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Combined Effect of Chemical Reaction and Transverse Magnetic Field on Free Convection Flow past a Vertical Cone

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***Abstract*:** The simultaneous effect of chemical reaction and magnetic field on an unsteady laminar free convection flow past an isothermal vertical cone is studied in this paper. The non linear governing equations are first written into a dimensionless form, and then Alternating Direction Implicit (ADI) Technique is applied to obtain numerical solutions of the governing equations. Flow variables are obtained and are presented graphically for different values of Prandtl number, Schmidt number. From numerical results, it is noticed that higher values of Prandtl number as well as Schmidt number results in decrease in velocity.

***Keywords*:** Chemical reaction, free convection flow, Magnetic field, vertical cone.

I. INTRODUCTION

The study of effect of chemical reaction and transverse magnetic field on heat and mass transfer has various applications in science and technology. Few applications where it plays important role are in the steel industry for magnetic controlling of molten iron flow and in nuclear reactors for cooling of liquid metal. Numerous researches have been done to study the problem of free convection in the presence of chemical reaction with the effect of a magnetic field.

Anjali Devi and Kandasamy [1] used R.K. Gill's method to study a non- linear MHD flow over an accelerating vertical surface with heat source and thermal stratification in the presence of suction or injection and obtained approximate numerical solution of the governing equations. Afify [2] applied similarity transformation technique to study the effect of radiation and chemical reaction on free convective flow and mass transfer past a vertical isothermal cone surface in the presence of a transverse magnetic field. Kandasamy, Periyasamy, and Sivagnana Prabhu [3] used Gill method to analyze the effect of chemical reaction, heat and mass transfer on MHD flow of an incompressible, viscous, electrically conducting and Boussinesq fluid over a vertical stretching surface with heat source and thermal stratification effects and obtained an approximate numerical solution for the flow problem.

Al-Odat and Al-Azab [4] applied an implicit finite-difference scheme of Crank–Nicolson type to numerically investigate the effect of first order chemical reaction on transient MHD free convective flow over an impulsively started vertical plate. El-Kabeir and Abdou [5] studied the effect of chemical reaction, mass and heat transfer on nonlinear MHD flow of an electrically conducting and Boussinesq fluid over a vertical isothermal cone surface in micropolar fluids with heat generation/absorption. Abdou and EL-Kabeir [6] investigated MHD free convection heat and mass transfer flow in a micropolar fluid over a vertical porous plate with uniform surface temperature with radiation and chemical reaction. Rajeswari, Jothiram and Nelson [7] studied influence of chemical reaction, heat and mass transfer on non linear MHD boundary layer flow of an electrically conducting viscous incompressible fluid past a vertical porous plate in the presence of suction. Using similarity transformation, they transformed the governing nonlinear PDE into nonlinear ordinary differential equations and obtained solutions using shooting method.

Rashad, Modather and Chamka [8] used shooting method to investigate the effect of chemical reaction and thermal radiation on free convective heat and mass transfer of an electrically conducting and chemically-reacting MHD fluid flow from over stretching surface embedded in a saturated porous medium. Chandrakala and Bhaskar [9] studied the effect of magnetic field and homogeneous chemical reaction of first order on the transient convection flow of an incompressible viscous fluid past an impulsively started infinite vertical plate having variable temperature. The effects of magnetic field parameter, chemical reaction parameter, Prandtl number, Schmidt number, thermal Grashof number and mass Grashof number on flow variables like velocity, temperature and concentration were studied. The effect of homogeneous chemical reaction of first order on the MHD convection flow of an incompressible viscous fluid past an impulsively started isothermal vertical plate with uniform mass diffusion was studied by Chandrakala and Bhaskar [10]. Sheri and Shamshuddin [11] used finite element method and presented results for heat and mass transfer on MHD flow of micro polar fluid in the presence of viscous dissipation and chemical reaction. Santhosha et al [12] used regular perturbation method to investigate the influence of radiation and chemical on MHD convective heat and mass transfer flow of electrically conducting elastic fluid through porous medium delimited by a porous plate accompanied by heat generation/absorption. Garg and Shipra [13] obtained exact solution of MHD free convective and mass transfer flow in presence of uniform magnetic field near a moving infinite vertical plate in the presence of heat source/sink. The results are in terms of exponential and complementary error function using Laplace transformation method.

From these studies, it is clear that the study of combined effect of chemical reaction and transverse magnetic field on free convection flow past a semi infinite vertical cone have not received adequate attention. This has motivated the present study. In the present paper, the combined effect of chemical reaction and transverse magnetic field on unsteady flow past a vertical cone is analyzed. The dimensionless form of the governing boundary layer equations is used. The resulting system of equations is then solved by Alternating- direction-implicit technique. The paper has six sections. Section I contains the introduction of the problem. The formulation of the problem along with the initial and boundary conditions is done in Section II. Section III discusses the Alternating Direction technique and section IV consists of the stability analysis of the problem. Section V contains the results obtained and discussion of these results. Section VI concludes the research work.

II. PROBLEM FORMULATION

We consider an unsteady, two dimensional, viscous incompressible, electrically conducing fluid flow past a semi-infinite isothermal vertical cone in the presence of a chemical reaction as well as transversely applied magnetic field. We are making following assumptions

1. The surface of the cone makes an angle θ with the horizontal. The local radius of the cone is r' .
2. The X- axis is measured along the surface of the cone from the apex $(x'=0)$ and the Y-axis is measured normally from the cone to the fluid.
3. The ambient fluid temperature is T'_∞ . At time $t' \le 0$, the cone and the fluid are at the same temperature T'_∞ and the concentration is equal to C'_∞ . At $t' > 0$, the temperature of the cone surface is $T'_w\ (>T'_\infty)$ and the species concentration is $C'_w\ (>C'_\infty)$.
4. The gravitational acceleration is acting downward.
5. The chemical reaction between the fluid and the species is assumed to be homogenous and first-order. The heat generated during the reaction is assumed as neglected. Also, the concentration of species is low.
6. A uniform magnetic field B_0 is applied along the Y-axis.
7. The fluid properties are assumed to be constant.
8. The effect of viscous dissipation is assumed to be negligible.

The flow is described by the following governing equations under above assumptions and with application of the Boussinesq's approximation

$$\frac{\partial(r'u')}{\partial x'}+\frac{\partial(r'v')}{\partial y'}=0 \qquad (1)$$

$$\frac{\partial u'}{\partial t'}+u'\frac{\partial u'}{\partial x'}+v'\frac{\partial u'}{\partial y'}=g\beta\sin\theta(T'-T'_\infty) + g\beta^*\sin\theta(C'-C'_\infty)+\upsilon\frac{\partial^2 u'}{\partial y'^2}-\frac{\sigma B_0^2}{\rho}u' \qquad (2)$$

$$\frac{\partial T'}{\partial t'}+u'\frac{\partial T'}{\partial x'}+v'\frac{\partial T'}{\partial y'}=\alpha\frac{\partial^2 T'}{\partial y'^2} \qquad (3)$$

$$\frac{\partial C'}{\partial t'}+u'\frac{\partial C'}{\partial x'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}-K'C' \qquad (4)$$

The initial and boundary conditions are:

$$\begin{aligned}
&t' \le 0 \ : \\
&u'=0\ ,\ v'=0,\ T'=T'_\infty\ ,\ C'=C'_\infty \\
&t'>0\ : \\
&u'=0\ ,\ v'=0,\ T'=T'_w\ ,\ C'=C'_w \quad at\ \ y'=0 \\
&u'\to 0\ ,\ T'\to T'_\infty, C'\to C'_\infty \quad at\ \ y'\to\infty \\
&u'=0\ ,\ T'=T'_\infty\ ,\ C'=C'_\infty \quad at\ \ x'=0
\end{aligned} \qquad (5)$$

Where u' and v' are the velocity components in the x' and y' directions, respectively; ρ is fluid density, g is acceleration due to gravity , t' is time, T' and C' are temperature and species concentration of the fluid in the boundary layer, β is volumetric coefficient of thermal expansion, T'_w is the temperature far away from the cone surface, B_0 is the magnetic field induction, σ is electrical conductivity, υ is kinematic viscosity, α is thermal diffusivity, D is chemical molecular diffusivity, K' is chemical reaction, β^* concentration expansion coefficient. We introduce the non-dimensional quantities

$$x=\frac{x'}{L}\ ,\ y=\frac{y'}{L}Gr^{1/4}\ ,\ u=\frac{u'L}{\upsilon}Gr^{-1/2}\ ,v=\frac{v'L}{\upsilon}Gr^{-1/4}$$

$$t=\frac{\upsilon t'}{L^2}Gr^{1/2}\ ,r=\frac{r'}{L},\ T=\frac{(T'-T'_\infty)}{(T'_w-T'_\infty)}\ ,C=\frac{(C'-C'_\infty)}{(C'_w-C'_\infty)}$$

$$Gr=\frac{g\beta L^3(T'_w-T'_\infty)\sin\theta}{\upsilon^2}\ ,\ Gc=\frac{g\beta^* L^3(C'_w-C'_\infty)\sin\theta}{\upsilon^2}$$

$$\Pr = \frac{\upsilon}{\alpha},\ Sc = \frac{\upsilon}{D},\ K = \frac{K'L^2}{\upsilon}Gr^{-1/2},$$
$$M = \frac{\sigma B_0^{\,2} L^2}{\rho\upsilon}Gr^{-1/2},\ N = \frac{Gc}{Gr} \tag{6}$$

where L is the reference length, υ is the kinematic viscosity, $\Pr$ is Prandtl number, Sc is Schmidt number, Gr is the Grashof number, Gc is mass Grashof number, K is porosity, M is magnetic field parameter, N is the buoyancy ratio parameter and $r' = x' \sin\theta$.

We can write Eqn. (1)-(4) in non-dimensional form as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{u}{x} = 0 \tag{7}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = T + NC + \frac{\partial^2 u}{\partial y^2} - Mu \tag{8}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KC \tag{10}$$

The initial and boundary conditions (5) are written as

$$\begin{aligned}
&t \le 0 : \\
&u = 0,\ v = 0,\ T = 0,\ C = 0 \qquad \forall\, x, y \\
&t > 0 : \\
&u = 0,\ v = 0,\ T = 1,\ C = 1 \qquad at\ \ y = 0 \\
&u \to 0,\ T \to 0,\ C \to 0 \qquad at\ \ y \to \infty \\
&u = 0,\ T = 0,\ C = 0 \qquad at\ \ x = 0
\end{aligned} \tag{11}$$

III. NUMERICAL TECHNIQUE

Applying Alternating-Direction-Implicit technique, the two dimensional, unsteady and non-linear partial differential equations given by (7)-(10) with the initial and boundary conditions (11) are solved. This scheme consists of two steps which splits an unsteady two dimensional problem into two separate one-dimensional problems. In first step the difference equations are made implicit in x at an intermediate time level $n + \frac{1}{2}$ and the unknowns associated with the x-derivatives are evaluated. The implicit difference equations at the time level $n + \frac{1}{2}$ are written as

$$\frac{u_{i+1,j}^{n+\frac{1}{2}} - u_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x} + \frac{v_{i,j+1}^{n} - v_{i,j-1}^{n}}{2\Delta y} + \frac{u_{i,j}^{n}}{\Delta x} = 0 \tag{12}$$

$$\frac{u_{i,j}^{n+\frac{1}{2}} - u_{i,j}^{n}}{\Delta t/2} + u_{i,j}^{n}\left(\frac{u_{i+1,j}^{n+\frac{1}{2}} - u_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right) + v_{i,j}^{n}\left(\frac{u_{i,j+1}^{n} - u_{i,j-1}^{n}}{2\Delta y}\right)$$
$$= T_{i,j}^{n} + NC_{i,j}^{n} + \left(\frac{u_{i,j+1}^{n} - 2u_{i,j}^{n} + u_{i,j-1}^{n}}{(\Delta y)^2}\right) - Mu_{i,j}^{n} \tag{13}$$

$$\frac{T_{i,j}^{n+\frac{1}{2}} - T_{i,j}^{n}}{\Delta t/2} + u_{i,j}^{n}\left(\frac{T_{i+1,j}^{n+\frac{1}{2}} - T_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right) +$$
$$v_{i,j}^{n}\left(\frac{T_{i,j+1}^{n} - T_{i,j-1}^{n}}{2\Delta y}\right) = \frac{1}{\Pr}\left(\frac{T_{i,j+1}^{n} - 2T_{i,j}^{n} + T_{i,j-1}^{n}}{(\Delta y)^2}\right) \tag{14}$$

$$\frac{C_{i,j}^{n+\frac{1}{2}} - C_{i,j}^{n}}{\Delta t/2} + u_{i,j}^{n}\left(\frac{C_{i+1,j}^{n+\frac{1}{2}} - C_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right) + v_{i,j}^{n}\left(\frac{C_{i,j+1}^{n} - C_{i,j-1}^{n}}{2\Delta y}\right) \tag{15}$$
$$= \frac{1}{Sc}\left(\frac{C_{i,j+1}^{n} - 2C_{i,j}^{n} + C_{i,j-1}^{n}}{(\Delta y)^2}\right) - KC_{i,j}^{n}$$

The Eqns. (12) -(15) reduces into tri-diagonal form, we obtain solution for $u_{i,j}^{n+\frac{1}{2}}$ and $T_{i,j}^{n+\frac{1}{2}}$ for all i, keeping j fixed, using Thomas Algorithm. This step is repeated for next value $j + 1$ and so on. In the end of this step, the values of $u_{i,j}^{n+\frac{1}{2}}$ and $T_{i,j}^{n+\frac{1}{2}}$ at intermediate time level $n + \frac{1}{2}$ is known for all (i, j).

In the next step, difference equations are made implicit in y at time level n and the unknowns associated with the y-derivatives are evaluated. The implicit difference equations at the time level n are written as

$$\frac{u_{i+1,j}^{n+\frac{1}{2}} - u_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x} + \frac{v_{i,j}^{n+1} - v_{i,j-1}^{n+1}}{\Delta y} + \frac{u_{i,j}^{n+\frac{1}{2}}}{\Delta x} = 0 \tag{16}$$

$$\frac{u_{i,j}^{n+1} - u_{i,j}^{n+\frac{1}{2}}}{\Delta t/2} + u_{i,j}^{n}\left(\frac{u_{i+1,j}^{n+\frac{1}{2}} - u_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right) + v_{i,j}^{n}\left(\frac{u_{i,j+1}^{n+1} - u_{i,j-1}^{n+1}}{2\Delta y}\right) \tag{17}$$
$$= T_{i,j}^{n+\frac{1}{2}} + NC_{i,j}^{n+\frac{1}{2}} + \left(\frac{u_{i,j+1}^{n+1} - 2u_{i,j}^{n+1} + u_{i,j-1}^{n+1}}{(\Delta y)^2}\right) - Mu_{i,j}^{n+\frac{1}{2}}$$

$$\frac{T_{i,j}^{n+1} - T_{i,j}^{n+\frac{1}{2}}}{\Delta t/2} + u_{i,j}^{n}\left(\frac{T_{i+1,j}^{n+\frac{1}{2}} - T_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right) + v_{i,j}^{n}\left(\frac{T_{i,j+1}^{n+1} - T_{i,j-1}^{n+1}}{2\Delta y}\right)$$
$$= \frac{1}{\Pr}\left(\frac{T_{i,j+1}^{n+1} - 2T_{i,j}^{n+1} + T_{i,j-1}^{n+1}}{(\Delta y)^2}\right) \tag{18}$$

$$\frac{C_{i,j}^{n+1}-C_{i,j}^{n+\frac{1}{2}}}{\Delta t/2}+u_{i,j}^{n}\left(\frac{C_{i+1,j}^{n+\frac{1}{2}}-C_{i-1,j}^{n+\frac{1}{2}}}{2\Delta x}\right)+v_{i,j}^{n}\left(\frac{C_{i,j+1}^{n+1}-C_{i,j-1}^{n+1}}{2\Delta y}\right)$$
$$=\frac{1}{Sc}\left(\frac{C_{i,j+1}^{n+1}-2C_{i,j}^{n+1}+C_{i,j-1}^{n+1}}{(\Delta y)^2}\right)-KC_{i,j}^{n+\frac{1}{2}} \quad (19)$$

Reducing eqns. (16)-(19) to tri-diagonal form we yield solution for $v_{i,j}^n$, $u_{i,j}^n$ and $T_{i,j}^n$ for all j, keeping i fixed, using Thomas Algorithm. The calculations are repeated for all values of i . The values of $v_{i,j}^n$, $u_{i,j}^n$ and $T_{i,j}^n$ at next time level n is known for all (i, j) at the end of this step. Here, the subscript i in $u_{i,j}^n$, $v_{i,j}^n$, $T_{i,j}^n$ represents the grid node along the x- direction and j subscript represents the grid node along the y- direction.

We are taking the domain of integration to be a rectangular region with sides

$$x=0\ ,\ x=1$$
$$y=0\ ,\ y=14$$

where the boundary condition $y=14$ corresponds to conditions at infinity. The mesh size is taken as $\Delta x=0.05,\ \Delta y=0.25$ with the time step as $\Delta t=0.01$. Computations are performed to make the absolute difference between values of both u and T at two consecutive time steps as negligible.

IV. STABILITY ANALYSIS

We examine the stability of differencing scheme by employing Von-Neumann Technique. The general term of the Fourier expansion for u and T at an arbitrary time $t=0$ is assumed to be of the form $e^{iax}e^{iby}$ where $i=\sqrt{-1}$. At any time t, these can be written as

$$u=F(t)e^{iax}e^{iby}$$
$$T=G(t)e^{iax}e^{iby}$$
$$C=H(t)e^{iax}e^{iby} \quad (20)$$

We substitute these in Eqns. (17), (18) and (19). We take

$$u^{n+1}=F'(t) \quad u^{n+\frac{1}{2}}=F(t)$$
$$T^{n+1}=G'(t) \quad T^{n+\frac{1}{2}}=G(t)$$
$$C^{n+1}=H'(t) \quad C^{n+\frac{1}{2}}=H(t)$$

On simplification eqns. (17) - (19) gives

$$F'\left(\frac{2}{\Delta t}+\frac{2}{(\Delta y)^2}\left(1-\cos(b\Delta y)\right)+i\frac{v}{\Delta y}\sin(b\Delta y)\right)$$
$$=F\left(\frac{2}{\Delta t}-i\frac{u\sin(a\Delta x)}{\Delta x}-M\right)+G+NH \quad (21)$$

$$G'\left(\frac{2}{\Delta t}+\frac{2}{(\Delta y)^2}\frac{1}{\Pr}\left(1-\cos(b\Delta y)\right)+i\frac{v}{\Delta y}\sin(b\Delta y)\right) \quad (22)$$
$$=G\left(\frac{2}{\Delta t}-i\frac{u\sin(a\Delta x)}{\Delta x}\right)$$

$$H'\left(\frac{2}{\Delta t}+\frac{2}{(\Delta y)^2}\frac{1}{Sc}\left(1-\cos(b\Delta y)\right)+i\frac{v}{\Delta y}\sin(b\Delta y)\right)$$
$$=H\left(\frac{2}{\Delta t}-K+i\frac{u\sin(a\Delta x)}{\Delta x}\right) \quad (23)$$

Taking

$$\frac{2}{\Delta t}+i\frac{v}{\Delta y}\sin(b\Delta y)=A$$
$$\frac{2}{(\Delta y)^2}\left(1-\cos(b\Delta y)\right)=B$$
$$i\frac{u\sin(a\Delta x)}{\Delta x}=C$$

Equations (21) - (23) can be written in matrix form as

$$\begin{bmatrix}F'\\G'\\H'\end{bmatrix}=\begin{bmatrix}\frac{(2/\Delta t)-C-M}{A+B} & \frac{1}{A+B} & \frac{N}{A+B}\\ 0 & \frac{(2/\Delta t)-C}{A+(B/\Pr)} & 0\\ 0 & 0 & \frac{(2/\Delta t)-K+C}{A+(B/Sc)}\end{bmatrix}\begin{bmatrix}F\\G\\H\end{bmatrix} \quad (24)$$

The stability of the differencing scheme can be established if the modulus of each Eigen value of the matrix does not exceed unity. Eigen values of the component matrix in (24) are its diagonal elements i.e. $\frac{(2/\Delta t)-C-M}{A+B}$, $\frac{(2/\Delta t)-C}{A+(B/\Pr)}$ and $\frac{(2/\Delta t)-K+C}{A+(B/Sc)}$.We first check if

$$\left|\frac{(2/\Delta t)-C-M}{A+B}\right|\le 1$$

Since

$$\left|\frac{(2/\Delta t)-C-M}{A+B}\right|$$
$$=\left|\frac{\frac{2}{\Delta t}-i\frac{u\sin(a\Delta x)}{\Delta x}-M}{\frac{2}{\Delta t}+i\frac{v}{\Delta y}\sin(b\Delta y)+\frac{2}{(\Delta y)^2}\left(1-\cos(b\Delta y)\right)}\right|$$

We can clearly see that the real part of the numerator is always less than or equal to the real part of the denominator. Therefore, $\left|\frac{(2/\Delta t)-C-M}{A+B}\right|\le 1$. Similarly, we can easily prove that

$$\left|\frac{(2/\Delta t)-C}{A+(B/\Pr)}\right|\le 1 \text{ and } \left|\frac{(2/\Delta t)-K+C}{A+(B/Sc)}\right|\le 1$$

Hence, the differencing scheme is unconditionally stable.

V. RESULT AND DISCUSSION

The flow variables $u-$velocity and temperature T are obtained by carrying out numerical computations at different time intervals and for values of $\Pr = 0.7, 7.0$; $Sc = 0.5, 5.0$; $M = 0.5, 1$; $N = 1, 2$ and $K = 0.2$ using the Alternating direction implicit technique discussed in section 3. Taking $0 \le x \le 1$; $0 \le y \le 14$; $\Delta x = 0.05$, $\Delta y = 0.25$; $\Delta t = 0.01$, the ADI algorithm has been implemented in MATLAB programming language. The behavior of flow variables is studied with change in Prandtl number, Schmidt number, magnetic field parameter and buoyancy ratio parameter of the fluid.

In Fig.1, transient velocity profiles are plotted for different values of Prandtl number $(\Pr = 0.7, 7.0)$ and Schmidt number $(Sc = 0.5, 5.0)$. In Fig. 2 the transient velocity profiles are plotted for different values of magnetic field parameter $(M = 0.5, 1)$ and buoyancy ratio parameter $(N = 1, 2)$.

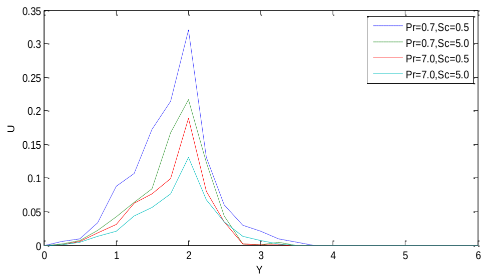

Fig. 1: Velocity profile at x=1.0 for $M = 0.5, N = 1$ at t=1.0

As expected, the velocity for $\Pr = 7.0$ (water) is always less than the velocity for $\Pr = 0.7$ (air) for fixed values of other parameters. It is noticed that an increase in Sc results in a fall in the velocity. It can be seen that as N increases, the velocity increases near the cone surface. As expected, an increase in value of magnetic field parameter M, results in decrease in velocity since a magnetic field retards the free flow of the fluid.

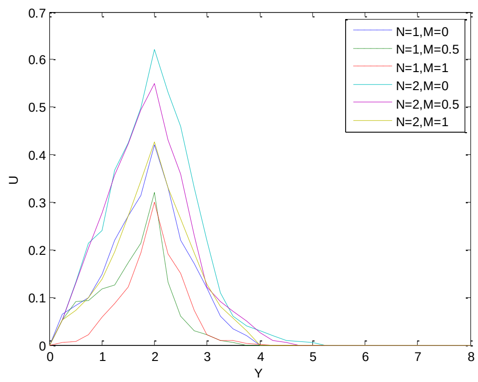

Fig. 2: Velocity profile at x=1.0 for $\Pr = 0.7, Sc = 0.5$ at t=1.0

The effect of different values of Prandtl number $(\Pr = 0.7, 7.0)$ and Schmidt number $(Sc = 0.5, 5.0)$ on the temperature can be seen in Fig. 3. Fig. 4 represents the transient temperature profiles for different values of magnetic field parameter $(M = 0.5, 1)$ and buoyancy ratio parameter $(N = 1, 2)$ High values of Prandtl number results in steeper temperature profiles because of higher heat transfer rate. It is noticed that the temperature increases with increase in value of Sc as well as M. It can be seen that an increment in value of N results in fall in the temperature.

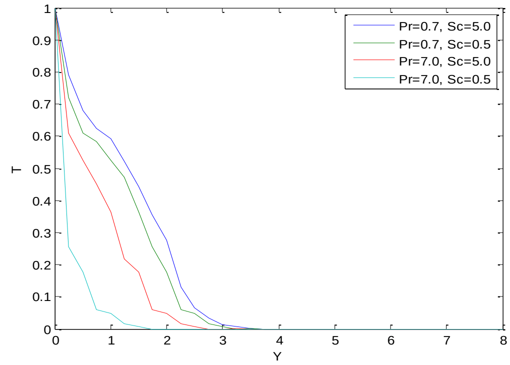

Fig. 3: Temperature profile at x=1.0 for $M = 0.5, N = 1$ at t=1.0

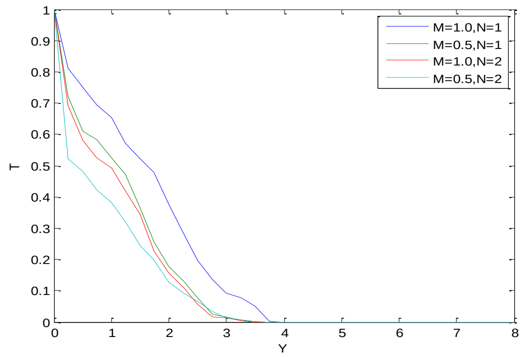

Fig. 4: Temperature profile at x=1.0 for $\Pr = 0.7, Sc = 0.5$ at t=1.0

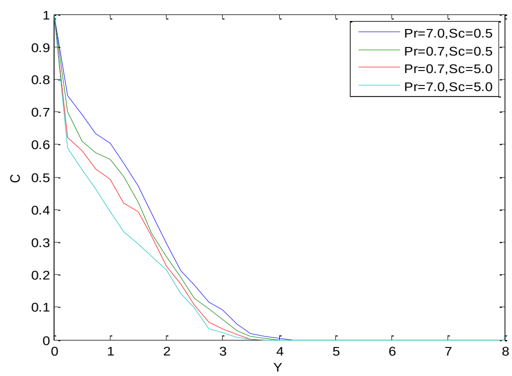

Fig. 5: Concentration profile at x=1.0 for $M = 0.5, N = 1$ at t=1.0

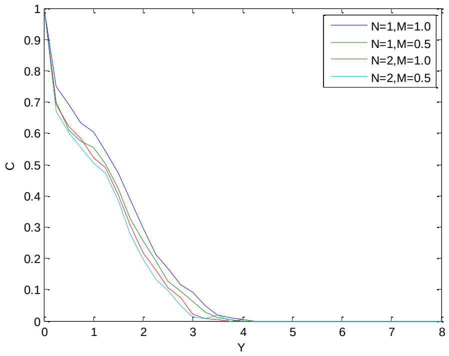

Fig.6: Concentration profile at x=1.0 for $\Pr = 0.7, Sc = 0.5$ at t=1.0

The transient concentration profiles are shown in Fig 5 for different values of Prandtl number $(\Pr = 0.7,\ 7.0)$ and Schmidt number $(Sc = 0.5\ , 5.0)$ Fig. 6 shows the transient concentration profiles for different values of magnetic field $(M = 0.5, 1)$ and buoyancy ratio parameter $(N = 1, 2)$. It is seen that the species concentration increases with increase in value of Pr, whereas it decreases with higher values of the Schmidt number. The species concentration increases with increase in value of M but it decreases with increase in value of *N*.

VI. CONCLUSION

An MHD flow past a semi-infinite vertical cone with a chemical reaction is studied in this paper. The dimensionless governing equations are solved numerically using ADI technique. The conclusions of the study are as follows:

1. When Pr, Sc or *M* increases, the velocity of the fluid decreases. With increased values of *N* velocity of the fluid increases
2. With increased value of Pr or *N*, the temperature near the cone surface decreases; whereas it increases with higher values of Sc or *M.*
3. The species concentration increases in the case of higher values of Pr or *M* and decreases for higher values of Sc or *N*.

The results obtained are in good agreement with the previous studies [14] available.

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