frac{u_{i-1,\,j}-2u_{i,\,j}+u_{i+1,\,j}}{(\Delta y)^2}\right)$$
$$-\frac{1}{2}\left(M+\frac{1}{K}\right)\left(\frac{u_{i,\,j+1}+u_{i,\,j}}{\Delta y}\right)+\frac{1}{2}(Gr)\left(\frac{\theta_{i,\,j+1}+\theta_{i,\,j}}{\Delta y}\right)+\frac{1}{2}(Gc)\left(\frac{C_{i,\,j+1}+C_{i,\,j}}{\Delta y}\right) \tag{19}$$

$$\frac{1}{4}\left(\frac{\theta_{i,\,j+1}-\theta_{i,\,j}}{\Delta t}\right)-B\left(\frac{\theta_{i+1,\,j}-\theta_{i,\,j}}{\Delta y}\right)=\frac{1}{2\Pr}\left(\frac{\theta_{i-1,\,j+1}-2\theta_{i,\,j+1}+\theta_{i+1,\,j+1}}{(\Delta y)^2}+\frac{\theta_{i-1,\,j}-2\theta_{i,\,j}+\theta_{i+1,\,j}}{(\Delta y)^2}\right) \tag{20}$$

$$\frac{1}{4}\left(\frac{C_{i,\,j+1}-C_{i,\,j}}{\Delta t}\right)-B\left(\frac{C_{i+1,\,j}-C_{i,\,j}}{\Delta y}\right)=\frac{1}{2Sc}\left(\frac{u_{i-1,\,j+1}-2u_{i,\,j+1}+u_{i+1,\,j+1}}{(\Delta y)^2}+\frac{u_{i-1,\,j}-2u_{i,\,j}+u_{i+1,\,j}}{(\Delta y)^2}\right)$$
$$-\frac{1}{2}(k_r)\left(\frac{C_{i,\,j+1}+C_{i,\,j}}{\Delta y}\right) \tag{21}$$

Here the suffix i corresponds to y and j corresponds to t. Also $B = 1 + \varepsilon A e^{i\omega t}$, $\Delta t = t_{j+1} - t_j$ and $\Delta y = y_{i+1} - y_i$

The complete solution of the discrete equations (19) – (21) proceeds as follows:

Step – (1): Knowing the values of C, θ and u at a time $t = j$, calculate C and θ at a time $t = j+1$ using equations (20) and (21) and solving tri – diagonal linear system of equations.

Step – (2): Knowing the values of θ and C at time $t = j$, solve the equation (19) (*via* tri – diagonal matrix inversion) to obtain u at a time $t = j+1$.

We can repeat steps (1) and (2) to proceed from $t = 0$ to the desired time value.

The implicit Crank – Nicolson method is a second order method $\left(o\left(\Delta t^2\right)\right)$ in time and has no restrictions on space and time – steps, Δy and Δt, *i.e.,* the method is unconditionally stable. The finite differences scheme used, involves the values of the function at the six grid points. A linear combination of the "future" points is equal to another linear combination of the "present" points. To find the future values of the function, one must solve a system of linear equations, whose matrix has a tri – diagonal form.

The computations were carried out for $Gr = 1.0, Gc = 1.0, \Pr = 0.71$ (Air), $Sc = 0.22$ (Hydrogen), $M = 1.0$, $K = 1.0, A = 1.0, \varepsilon = 0.001, \omega t = \frac{\pi}{4}, k_r = 1.0$, $t = 1.0$ and $\Delta y = 0.1, \Delta t = 0.001$ and the procedure is repeated till $y =$ 4. In order to check the accuracy of numerical results, the present study is compared with the available theoretical solution of Seethamahalakshmi *et al*. [20] and they are found to be in good agreement.

IV. Results and Discussions

In the preceding sections, the problem of chemical reaction effects on an unsteady MHD free convection flow past an infinite vertical porous plate with constant suction was formulated and the dimensionless governing equations were solved by means of a finite difference method. In the present study we adopted the following default parameter values of finite difference computations: $Gr = 1.0$, $Gc = 1.0$, $\Pr = 0.71$ (Air), $Sc = 0.22$ (Hydrogen), $M = 1.0$, $K = 1.0$, $A = 1.0$, $\varepsilon = 0.001, \omega t = \frac{\pi}{4}$, $k_r = 1.0$ and $t = 1.0$. All graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

The influence of thermal Grashof number, Gr, on the velocity is shown in Figure (1). The thermal Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. The flow is accelerated due to the enhancement in buoyancy force corresponding to an increase in the thermal Grashof number. The positive values of Gr correspond to cooling of the plate by natural convection. Heat is therefore conducted away from the vertical plate into the fluid which increases the temperature and thereby enhances the buoyancy force. In addition, it is seen that the peak values of the velocity increases rapidly near the plate as thermal Grashof number increases and then decays smoothly to the free stream velocity. Figure (2) presents typical velocity profiles in the boundary layer for various values of the solutal Grashof number, Gc. The solutal Grashof number Gc defines the ratio of the species buoyancy force to the viscous hydrodynamic force. It is noticed that the velocity increases with increasing values of the solutal Grashof number.

Figures (3) and (8) show the behavior of velocity and temperature profiles for different values Prandtl number. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing velocity. It is observed that an increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. 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 as the thermal boundary later is thicker and the rate of heat transfer is reduced. The effect of Schmidt number Sc on the velocity and concentration are shown in figures (4) and (9). As the Schmidt number increases, the velocity and concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. Reductions in the velocity and concentration distributions are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

The effect of Hartmann number, M on the velocity is shown in figure (5). The velocity decreases with an increase in the Hartmann number. It is because that the application of transverse magnetic field will result a resistive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity. Also, the boundary layer thickness decreases with an increase in the Hartmann number. Figure (6) shows the effect of the permeability of the porous medium parameter, K on the velocity distribution. As shown, the velocity is increasing with the increasing dimensionless porous medium parameter. The effect of the dimensionless porous medium K becomes smaller as K increase. Physically, this result can be achieved when the holes of the porous medium may be neglected. Figures (7) and (10), illustrate the behavior velocity and concentration for different values of chemical reaction parameter, k_r. It is observed that an increase in leads to a decrease in both the values of velocity and concentration. A distinct velocity escalation occurs near the wall after which profiles decay smoothly to the stationary value in free stream. Chemical reaction therefore boosts momentum transfer, i.e., accelerates the flow.

The profiles for skin – friction (τ) due to velocity under the effects of Grashof number (Gr), Modified Grashof number (Gc), Prandtl number $(\Pr)$, Schmidt number (Sc), Hartmann number (M), Permeability parameter (K) and Chemical reaction parameter (k_r) are presented in the table – 1 respectively. We observe from this table – 1, the skin – friction (τ) increases under the effects of Grashof number (Gr), Modified Grashof number (Gc) and Permeability parameter (K). And decreases under the effects of Prandtl number $(\Pr)$, Schmidt number (Sc), Hartmann number (M) and Chemical reaction parameter (k_r)

Table – 1: Skin – friction results (τ) for the values of $Gr, Gc, \Pr, Sc, M, K$ and k_r

Gr	Gc	$\Pr$	Sc	M	K	k_r	τ
1.0	1.0	0.71	0.22	1.0	1.0	1.0	5.8411
2.0	1.0	0.71	0.22	1.0	1.0	1.0	8.9829
1.0	2.0	0.71	0.22	1.0	1.0	1.0	8.5404
1.0	1.0	7.00	0.22	1.0	1.0	1.0	4.4432
1.0	1.0	0.71	0.30	1.0	1.0	1.0	5.7113
1.0	1.0	0.71	0.22	2.0	1.0	1.0	4.5870
1.0	1.0	0.71	0.22	1.0	2.0	1.0	6.8033
1.0	1.0	0.71	0.22	1.0	1.0	2.0	5.5172

Table – 2: Rate of heat transfer (Nu) values for different values of $\Pr$ and Rate of mass transfer (Sh) values for different values of Sc and k_r

$\Pr$	Nu	Sc	k_r	Sh
0.71	7.7337	0.22	1.0	6.7401
7.00	4.9322	0.30	1.0	6.4490
		0.22	2.0	6.0074

The profiles for Nusselt number (Nu) due to temperature profile under the effect of Prandtl number $(\Pr)$is presented in the table – 2. From this table we observe that, the Nusselt number (Nu) due to temperature profiles decreases under the effect of Prandtl number $(\Pr)$. The profiles for Sherwood number (Sh) due to concentration profiles under the effect of Schmidt number (Sc) and Chemical reaction parameter (k_r) are presented in the table – 2. We see from this table the Sherwood number (Sh) due to concentration profiles decreases under the effects of Schmidt number (Sc) and Chemical reaction parameter (k_r).

Table – 3: Comparison of present Skin – friction results (τ) with the Skin – friction results (τ^*) obtained by Seethamahalakshmi *et al*. [20] for different values of $Gr, Gc, \Pr, Sc, M$ and K

Gr	Gc	$\Pr$	Sc	M	K	τ	τ^*
1.0	1.0	0.71	0.22	1.0	1.0	4.5517	4.5508
2.0	1.0	0.71	0.22	1.0	1.0	6.2941	6.2931
1.0	2.0	0.71	0.22	1.0	1.0	6.5403	6.5397
1.0	1.0	7.00	0.22	1.0	1.0	3.9954	3.9922
1.0	1.0	0.71	0.30	1.0	1.0	4.2225	4.2216
1.0	1.0	0.71	0.22	2.0	1.0	3.8467	3.8449
1.0	1.0	0.71	0.22	1.0	2.0	4.9277	4.9260

In order to ascertain the accuracy of the numerical results, the present results are compared with the previous results of Seethamahalakshmi *et al*. [20] for Gr = Gc = 1.0, $\Pr$ = 0.71, Sc = 0.22, M = 1.0 and K = 1.0 in table – 3. They are found to be in an excellent agreement.

V. Conclusions

In this paper, the chemical reaction effects on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction was considered. The non – dimensional governing equations are solved with the help of finite difference method. The conclusions of the study are as follows:

1. The velocity increases with the increase in thermal Grashof number, solutal Grashof number and Permeability parameter.
2. The velocity decreases with an increase in the Hartmann number.
3. An increase in the Prandtl number decreases the velocity and temperature.
4. The velocity as well as concentration decreases with an increase in the Schmidt number.
5. The velocity as well as concentration decreases with an increase in the chemical reaction parameter.
6. The skin – friction increases with the increase in thermal Grashof number, solutal Grashof number and Permeability parameter.
7. The skin – friction decreases with an increase in the Hartmann number, Prandtl number, Schmidt number and Chemical reaction parameter.
8. An increase in the Prandtl number decreases the Nusselt number.
9. The Sherwood number decreases with an increase in the Schmidt number and Chemical reaction parameter.
10. On comparing the skin – friction (τ) results with the skin – friction (τ^*) results of Seethamahalakshmi *et al*. [20] it can be seen that they agree very well.

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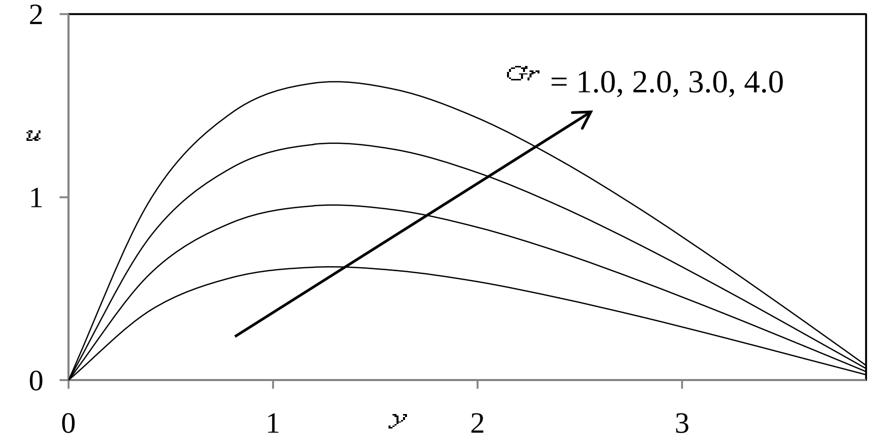

Figure 1. Velocity profiles for different values of Gr

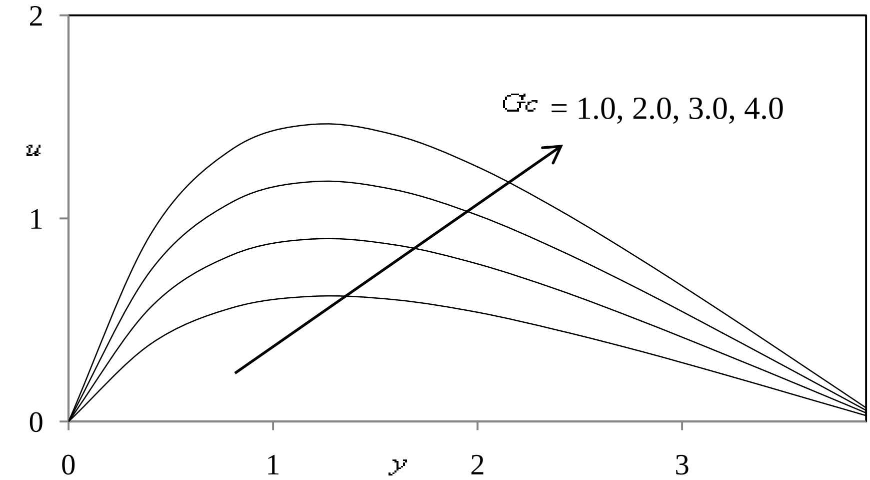

Figure 2. Velocity profiles for different values of Gc

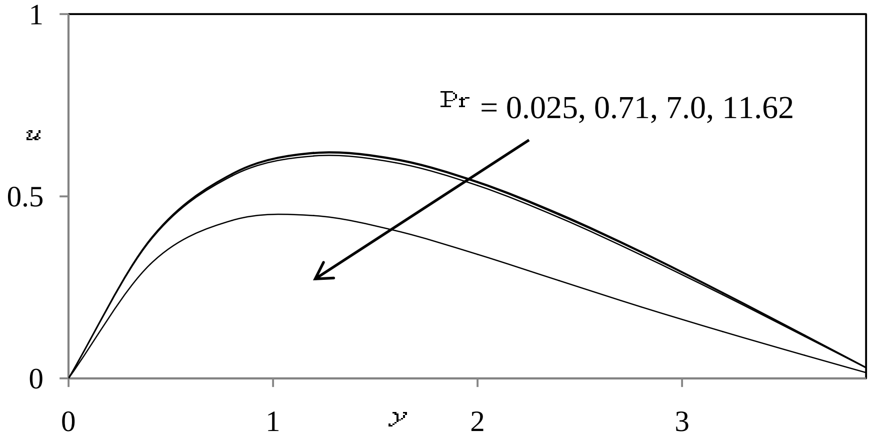

Figure 3. Velocity profiles for different values of $\Pr$

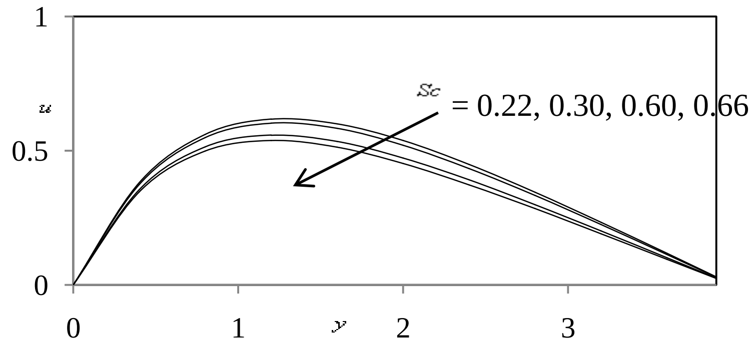

Figure 4. Velocity profiles for different values of Sc

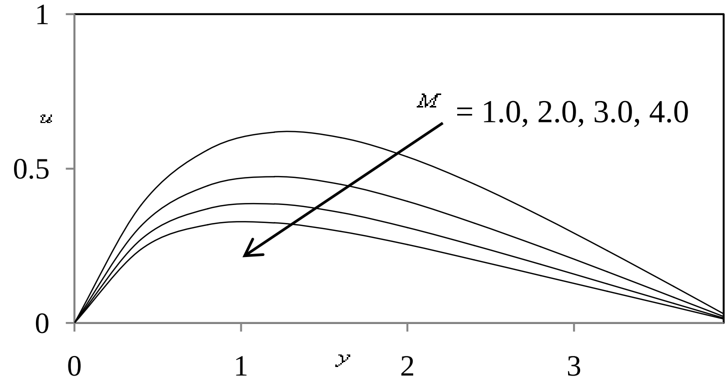

Figure 5. Velocity profiles for different values of M

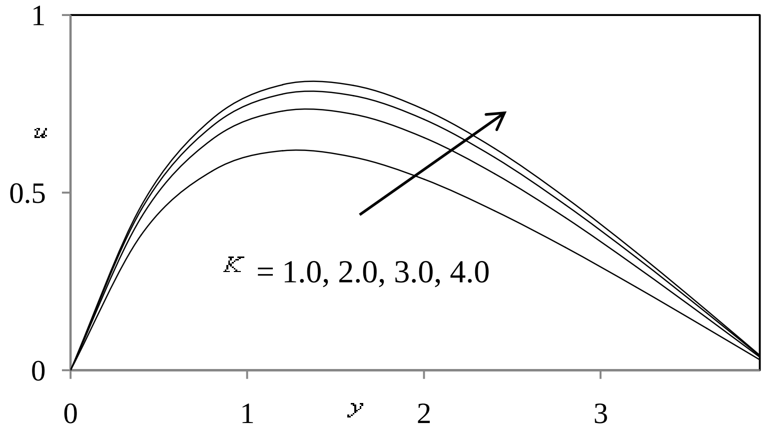

Figure 6. Velocity profiles for different values of K

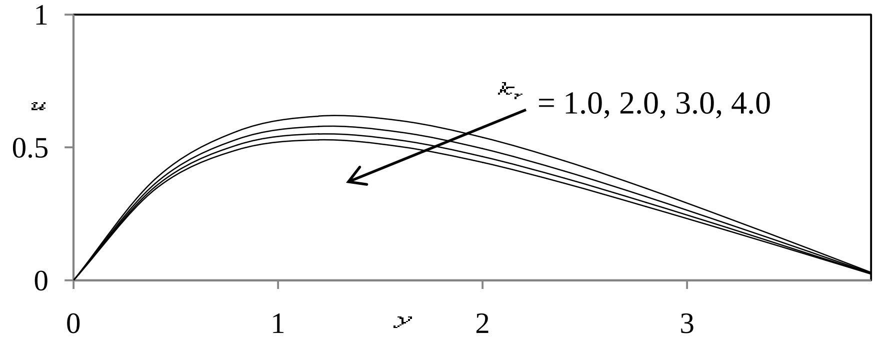

Figure 7. Velocity profiles for different values of k_r

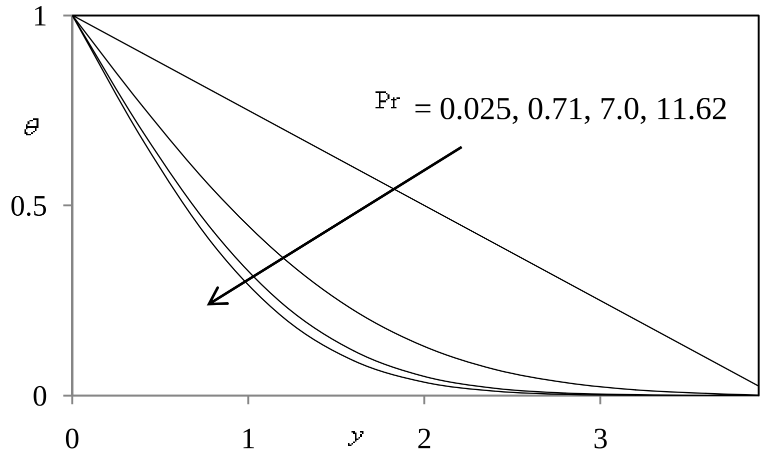

Figure 8. Temperature profiles for different values of Pr

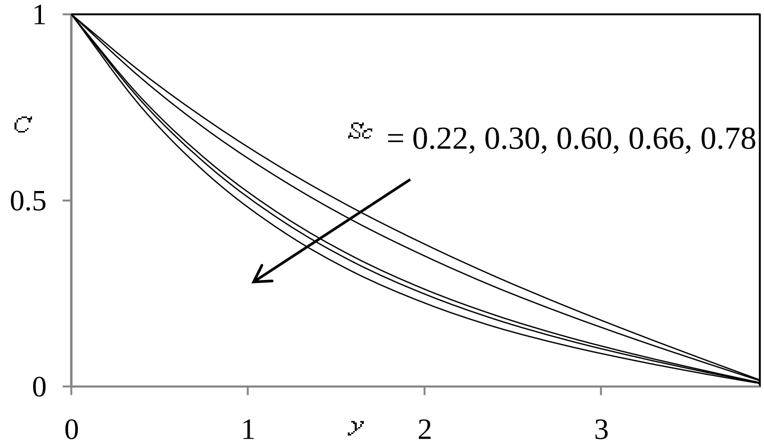

Figure 9. Concentration profiles for different values of Sc

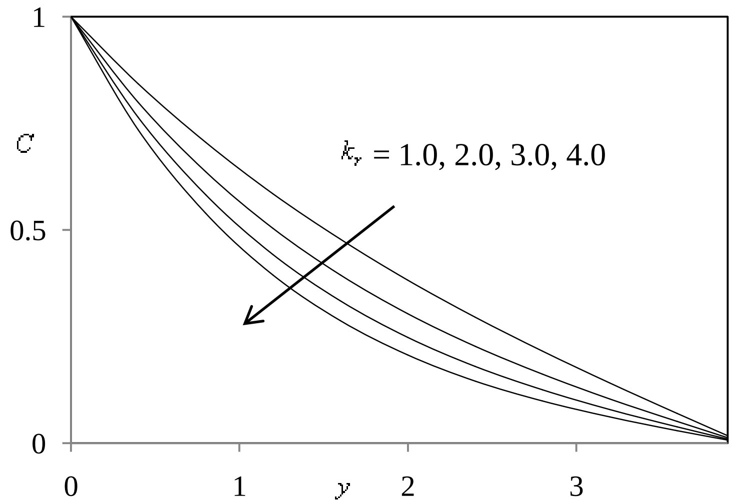

Figure 10. Concentration profiles for different values of k_r