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UNSTEADY HEAT AND MASS TRANSFER IN CONVECTIVE MHD THROUGH A VERTICAL PERMEABLE PLATE IN A POROUS MEDIUM WITH THERMAL RADIATION, CHEMICAL REACTION AND VISCOUS DISSIPATION

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ABSTRACT

In this present article, we analyzed the unsteady MHD flow of viscous, incompressible and electrically conducting fluid past a vertical porous channel under the influence of thermal radiation and chemical reaction. The transformed conservation equations are solved analytically subject to physically appropriate boundary conditions by using two term perturbation technique. It is observed that the velocity is decreased with increasing chemical reaction parameter. Increasing rarefaction parameter increases the velocity and but increasing suction parameter decreases the velocity. The study is relevant to chemical materials processing applications. An analysis to investigate the combined effects of heat and mass transfer on free convection unsteady magneto hydrodynamic (MHD) flow of viscous fluid embedded in a porous medium is presented. The flow in the fluid is induced due to uniform motion of the plate. The influence of a number of emerging non-dimensional parameters namely, Magnetic parameter, Prandtl number, Thermal radiation parameter and Schmidt number examined in detail. Furthermore, the influence of these parameters on heat transfer rate and skin friction is also investigated. The influence of various embedded flow parameters such as the Hartmann number, permeability parameter, Grashof number, dimensionless time, chemical reaction parameter, Schmidt number, and Soret number is analyzed graphically. Numerical solutions for skin friction are also obtained in tabular forms.

KEYWORDS: MHD; Magnetic parameter; Suction parameter; Chemical reaction, Nusselt number, and Sherwood number.

1. INTRODUCTION

The dynamics of fluids during porous channel has been a fashionable area of research concerning to numerous growing applications in chemical, mechanical and resource process engineering. The process of heat transfer or heat and mass transfer together occurs all together in a moving fluid and plays an important role in the design of chemical processing equipment, nuclear reactors, and formation and dispersion of fog. example of such fluids include clay coating, coal, oil slurries, shampoo, paints, and suspensions, cosmetic products, grease, custard and physiological liquids (blood, bile and synovial fluid). The boundary layer behavior of visco elastic fluid has several technical applications in engineering such as paper production, glass fiber, manufacture of foods, polymer extrusion in a melt spinning process, aerodynamic extrusion of plastic sheets and many others. Combined heat and mass transfer with chemical reaction in geometric with and without porous media has been studied by authors. A detailed discussion on this topic can be found in Raptis.[1] Effect of variable suction and thermophoresis on steady MHD combined free-forced convective heat and mass transfer flow over a semi-infinite permeable inclined plate in the presence of thermal radiation was investigated by Alam *et al*.[2] Muthucumaraswamy.[3] presented an exact solution to the problem of flow past an impulsively started infinite vertical plate in the presence of uniform heat and mass flux at the plate using Difference equations technique. Chamkha *et al*.[4] were investigated on unsteady MHD heat and mass transfer by mixed convection flow in the forward stagnation region of a rotating sphere at different wall conditions. Jaiswal and Soundalgekar.[5] were discussed the oscillating plate temperature effects on a flow past an infinite vertical porous plate with constant suction and embedded in a porous medium. The MHD effects on the convective boundary layer flow in porous medium considered by Nield and Bejan.[6] Sahin Ahamed and Zueco.[7] made a study to investigate the combined heat and mass transfer by mixed convection MHD flow along a porous plate with chemical reaction in presence of heat source. Pal and Shiva kumara.[8] were discussed on mixed convection heat transfer from a vertical heated plate embedded in a sparsely packed porous medium. Bhuvanavijaya and Mallikarjuna.[9] were investigated on the effect of variable thermal conductivity on convective heat and mass transfer over a vertical plate in a rotating system with variable porosity regime. Dursunkaya and Worek.[10] were observed the diffusion thermo and thermal-diffusion effects in transient and steady natural convection from vertical surface. Free convection effects on flow past an exponentially accelerated vertical plate was studied by Singh and Naveen Kumar.[11] The study of magneto hydrodynamic flow has many important industrial technological and geothermal applications such as high temperature plasmas, cooling of nuclear reactors, MHD accelerators, power generation systems and liquid metal. Specially to control the behavior of the boundary layer several artificial methods have been developed and out of that, the application of MHD principal is an important method for affecting the flow field in the desired direction by altering the structure of the boundary layer. Chen.[12] reported the magneto hydrodynamic mixed convection of a power-law fluid past a stretching surface in the presence of thermal radiation and internal heat generation/absorption. Elbashbeshy and Aldawody.[13] presented the effects of thermal radiation and magnetic field on unsteady mixed convection flow and heat transfer over a porous stretching surface in the presence of internal heat generation/absorption. Mostafa.[14] was introduced the variable viscosity and chemical reaction effects on mixed convection heat and mass transfer along a semi-infinite vertical plate. Radiative heat transfer flow is very important in manufacturing industries for the design of reliable equipment, nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites, and space vehicles. The effect of variable viscosity on MHD viscoelastic fluid flow and heat transfer over a stretching sheet was studied by Prasad *et al.*[15] Pal and Mondal.[16] Analyzed the Soret and Dufour effects on MHD non-Darcian mixed convection heat and mass transfer over a stretching sheet with non-uniform heat source/sink. Buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and ohmic heating was investigated by Dulal pal.[17] Chaudhaury and Arpita.[18] presented the combined heat and mass transfer effects on MHD free convection flowpast an oscillating plate embedded in porous medium. Turkyilmazoglu and Pop.[19] discussed the soret and heat source effects on the unsteady radiative MHD free convection flow from an impulsively started infinite vertical plate. Mohammed Ibrahim.[20] considered the radiation and mass transfer effects on MHD oscillatory flow in a channel filled with porous medium in the presence of chemical reaction. Alam *et al.*[21] were studied numerically the combined free forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal diffusion. Toki and Tokis.[22] obtained the exact solutions for the unsteady free convection flows on a porous plate with time depending heating. Das.[23] developed the closed form solutions for the unsteady MHD free convection flow with thermal radiation and mass transfer over a moving vertical plate. In this continuation, the effect of heat mass transfer on unsteady MHD free convection flow past a moving vertical plate in a porous medium was investigated by Das and Jana.[24] Recently, Osman et al.[25] analyzed the thermal radiation and chemical reaction effects on unsteady MHD free convection flow through a porous plate embedded in a porous medium with heat source/sink and the closed form solutions are obtained. Khan et al.[26] and Sparrow and Cess.[27] analyzed the effects of Hall current and mass transfer on the unsteady MHD free convection flow in a porous channel. The motion in fluid is induced to the external pressure gradient and the closed form solutions for the velocity, temperature, and concentration fields are obtained.

2. Mathematical Formulation

Consider the unsteady two dimensional nonlinear MHD free convective flows of a viscous incompressible and electrically conducting fluid past an infinite heated vertical porous plate embedded in a porous medium under the influence of thermal and concentration buoyancy effects. Let the x^*- axis be taken in vertically upward direction along the plate and y^*- axis is normal to the plate. It is assumed that there exist a homogeneous chemical reaction of first order with constant rate Kr^* between the diffusing species and the fluid. A uniform magnetic field is applied in the direction perpendicular to the plate. The viscous dissipation and the Joule heating effects are assumed to be negligible in the energy equation. The magnetic Reynolds number and transverse applied magnetic field are assumed to be very small, so that the produced magnetic field is insignificant. Also it is supposed that there is no applied voltage, so that the electric field is vanished. 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. Hence the Soret and Dufour effects are negligible and the temperature in the fluid flow is governed by the energy concentration equation involving radiative heat temperature. Under the above hypothesis as well as Boussinesq's approximation, the equations of conservation of mass, momentum, energy and concentration governing the free convective nonlinear boundary layer flow over a vertical porous plate in porous channel can be expressed as:

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

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = v\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T^*_\infty) + g\beta(C^* - C^*_\infty) - \frac{\sigma B_0^2}{\rho}u^* - \frac{v}{k^*}u^* + \frac{\gamma}{C_p}\left(\frac{\partial u}{\partial y}\right)^2 \qquad (2)$$

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \alpha\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*} \qquad (3)$$

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} + \frac{D K_T}{T_m}\frac{\partial^2 T^*}{\partial y^{*2}} - K_r^*(C_* - C^*_\infty) \qquad (4)$$

Where $u^*$and v^* are the velocity components in x^* and y^* directions respectively, $t^*$is the time, p^* is pressure, k thermal conductivity, ρ the fluid density, g the acceleration due to gravity, β and $\beta^*$the thermal and concentration expansion coefficients respectively.

The corresponding boundary conditions for the velocity, temperature and concentration fields are given as follows:

$$u^* = L^*\left(\frac{\partial u^*}{\partial y^*}\right), T^* = T_\infty^* + \varepsilon(T_w^* - T_\infty^*)\exp\left(\omega^* t^*\right), C^* = C_\infty^* + \varepsilon(C_w^* - C_\infty^*)\exp\left(\omega^* t^*\right) \quad \text{at} \quad y^* = 0$$
$$u^* \to 0, \quad T^* \to T_\infty^*, \quad C^* \to C_\infty^* \quad \text{as} \quad y^* \to \infty \qquad (5)$$

Where T_w^* and T_∞^* are the temperature at the wall and infinity.C_w^* and C_∞^* are the spices concentrations at the wall and at infinity respectively,ε <<1 is a very small positive constant,ω^* is the frequency of oscillation.By using the Rosseland approximation, the radioactive flux vector q_r^* can be written as:

$$q_r^* = -\frac{4\sigma^*}{3a^*}\frac{\partial T_w^{*4}}{\partial y^*} \qquad (6)$$

Where,σ^* and a^* are the Stefan –Boltzmann constant and the mean absorption coefficient respectively.We assume that the temperature difference within the flow is sufficiently small such that T^{*4} may be expressed as a linear function of the temperature.This is accomplished by expanding in a Taylor series about the free stream temperature

T_∞^* and neglecting higher order terms, thus

$$T_w^{*4} \cong 4T_\infty^{*3} T_w^* - 3T_\infty^{*4} \qquad (7)$$

From equation (1), it is clear that suction velocity at the plate is either a constant or function of time only. Hence the suction velocity normal to the plate is assumed to be in the form

$$v^* = -V_0\left[1 + \varepsilon A \exp(i\omega^* t^*)\right] \qquad (8)$$

Where A is a real positive constant, and ϵ is small such that ϵ <<1, ϵ A<<1, and V_0 is a non-zero positive constant, the negative sign indicates that the suction is towards the plate.

Now we introduce the following non-dimensional quantities.

$$u = \frac{u^*}{V_0},\ v = \frac{v^*}{V_0},\ y = \frac{V_0 y^*}{\nu},\ t = \frac{t^* V_0^2}{4\nu},\ \omega = \frac{4\omega^*\nu}{V_0^2},\ R = \frac{a^* k}{4\sigma^* T_\infty^{*3}\nu^2}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},\ \phi = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, K = \frac{K^* V_0^2}{\nu^2},$$
$$\Pr = \frac{\nu\rho c_p}{k},\ h = \frac{V_0 L^*}{\nu},\ Kr = \frac{K_r^*\nu}{V_0^2}, Sc = \frac{\nu}{D},\ M = \frac{\sigma B_0^2\nu}{\rho V_0^2},\ Gr = \frac{\nu\beta g\left(T_w^* - T_\infty^*\right)}{V_0^3},\ Gc = \frac{\nu\beta^* g\left(C_w^* - C_\infty^*\right)}{V_0^3}. \qquad (9)$$

According to the equations (6), (7), (8) and (9), the equations (2), (3) and (4) can be reducing to the following non- dimensional form.

$$\frac{1}{4}\frac{\partial u}{\partial t}-\left[1+\varepsilon A\exp(i\omega t)\right]\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\theta+Gc\phi-\left[M+\frac{1}{K}\right]u \quad (10)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t}-\left[1+\varepsilon A\exp(i\omega t)\right]\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\left[1+\frac{4}{3R}\right]\frac{\partial^2 \theta}{\partial y^2} \quad (11)$$

$$\frac{1}{4}\frac{\partial \phi}{\partial t}-\left[1+\varepsilon A\exp(i\omega t)\right]\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2}-Kr\phi \quad (12)$$

The corresponding dimensionless boundary conditions are

$$u=h\frac{\partial u}{\partial y},\quad \theta=1+\varepsilon\exp(i\omega t),\quad \phi=1+\varepsilon\exp(i\omega t)\quad \text{at}\quad y=0 \quad (13)$$
$$u\to 0,\quad \theta\to 0,\quad \phi\to 0\quad \text{as}\quad y\to\infty$$

Solution of the Problem

In order to reduce the above system of partial differential equations to a system of ordinary equations into non-dimensional form, we may represent the velocity, temperature and concentration as

$$u(y,t)=u_0(y)+\varepsilon\exp(i\omega t)u_1(y)+O(\varepsilon^2)+------ \quad (14)$$

$$\theta(y,t)=\theta_0(y)+\varepsilon\exp(i\omega t)\theta_1(y)+O(\varepsilon^2)+------ \quad (15)$$

$$\phi(y,t)=\phi_0(y)+\varepsilon\exp(i\omega t)\phi_1(y)+O(\varepsilon^2)+------ \quad (16)$$

Substituting (14) - (16) in equations (10) - (12) and equating harmonic and non-harmonic terms, and neglecting the higher order terms of O (ϵ^2), we obtain

$$u_0''+u_0'-\left(M+\frac{1}{K}\right)u_0=-\left[Gr\theta_0+Gc\phi_0\right] \quad (17)$$

$$u_1''+u_1'-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)u_1=-\left[Gr\theta_1+Gc\phi_1+Au_0'\right] \quad (18)$$

$$\theta_0''+\Pr\left(1+\frac{4}{3R}\right)\theta_0'=0 \quad (19)$$

$$\theta_1'' + \Pr\left(1+\frac{4}{3R}\right)\theta_1' - \Pr\frac{i\omega}{4}\left(1+\frac{4}{3R}\right)\theta_1 = -2A\Pr\left(1+\frac{4}{3R}\right)\theta_0' \tag{20}$$

$$\phi_0'' + Sc\phi_0' - ScKr\phi_0 = 0 \tag{21}$$

$$\phi_1'' + Sc\phi_1' - \left(\frac{i\omega}{4}+Kr\right)Sc\phi_1 = -ASc\phi_0' \tag{22}$$

Where the primes denote the differentiation with respect to y.

The corresponding non dimensional boundary conditions can be written as

$$u_0 = h\left(\frac{\partial u_0}{\partial y}\right),\ u_1 = h\left(\frac{\partial u_1}{\partial y}\right),\ \theta_0 = 1,\ \theta_1 = 1,\ \phi_0 = 1,\ \phi_1 = 1 \quad \text{at} \quad y = 0$$

$$u_0 \to 0,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ \phi_0 \to 0,\ \phi_1 \to 0 \quad \text{as} \quad y \to \infty \tag{23}$$

The analytical solutions of equations (17) – (22) with satisfying the boundary conditions (23) are given by

$$u_0 = A_8 e^{-B_4 y} + A_6 e^{-B_1 y} + A_7 e^{-B_2 y} \tag{24}$$

$$u_1 = A_{13} e^{-B_5 y} + A_9 e^{-B_1 y} + A_{10} e^{-A_1 y} + A_{11} e^{-B_3 y} + A_{12} e^{-B_2 y} \tag{25}$$

$$\theta_0 = e^{-A_1 y} \tag{26}$$

$$\theta_1 = A_2 e^{-A_1 y} + A_3 e^{-B_1 y} \tag{27}$$

$$\phi_0 = e^{-B_2 y} \tag{28}$$

$$\phi_1 = A_5 e^{-B_3 y} + A_4 e^{-B_2 y} \tag{29}$$

According to the above solutions, the velocity, temperature and concentration distributions in the boundary layerbecome

$$u(y,t) = A_8\exp(-B_4 y) + A_6\exp(-B_1 y) + A_7\exp(-B_2 y) + \varepsilon\left[A_{13}\exp(-B_5 y) + A_9\exp(-B_1 y) + A_{10}\exp(-A_1 y) + A_{11}\exp(-B_3 y) + A_{12}\exp(-B_2 y)\right]\exp(i\omega t) \tag{30}$$

$$\theta(y,t) = \exp(-A_1 y) + \varepsilon\left[A_2\exp(-A_1 y) + A_3\exp(-B_1 y)\right]\exp(i\omega t) \tag{31}$$

$$\phi(y,t) = \exp(-B_2 y) + \varepsilon\left[A_5\exp(-B_3 y) + A_4\exp(-B_2 y)\right]\exp(i\omega t) \tag{32}$$

3.1 Skin-friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –

dimensional form is givenby.

$$C_f = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = (B_4A_8 + B_1A_6 + B_2A_7) + \varepsilon\left(B_5A_{13} + B_1A_9 + A_1A_{10} + A_{11}B_3 + A_{12}B_2\right)\exp(i\omega t) \tag{33}$$

3.2. Nusselt number

From temperature field, now we study Nusselt number (rate of change of heat transfer) which is given in non-dimensional form as

$$Nu\,\mathrm{Re}_x^{-1} = -\left(1+\frac{4R}{3}\right)\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = \left(1+\frac{4R}{3}\right)\left[A_1 + \varepsilon\left(A_3B_1 + A_1A_2\right)\exp(i\omega t)\right] \tag{34}$$

3.3 Sherwood number

From concentration field, now we study Sherwood number (rate of change of mass transfer) which is given in non-dimensional form as

$$Sh_x\,\mathrm{Re}_x^{-1} = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = B_2 + \varepsilon\left(B_3A_5 + B_2A_4\right)\exp(i\omega t) \quad \text{where } \mathrm{Re}_x = \frac{V_0 x}{\nu} \text{ is the Reynolds number} \tag{35}$$

3. RESULTS AND DISCUSSION

In order to obtain the physical significance of the problem, we have plotted velocity, temperature, concentration, the rate of heat transfer and the rate of mass transfer for different values of the physical parameters like Magnetic parameter M, thermal Grashof number Gr, Permeability parameter K, Solutal Grashof number Gc, Thermal radiation R, Prandtl number $\Pr$, Schmidt number Sc and Chemical reaction parameter Kr. In the present study following default parameter values are adopted for computations: Gc = 5.0, Gm = 10.0, R =1.0

$$\omega t = \frac{\pi}{2},\ Sc = 0.60,\ K = 10.0, Kr = 0.1, R = 1.0, \Pr = 0.71, M = 1.0\,A = 0.5, h = 0.2, \varepsilon = 0.001.$$

All graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

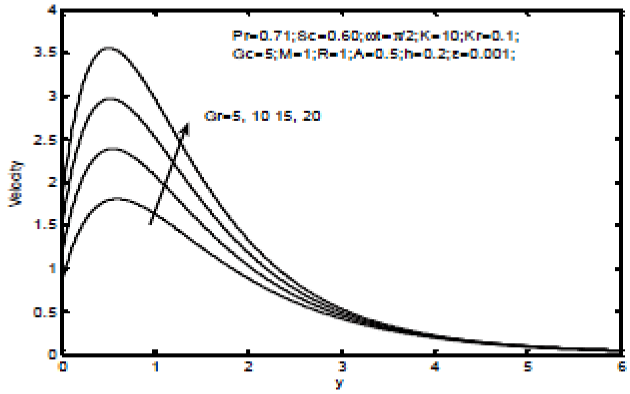

Figure1. Influence of Grashof number on velocity profiles.

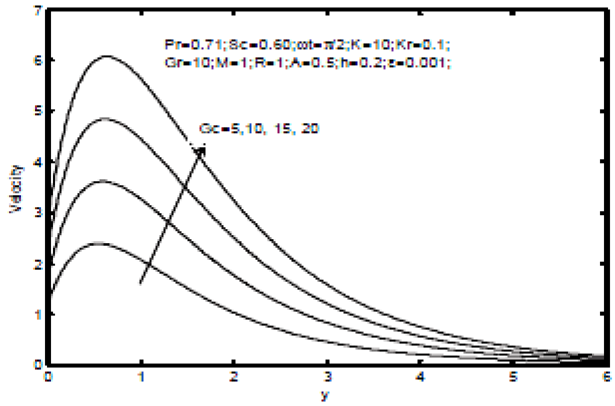

Figure2. Influence of Solutal Grashof number on velocity profiles.

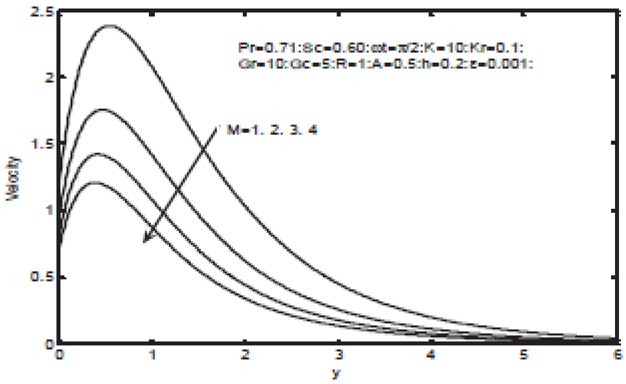

Figure3. Influence of Magnetic parameter on velocity profiles.

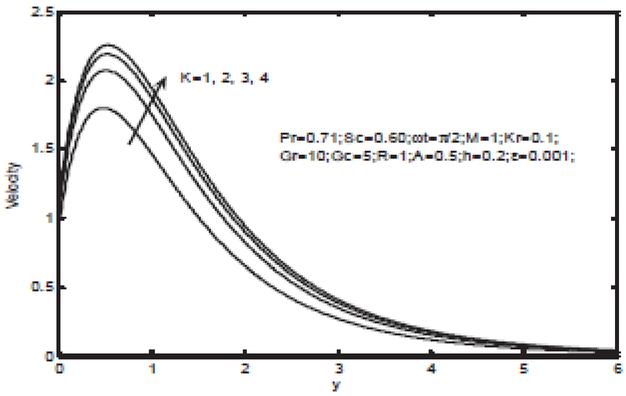

Figure4. Influence of Permeability parameter on velocity profiles.

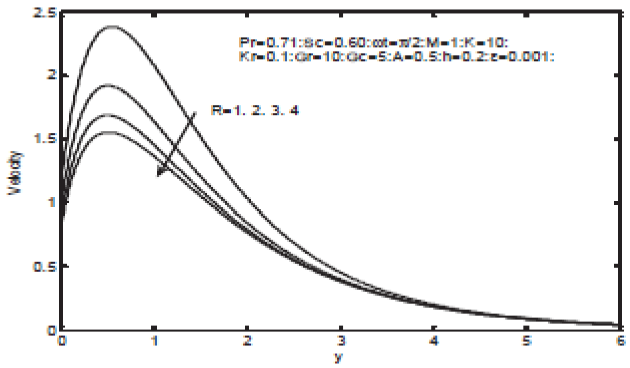

Figure 5. Influence of Radiation parameter on velocity profiles.

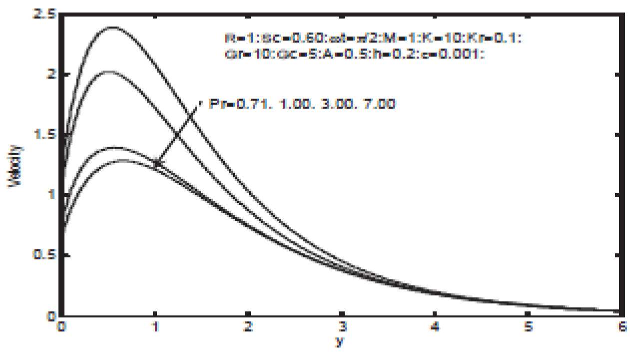

Figure 6. Influence of Prandtl number on velocity profiles.

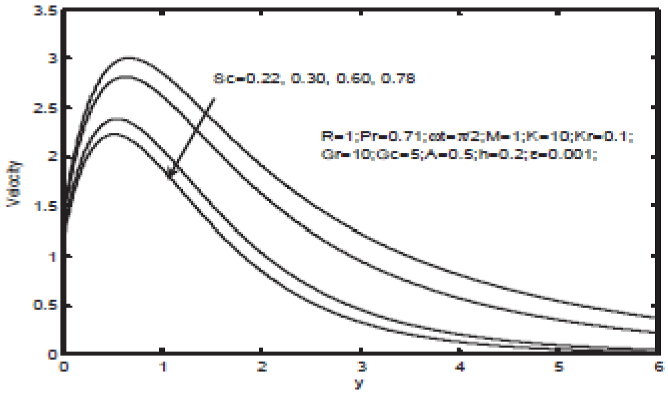

Figure7. Influence of Schmidt number on velocity profiles.

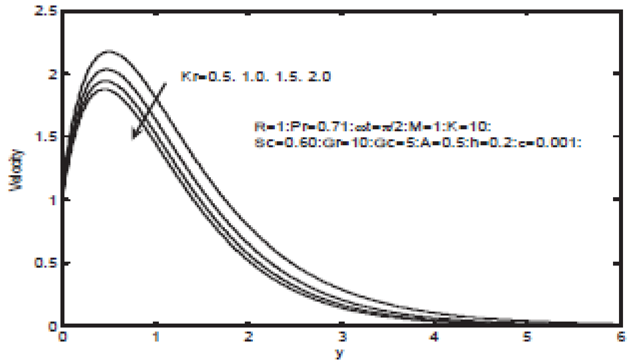

Figure 8. Influence of Chemical reaction parameter on velocity profiles.

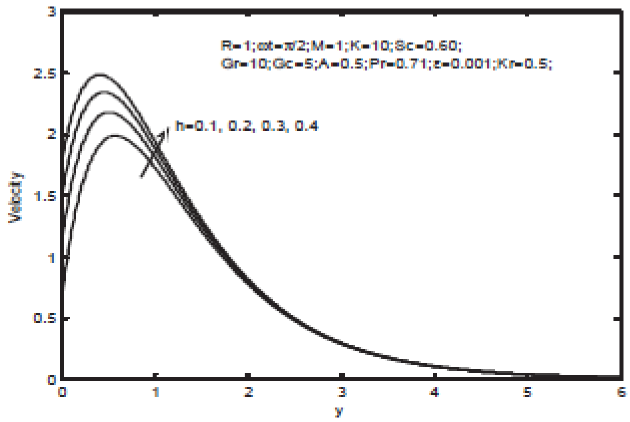

Figure 9. Influence of Refraction parameter on velocity profiles.

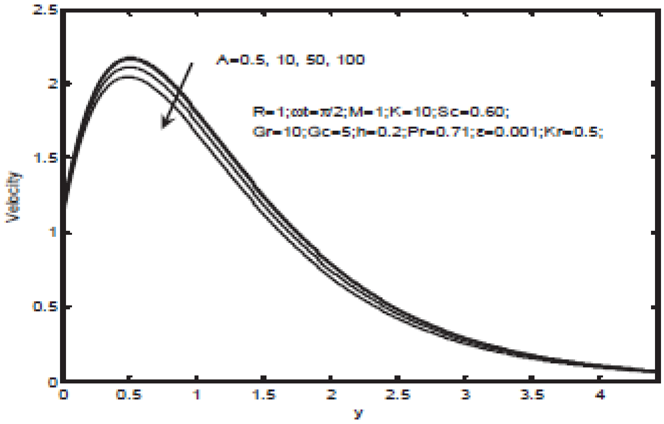

Figure 10. Influence of Suction parameter on velocity profiles.

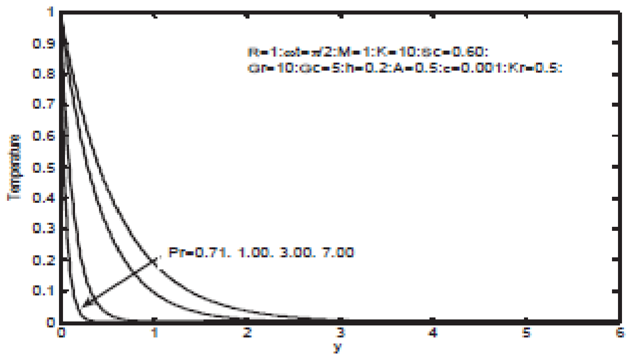

Figure11.Influence of Prandtl number on Temperature profiles.

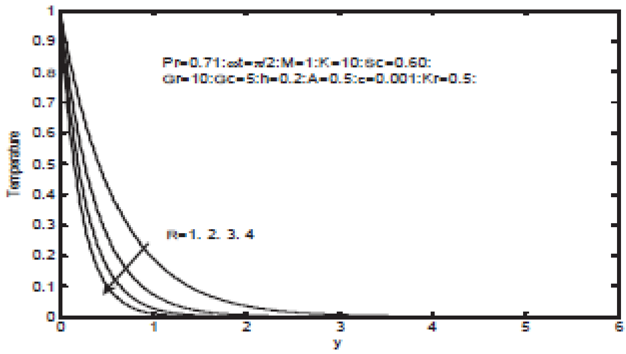

Figure12. Influence of Radiation parameter on Temperature profiles.

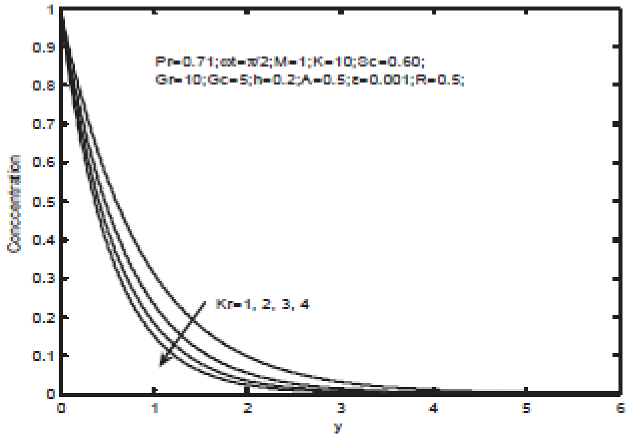

Figure 13. Influence of Chemical reaction parameter on concentration profiles.

Figure 1 depicts the velocity response to distinct values of the thermal Grashof number Gr. It is found that an increase in the thermal Grashof number results to rise in the values of velocity due to enhancement in buoyancy force. Here the positive values of the thermal Grashof number correspond to cooling of the surface. Figure 2 shows the typical velocity profiles in the boundary layer for distinct values of the solutal Grashof number *Gc*. The velocity distribution attains a distinctive maximum value in the region of the plate surface and then decrease properly to approach the free stream value. This is evident in the increase in the value of velocity as solutal Grashof number increases. Figure 3 depicts effect of Magnetic parameter *M* on the velocity of the flow field. Here the velocity profiles are drawn against y for four different values of *M* .The Magnetic parameter is found to decrease the velocity of the flow field at all points. Figure 4 shows the effect of the permeability of the porous medium parameter*K* on the velocity distribution. It is found that the velocity increases with an increase in *K* . For different values of thermal Radiation parameter *R* on the velocity and temperature profiles are shown in Figure 5 and Figure12. The radiation parameter *R* is found to decelerate the velocity and temperature of the flow field at all points. Higher the radiation parameter, the more sharper is the reduction in velocity and temperature. Figure 6 and Figure 11 shows the plot of velocity and temperature of the flow field against different values of prandtl number Pr taking other parameters are constant, it is observed that the velocity and temperature of the flow field decreases in magnitude as prandtl number Pr increases. Thus higher prandtl number leads to faster cooling of the plate.

The effect of the Schmidt number *Sc* on the velocity and concentration are shown in Figure 7

The flow field suffers a decrease in velocity at all points in presence of heavier diffusing species. The concentration distribution is found to decrease faster as the diffusing foreign species becomes heaver. Thus increase in Schmidt number leads to faster decrease in concentration of the flow field. Figure 8 and Figure 13, illustrates the behavior velocity and concentration for different values of chemical reaction parameter Kr . It is observed that an increase in Kr leads to a decrease in both the values of velocity and concentration. Figure 9 shows the effect of rarefaction parameter on velocity profiles. We observe that the velocity gradient at the surface increase with the increase of rarefaction parameter. Figure10 illustrates the effect of suction parameter on velocity profiles. It is observed that the suction parameter increases for higher values, velocity profiles decreases.

4. CONCLUSIONS

The present investigation brings out the following conclusions of physical interest on the velocity, temperature andconcentration distribution of the flow field.

- The Grashof number for heat transfer (Gr) and mass transfer (Gm) accelerate the velocity of the flow field at all points. But the increase in velocity of the flow field is more significant in presence of mass transfer.
- The reduction in velocity at any point of the flow field is faster as the radiation parameter becomes larger. Thus greater radiation leads to faster reduction in the velocity of the flow field.
- In presence of heavier diffusing species, the flow field suffers a greater reduction in velocity at all points.
- At any point in the flow field, the cooling of the plate is faster as Prandtl number becomes larger. ThusPrandtl number leads to faster cooling of the plate.
- The flow field suffers a faster decrease in concentration at all points as the diffusing foreign species present in the flow field becomes heavier and leads to a faster reduction of concentration of the flow field.

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