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A STUDY ON MHD UNSTEADY FLOW PAST A SEMI-INFINITE VERTICAL PLATE WITH HEAT AND MASS TRANSFER IN THE PRESENCE OF CHEMICAL REACTION

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ABSTRACT

A numerical investigation on the study of MHD unsteady flow past a semi-infinite vertical plate with heat and mass transfer in the presence of transversely applied magnetic field and chemical reaction is carried out. The heat due to viscous dissipation and induced magnetic field are assumed to be negligible. The dimensionless governing equations are solved using the implicit finite difference scheme of Crank-Nicolson type. The effects of governing parameters on the velocity flow, temperature and concentration profiles of heat and mass transfer characteristics are presented graphically and discussed for various flow parameters.

Keywords: Chemical reaction, Magnetic field, Grash of number, Vertical plate.

1. INTRODUCTION

Heat transfer is a branch of thermal engineering that deals with the rate of transfer of thermal energy (heat) between physical systems due to temperature difference(Vasu et al., 2011; Chamkha et al., 2001 and Reddy, et al., 2016.).

The modes of heat transfer are conduction, convention and radiation. Industrial application of heat transfer includes die casting, oil and gas, food, chemical, polymers and industrial laundry and so on. Conduction refers to the transfer of heat between two bodies or two part of the same body through molecules which are more or less stationary, whereas convention heat transfer occurs because of the motion of fluid past a heated surface, in which the faster the motion, the greater the heat transfer (Nag, 2002).

Convection is divided into three different types such as forced, free and mixed convection. Fluid motion is induced by some external resources such as fluid machinery or vehicle motion (examples are fan, pumps and compressors), the process known as forced convection flow, while free or natural convection is when the motion in the fluid is induced by body forces such as gravitational or centrifugal forces. Mixed convection flow occurs when free (natural) and forced convection mechanisms simultaneously and significantly contribute to the heat transfer (Kays et al., 2005).

Free convection has its applications such as those found in heat transfer from a heater to air, heat transfer from nuclear fuel rods to the surrounding coolant, heat transfer from pipes, cooling of the electronic devises, the spreading of pollutants from smoke stacks and atmospheric and oceanic circulation as explained by Ghoshdastidar (2004). Free convection flows occur not only due to temperature difference, but also due to concentration difference or the combination of these two.

Thermo diffusion occurs when thermal gradient is applied to a mixture (Costesèque et al., 2011).The reciprocal phenomena of Soret effect is the Dufour effect otherwise called diffusion-thermo (Mortimer and Eyring, 1980; Reddy and Shamshuddin, 2016).

The effect of Soret and Dufour on heat mass transfer were neglected in the work of many researchers due to the assumption that they are negligible in magnitude than the ones prescribed by Fourier's and Fick's law. Recent advancement in heat and mass transfer shows that Dufour effect is important in transport problems while Soret effect is influential in mass transfer phenomenon (Arthur et al., 2015).

The Soret effect, for instance, has been utilized for isotope separation and in a mixture between gases with very light molecular weight (H2, He) and of medium molecular weight (H2, air). The models presented in Makinde et al., (2012) and Bhupendra et al., (2012) are some of the research works on MHD convective flow with Soret and Dufour effect. The minimum energy required for a system to begin a chemical reaction is known as activation energy. It was introduced by Svante Arrhenius in 1882 as reported by (Kumar *et al.*, 2018). Uwanta & Usman (2014) investigated the combined effects of Soret and Dufour on free convective heat and mass transfer on the unsteady one-dimensional boundary layer flow over a vertical channel in the presence of viscous dissipation and constant suction. The governing partial differential equations are solved numerically using the implicit Crank-Nicolson method. Also, Uwanta & Hamza (2014) examined the effect of suction/injection on unsteady hydromagnetic convective flow of reactive viscous fluid between vertical porous plates with thermal diffusion. The partial differential equations governing the flow have been solved numerically using semi-implicit finite-difference scheme. For steady case, analytical solutions have been derived using perturbation series method. Suction/injection is used to control the fluid flow in the channel, and an exothermic chemical reaction of Arrhenius kinetic is considered. Numerical results are presented graphically and discussed quantitatively with respect to various parameters embedded in the problem.

The unsteady natural convection flow past a semi-infinite vertical plate was first solved by Hellums and Churchill (1962), using an explicit finite difference method. Gebhart and Pera (1971) obtained the steady state solution for natural convection on a vertical plate with variable surface temperature and variable mass diffusion using similarity variables. Uwanta and Usman (2015) also studied the finite difference solutions of magneto hydrodynamic free convective flow with constant suction and variable thermal conductivity in a Darcy-Forchheimer porous medium. The resulting governing equations are non-dimensionalized, simplified and solved using Crank Nicolson type of finite difference method. To check the accuracy of the numerical solution, steady-state solutions for velocity, temperature and concentration profiles are obtained by using perturbation method. Jha et al., (2016a) studied the combined effect of suction/injection on MHD free-convection flow in a vertical channel with thermal radiation. The governing equations was solved numerically using implicit finite difference scheme. The accuracy of this scheme was established when the steady state version of the problem was solved using perturbation. The effect of various dimensionless parameters controlling the physical situation was extensively discussed with the aid of graphs. Another study was conducted by Chitra and Suhasini (2017) on the combined effect of a transverse Magnetic field and radiative heat transfer on unsteady oscillatory flow through a vertical channel filled with saturated porous medium and non-uniform wall temperature with the effect of suction or injection. The governing equation of oscillatory flow was non-dimensionalized, simplified and solved analytically. The effect of thermal radiation and the Magnetic field parameters on velocity profile, temperature, wall shear stress and the rate of heat transfer under the influence of Hartmann's number, Grashof number, Darcy parameter, suction /injection parameter are computed graphically.

Jha et al., (2018b) transient hydromagnetic free-convection and thermal radiation flow of viscous, incompressible electrically conducting fluid in the presence of magnetic field in a vertical channel formed by two infinite porous plates is analyzed. The Roseland diffusion approximation describes the radioactive heat flux in the energy equation. The non-linear time dependent energy and momentum equations under relevant initial and boundary conditions are solved numerically using implicit finite difference. To verify the accuracy of the numerical scheme, steady state version of the problem is solved by perturbation method. Similarly, Rehman, Idrees, Shah, and Khan (2019) investigated suction/injection effects on an unsteady MHD Casson thin film flow with slip and uniform thickness over a stretching sheet along variable flow properties. Present observation displays the joined effects of magnetic field, surface tension, suction/injection, and slippage at the boundary is to improve the thermal boundary layer thickness. Results for the heat flux (Nusselt number), skin friction coefficient, and free surface temperature are granted graphically and in a table form. The effects of natural parameters on the velocity and temperature profiles are investigated. Also, Prasad et al., (2020) examined the impact of suction/injection and health transfer on unsteady MHD flow over stretchable rotation disk. In achieving this it examined the unsteady magnetohydrodynamic two-dimensional boundary layer flow and heat transfer over a stretchable rotating disk with mass suction/injection is investigated. Temperature-dependent physical properties and convective boundary conditions are taken into account. The governing coupled nonlinear partial differential equations are transformed into a system of ordinary differential equations by adopting the well-known similarity transformations. Further, the solutions are obtained through the semi-analytical method called an Optimal Homotopy Analysis Method (OHAM). The obtained results are discussed graphically to predict the features of the involved key parameters which are monitoring the flow model.

Thus, the existing literature fails to incorporate chemical reaction despite it is numerous industrial applications such as polymer production, manufacturing ceramics or glass wave and food processing and so on. As such, this paper, investigates the MHD unsteady flow past an infinite vertical plate with heat mass transfer in the presence of chemical reaction.

2. FORMULATION OF THE PROBLEM

In this study, the unsteady flow of a viscous incompressible fluid past a semi-infinite vertical plate with mass transfer under the influence of transversely applied magnetic field is considered. The x-axis is taken along the plate in the vertically upward direction and the y-axis is also chosen perpendicular to the plate at the leading edge as shown in figure 1. The origin of x-axis is taken to be at the leading edge of the plate. The gravitational acceleration *g* is acting downward. Initially, (i.e., at time $t^1 = 0$), it is assumed that the plate and the fluid are at the same ambient temperature T^1_{∞}. And the specie is concentration C^1_{∞}. When $t^1 > 0$, the temperature of the plate and the species concentration is maintained to be $T^1_{.w}$ (greater than T^1_{∞}) and $C^1_{\infty.}$ (greater than $C^1_{\infty.}$) respectively.

It is assumed that the effect of viscous dissipation is negligible in the energy equation. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with other chemical species, which are present, and hence we neglect Soret and Duffer effects. There is chemical reaction between the fluid and the diffusing species. A uniformly transverse magnetic field is applied in the direction of flow. It is further assumed that the interaction of the induced magnetic field with the flow is considered to be negligible compared to the interaction of the applied magnetic field with the flow. The fluid properties are assumed to be constant except for the body force terms in the momentum equations which are approximately by the Boussinesq relations.

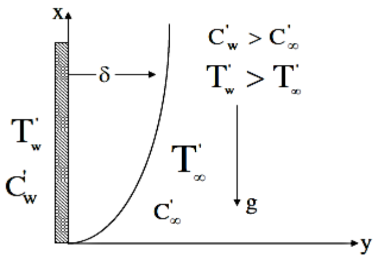

Figure 1: The Physical Coordinate System

$$\frac{\partial u'}{\partial t'} + v\frac{\partial u'}{\partial y'} = g\beta\,(T' + T'_{\infty}) + g\beta\,(C' + C'_{\infty}) + V\,\frac{\partial^2 u'}{\partial y^2} - \sigma\frac{B_0^2}{\rho}u, \qquad (3.1)$$

$$\frac{\partial T'}{\partial t'} + v\frac{\partial T'}{\partial y'} = \frac{\partial^2 T'}{\partial y^2}, \qquad (3.2)$$

$$\frac{\partial C'}{\partial t'} + v\frac{\partial C'}{\partial y'} = D\,\frac{\partial^2 C'}{\partial y^2} + K^*(C' - C'_{\infty}) \qquad (3.3)$$

The initial and boundary conditions are

$T' \leq 0$: u=0, u=o, $T' = T'_{\infty}$, $C' = C'_{\infty}$

$T' > 0$: u=0, u=0, $T' = T'_{\omega}$, $C' = C'_{\omega}$ at y = 0,

u=0, $T' = T'_{\infty}$, $C' = C'_{\infty}$, (3.4)

$u \to 0, T \to T_{\infty}, C \to C_{\infty},$ as $y \to \infty$

Where u *and* v are the velocity components in the x *and* y directions respectively, $C^1$is the species concentration, D is the co-efficient of diffusion in the mixture, T ′ is the temperature of the fluid in the boundary layer, $t^1$is the time, β is the volumetric coefficient of thermal expansion , β^* is the volumetric coefficient of expansion with concentration, v is the kinetic viscosity, g is the acceleration due to gravity and α is the thermal diffusivity, ρ is the density of fluid, $B^2{}_0$ is the magnetic field strength and σ is the electrical conductivity of the fluid.

On introducing the following non-dimensional quantities:

$$X = \frac{x}{L}, \quad Y= \frac{y}{L}\, Gr^{1/4}, U =\frac{uL}{v}\, Gr -^{1/2}, \; V= \frac{vL}{v} Gr^{1/4}, t= \frac{vt'}{L^2} Gr^{1/2},$$

$$T= \frac{T' - T'\infty}{T'\omega - T'\infty}, \quad C= \frac{C' - C'\infty}{C'\omega - C'\infty}, \quad Gr = \frac{g\beta L^3 (T' - T'\infty)}{v^2} \tag{3.5}$$

$$Gc= = \frac{g\beta * L^3 (C' - C'\infty)}{v^2}, \quad Pr = \frac{v}{\alpha}, Sc = \frac{v}{D}, \; N = \frac{Gc}{Gr}, \; M = \frac{\alpha B^2 0 L^2}{pv} Gr-^{1/2},$$

Here L is the length of the plate, Gr is the Grashop number, Gc is the modified Grash of number, M is the magnetic field parameter, N is the buoyancy ratio parameter, Sc is the Schmidt number and Pr is the Prandtl number.

On introducing the above equation 3.5 into equation 3.1, 3.2 and 3.3 then the equations are reduced to the following dimensionless form.

$$\frac{\partial U}{\partial t} + V\frac{\partial U}{\partial Y} = PT + NC + \frac{\partial^2 T}{Y^2}, - MU \tag{3.6}$$

$$\frac{\partial T}{\partial t} + V\frac{\partial T}{\partial Y} = \frac{1}{Pr}\frac{\partial^2 T}{\partial Y^2}, \tag{3.7}$$

$$\frac{\partial C}{\partial t} + V\frac{\partial C}{\partial Y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Y^2} + KrC, \tag{3.8}$$

The corresponding initial and boundary conditions in dimensionless for are as follows:

$t \leq 0$: U= 0, V= 0, T= 0, C= 0, for all y,

$t > 0$: U= 0, V= 0, T= 1, C= 1, at Y = 0,

U= 0, T= 0, C= 0, at Y = 0, (3.9)

$U \to 0$, $T \to 0$, $C \to 0$ as $Y \to \infty$

The local as well as average values of skin-friction, Nusselt number and Sherwood number in dimensionless form are as follows:

$$Tx= Gr^{3/4}\left(\frac{\partial u}{\partial Y}\right)_{Y=0}$$

$$T= Gr^{3/4}\int_0^1 \left(\frac{\partial U}{\partial Y}\right)_{Y=0} dX,$$

$$Nux= -Gr^{1/4} X \left(\frac{\partial T}{\partial Y}\right)_{Y=0}$$

$$Nu= -Gr^{1/4} X \int_0^1 \left(\frac{\partial T}{\partial Y}\right)_{Y=0} dX,$$

$$Sh_x= -Gr^{1/4} X \left(\frac{\partial C}{\partial Y}\right)_{Y=0}$$

$$Sh= -Gr^{1/4} X \int_0^1 \left(\frac{\partial C}{\partial C}\right)_{Y=0} dX, \qquad (3.10)$$

3. NUMERICAL PROCEDURE

The one-dimensional, non-linear, unsteady and coupled partial differential equations under the initial and boundary conditions are solved using an implicit finite difference scheme of Crank-Nicolson type which is fast convergent and unconditionally stable. Equations 3.11, 3.12 and 3.13 are simplified using finite difference as follows. The finite difference approximations equivalent to equations 3.6, 3.7, 3.8 and 3.9 are written below,

$$\frac{U_i^{j+1}-U_i^j}{\Delta t}+V\left(\frac{U_{i+1}^{j+1}-U_{i-1}^j}{2\Delta y}\right)=\frac{U_{i-1}^{j+1}-2U_i^{j+1}-U_{i-1}^{j+1}}{(\Delta y)^2}+PT_i^j+NC_i^j-MU_i^j \qquad (3.11)$$

$$\frac{T_i^{j+1}-T_i^j}{\Delta t}+V\left(\frac{T_{i+1}^{j+1}-T_{i-1}^j}{2\Delta y}\right)=\frac{I}{Pr}\left(\frac{T_{i-1}^{j+1}-2T_i^{j+1}+T_{i+1}^{j+1}}{(\Delta y)^2}\right) \qquad (3.12)$$

$$\frac{□_□^{□+1}-□_□^□}{□□}+□\left(\frac{□_{□+1}^{□+1}-□_{□-1}^□}{2□□}\right)=\frac{1}{□□}\left(\frac{□_{□-1}^{□+1}-2□_□^{□+1}+□_{□+1}^{□+1}}{(□□)^2}\right)+□□□_□^□ \qquad (3.13)$$

With the initial and boundary condition as follows,

$□_{□,□}$ = 0, $\theta_{□,□}$= 0, $C_{□,□}$= 0, for all j = 0,

$□_{□,□}$ = 0 $\theta_{□,□}$= 1, $C_{□,□}$= 1

$□_{h,□}$ = 0 $\theta_{h,□}$= 0, $C_{h,□}$= 0 (3.14)

Where $□_1=\frac{□□}{(□□)^2}$, $□_2=\frac{□□□}{2□□}$, $□_3=\frac{□□}{□□(□□)^2}$,

$□_4=\frac{□□□}{2□□}$ $□_5=\frac{□□}{□□(□□)^2}$, $□_6=\frac{□□□}{2□□}$

Equations 3.11, 3.12 and 3.13 are simplified as follows.

$$U_l\, □_{□-0}^{□+1}+□_□□_□^{□+1}-□_□□_{□+1}^{□+1}=□_2□_□^□-□_2□_{□+1}^{□+1}$$

$$\Delta t\, P\, \square_{\square}^{\square} + \Delta t N\, \square_{\square}^{\square} - \Delta t\, M \square_{\square}^{\square} \quad (3.15)$$

$$T_l\, \square_{\square-1}^{\square+1} + \square_{\square} \square_{\square}^{\square+1} - \square_{\square} \square_{\square+1}^{\square+1} = \square_4 \square_{\square-1}^{\square} + \square_{\square}^{\square} - \square_4 \square_{\square+1}^{\square+1}$$
(3.16)

$$C_l\, \square_{\square-1}^{\square+1} + C_c\, \square_{\square}^{\square+1} - C_r\, \square_{\square+1}^{\square+1} = \square_6 \square_{\square-1}^{\square} + \square_{\square}^{\square} - \square_6 \square_{\square+1}^{\square+1} + \square\square\square\square\, \square_{\square}^{\square}$$
(3.17)

Where $\square_{\square} = -\square_1$ $\quad U_{\square} = 1 + 2\square_1,$ $\quad U_{\square} = -\square_1$

$\square_{\square} = -\square_3$ $\quad \square_{\square} = 1 + 2\square_3,$ $\quad \square_{\square} = -\square_3$

$\square_{\square} = -\square_5$ $\quad \square_{\square} = 1 + 2\square_5$ $\quad \square_{\square} = -\square_5$

4. RESULTS AND DISCUSSION

In order to address the reaction of the following listed controlling parameters on flow region; finite difference method was used to solve non-linear dimensionless partial differential equations of the extended model. In the numerical computations arbitrary values were chosen for grashof number parameter (P); the Buoyancy ration parameter (N); Magnetic field parameter (M); the chemical reaction parameter (K_r); suction parameter (V); prandtl number parameter (P_r) and Schmidt's number parameter (S_c). The default values for the problem are:

P =10; N = 4; M= 2; K_r = 1.0; S_c =0.22; P_r = 0.71; v = 0.5; t = 1 and y take values from 0 to 1.

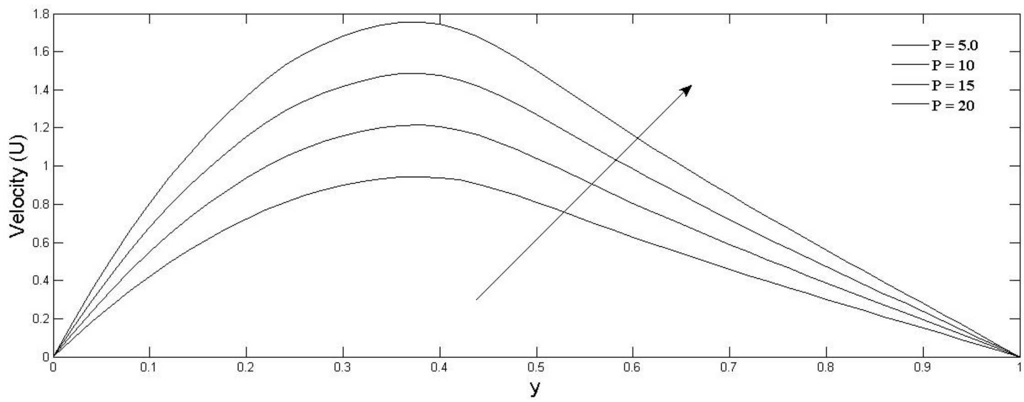

Figure 2: Effects of Grashof number (P) on velocity profile

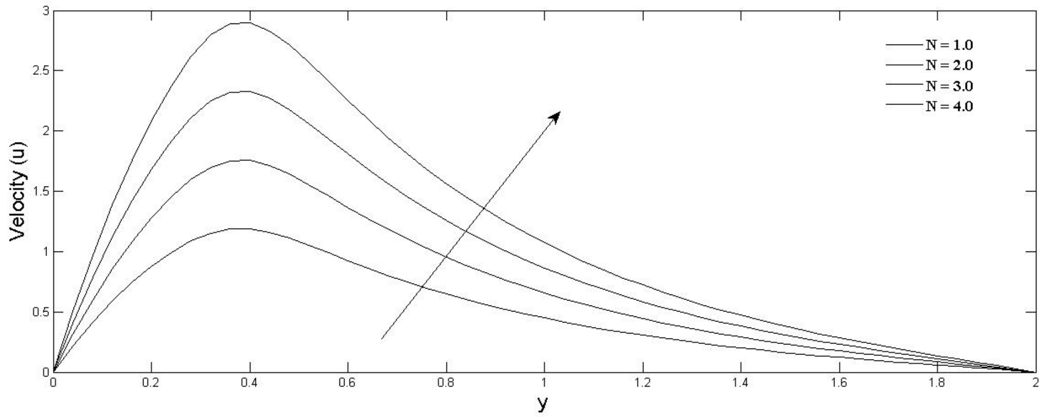

Figure 3: Effect of Buoyancy ratio parameter (N) on velocity profile

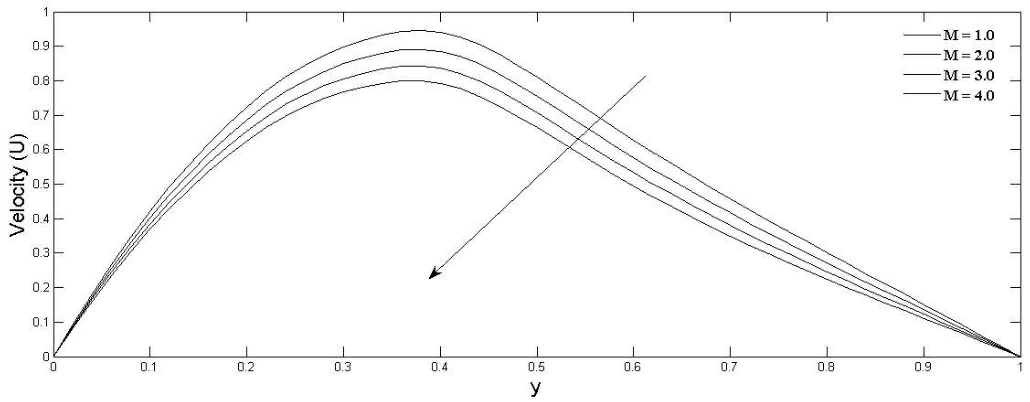

Figure 4: Effect of Magnetic field parameter (M) on velocity profile

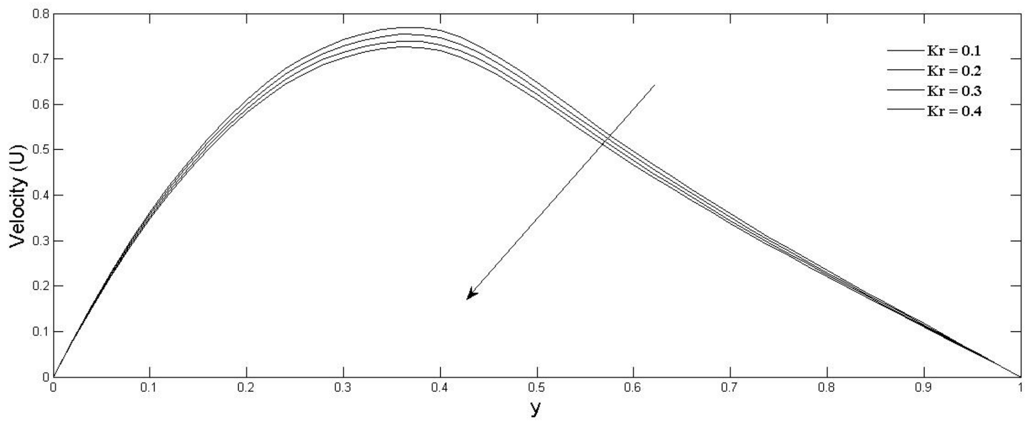

Figure 5: Effect of Chemical reaction (K_r) on velocity profile

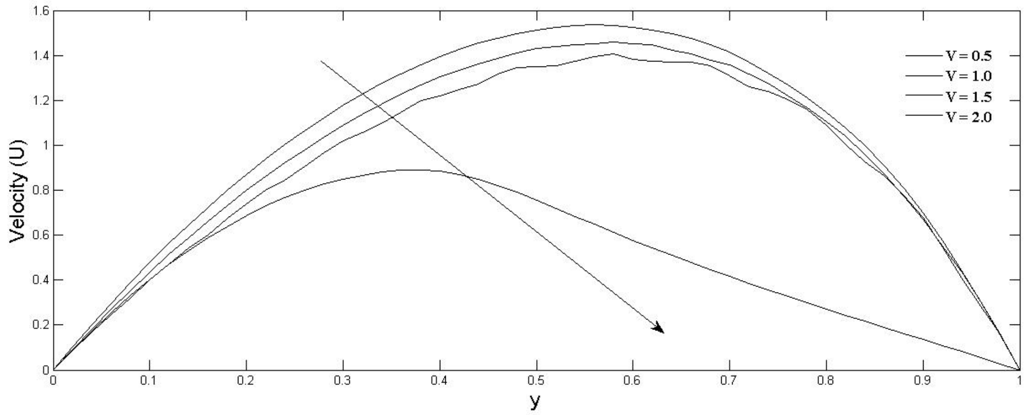

Figure 6: Effect of Suction parameter (V) on velocity profile

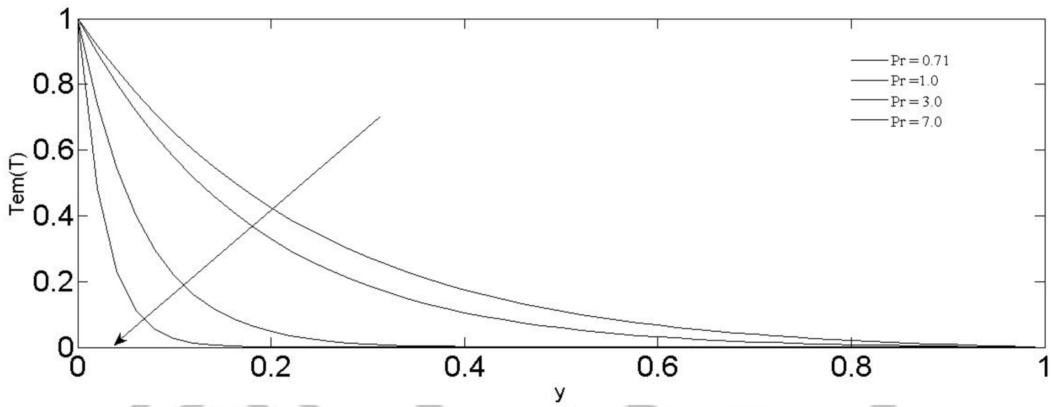

Figure 7: Effect of Prandtl number (P_r) on temperature profile

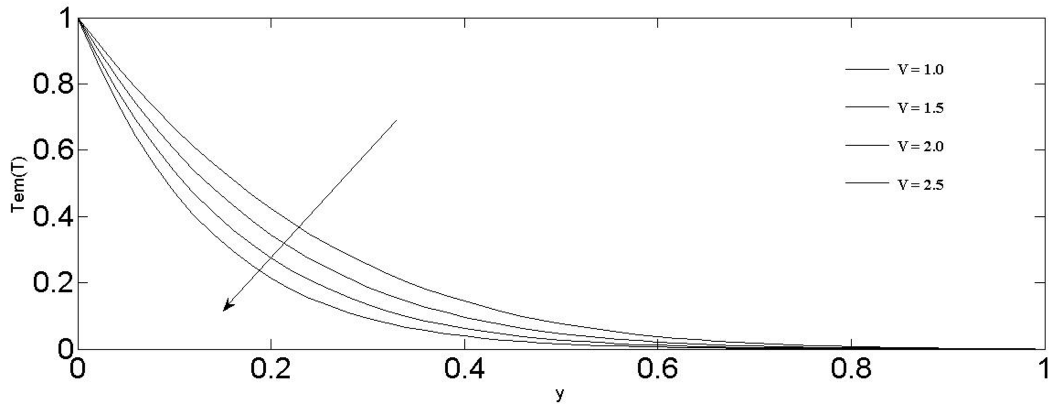

Figure 8: Effect of suction parameter (V) on temperature profile

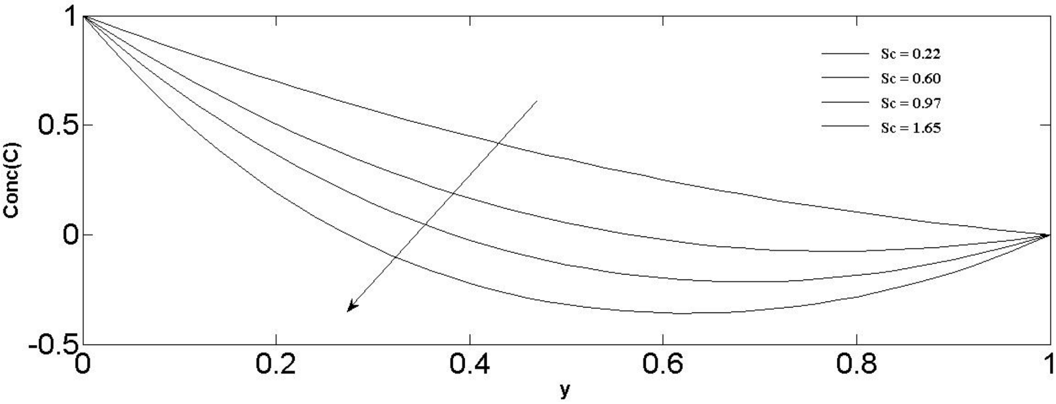

Figure 9: Effect of Schmidt's number (Sc) on concentration profile

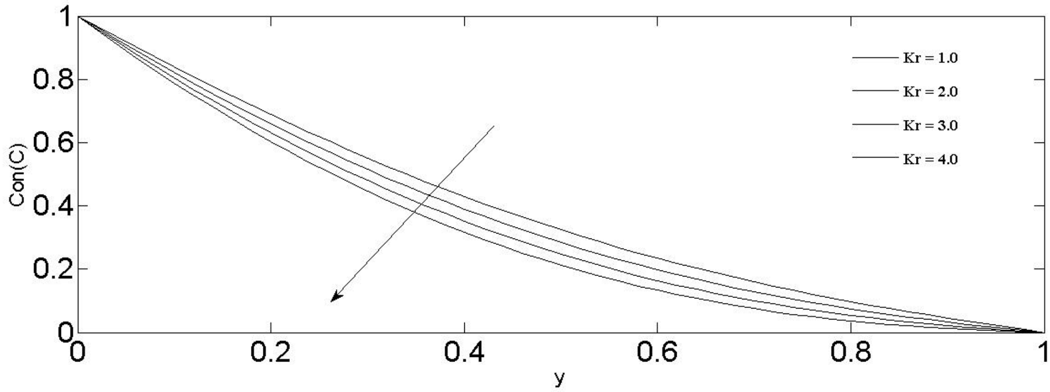

Figure 10: Effect of Chemical reaction (K_r) on concentration profile

Figure 1 gives the details about the control of grashof number parameter (p) on fluid velocity. From the figure it is noticed that as grashof number parameter increases the fluid velocity also raise up at all point of the fluid. Figure 2 shows the effect control of Buoyancy ratio parameter (N) on fluid velocity and it is observed that an increase of buoyancy ratio parameter (N) leads to rise in fluid velocity at all point of the flow. Figure 3 reveal the details about the control of magnetic parameter (M) on fluid velocity, from the figure it is observed that as magnetic parameter M rises the fluid velocity drop at all point of the flow fluid. Figure 4 demonstrates the influence of the chemical reaction parameter (K_r) on the fluid velocity. It is shown that increasing the values of chemical reaction parameter K_r decreases the fluid velocity at all point of the flow. Likewise figure 5 demonstrates the influence of suction parameter (V) on the fluid velocity. It is also observed that the fluid velocity decreases by raising the values of suction parameter (V). figure 6 displays the effect of prandtl number (P_r)

on fluid temperature. It is revealed from that figure the fluid temperature diminished by the values of prandtl number which reduce thermal diffusivity at high values of P_r. Figure 7 depicts the effect of suction parameter (V) on fluid temperature. It is observed from that figure the fluid temperature decreases by the raising values of suction parameters (V). figure 8 describes the effect of Schmidt's number parameter (S_c) on the fluid concentration. It is clearly seen that increasing the values of Schmidt's number (S_c) fall down the fluid concentration. Figure 9 display the influence of chemical reaction parameter (K_r) on the fluid concentration. It is clearly seen that the fluid concentration get diminished with increasing chemical reaction parameter (K_r).

5. CONCLUSIONS

The numerical investigation on MHD unsteady flow past a semi- infinite vertical plate with heat and mass transfer in the presence of chemical reaction has been studied. The governing equations are solved using the implicit Cra-Nicolson. The effects of governing parameters on the velocity flow, temperature and concentration of heat and mass transfer characteristics are presented graphically. The effects of Chemical reaction(Kr), Schmidts number(Sc), Suction(V), Magnetic field(M), Buoyancy ratio(N), Nusselt number(P), Prandtl number(Pr) parameters on the velocity, temperature and concentration profiles are revealed. The results show that the velocity and concentration profiles decreases by the increases of chemical reaction parameter, while an increase in prandtl number causes a retardation in the temperature profile.

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