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EFFECT OF ROTATION AND THERMAL RADIATION ON MHD CONVECTIVE FLOW ALONG AN INFINITE VERTICAL POROUS PLATE WITH VARIABLE SUCTION AND HEAT ABSORPTION

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ABSTRACT : *This paper deals with the study of the rotation and thermal radiation effects on MHD convective flow along an infinite vertical porous plate in presence of Hall current with variable suction and heat generation in a porous medium. A magnetic field of uniform strength is assumed to be applied in a direction normal to the porous plat . The equations governing the fluid flow are solved using the perturbation technique and the expressions for the velocity, the temperature and the concentration distributions have been obtained. Dimensionless velocity, temperature and concentration profiles are displayed graphically for different values of the parameters entering into the problem like Prandtl number(Pr),Hartmann number(M), Grashof number(Gr), modified Grashof number(Gc),Hall parameter (m), Heat source parameter δ Schmidt number (Sc), rotation Ω , porous medium k_1 and thermal radiation . The profiles of the skin friction coefficient , rate of heat transfer and mass transfer at the plate are demonstrated graphically for various values of the physical parameters involved in the problem and the result are physically interpreted.*

Keywords: *MHD, Rotation, Porous medium, Thermal radiation, heat absorption, heat transfer and mass transfer.*

Introduction

The effect of MHD convective flows through porous media has been widely inspection in the present years being to its appliances in engineering. In recent times, many researchers have been done on convection flow of MHD fluid in view of its numerous applications in geophysics, astrophysics, meteorology, aerodynamics, MHD power generators and pumps, boundary layer control energy generators, accelerators, aerodynamics heating, polymer technology, petroleum industry, purification of crude oil, in material processing such as extrusion, metal forming and glass fibre drawing. MHD convective flow through porous media is a major area of research for its wide range functions such as thermal energy storage devices, ground water systems, electronic cooling, boilers and nuclear process systems etc. Many researchers analysis MHD convective flow through fluid porous medium near a vertical porous plate considering different aspects of the problem. Relevant studies are being to Raptis et al.[27], Giendrean and Auriault[11], Chan[4], Cowling[8], Raptis and Mass alas[25], Cheng and Minkowyez[7], Ghosh- dastidar[10] and Raptis and Perdikis[26] etc.

The effect of thermal radiation on MHD free convection flow plays an important role in several scientific and industrial processes such as high temperature casting and levitation, thermo- nuclear fusion, furnace design, glass production, solar power technology etc. Pop and Soundal gekar [22] analysis the effect of Hall current on steady hydro magnetic flow past a past a porous plate. Prasad and Reddy[23] observed radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi- infinite vertical permeable moving plate embedded in a porous medium. Ferdows et. Al[9] analysed free convection flow with variable suction in presence of thermal radiation. Majunder and Deka[15] gave an exact solution for MHD flow past an impulsively started infinite vertical plate in the presence of thermal radiation. Jain and Sing[14] noticed that Hall and thermal radiation effects on an unsteady rotating free convection slip flow along a porous vertical moving plate. Chaudhary et al.[5] presented effects of Hall current and thermal radiation on an unsteady free convection slip flow along a vertical plate embedded in a porous medium with constant heat and mass flux. Seth et al.[29] discussed effects of thermal radiation and rotation on unsteady hydromagnetic free convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium. Singh and Pathak[31] studied effect of rotation and Hall current on mixed convection MHD flow through porous medium in a vertical channel in presence of thermal radiation. Ahmed and Sharma[1] have considered the radiation effect on a transient MHD flow with mass transfer past an impulsively fixed infinite vertical plate. Rajesh and Varma[24] solved radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion. Hossain et al.[12] investigated the influence of thermal radiation on convective flows over a porous vertical plate. Muthucumaraswamy and Senthil[20] investigated the effects of thermal radiation on heat and mass transfer over a moving vertical plate.

The study of heat absorption in moving fluids is important in problems dealing with thermal radiation and those concerned with dissociating fluids. The effect of heat generation may alter the temperature distribution which in turn can affect the particle deposition rate in nuclear reactors, electronic chips and semi- conductor refers. Several computational studies of reactive MHD boundary layer flow with heat and mass transfer in presence of heat generation or absorption have been found in recent years. Seth et al.[28] obtained effect of rotation on unsteady hydromagnetic natural convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium with thermal diffusion and heat absorption. Chamkha[3] investigated unsteady MHD convective flow with heat and mass transfer through a semi-infinite vertical porous plate with heat absorption. Hossain et al.[13] were analysed natural convection flow of a vertical surface with uniform temperature in the presence of heat absorption. Shankar et al.[30] were presented a numerical solutions for radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in porous medium with heat absorption using Galerkinfinite element method. Mohamad[19] discussed unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effect.

Makinde and Sibanda[17] discussed MHD mixed convection flow with heat and mass transfer past a vertical plate embedded in a uniform porous medium with constant wall suction in the presence of uniform transverse magnetic field. Makinde[16] investigated unsteady MHD mixed convection flow and mass transfer past a vertical porous plate embedded in a porous medium with constant heat flux. Aydin and Kaya[2] mixed convection flow over a permeable vertical plate with magnetic field. Singh et al.[31] investigated unsteady MHD free convective flow in a porous medium bounded by an infinite vertical porous plate in the presence of rotation. Pal and Shivakumara[21] discussed the mixed convection heat transfer from a vertical plate in a porous medium. Chauhan and Rastogi[6] investigated the effects of thermal radiation, porosity and suction on unsteady convective hydromagnetic vertical rotating channel.

The objective of the present work is to examine the effect of rotation and thermal radiation on MHD convection flow along an infinite vertical porous plate with variable suction and Heat absorption in a porous medium. The work is an extension of the work done by S. Masthanrao et al[18].

Formulation of the problem

The transient MHD free convection flow of an electrically conducting fluid over a porous vertical infinite plate with variable suction and heat generation has been considered. The x' - axis is assumed to be along the plate and the y' -axis is normal to the plate.

Under the Boussinesq's approximation and the boundary layer theory, the governing equations for the problem under consideration are

Continuity equation:

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

Conservation of momentum:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} + 2\Omega w' = \frac{\partial U'}{\partial t'} + \upsilon\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma\mu_e^2 H_0^2}{\rho\left(1+m^2\right)}\left(u' - U' + mw'\right) + g\beta\left(T' - T_\infty'\right)$$
$$+ g\beta'\left(C' - C_\infty'\right) - \frac{\upsilon u'}{K_1'} \tag{2}$$

$$\frac{\partial w'}{\partial t'} + v'\frac{\partial w'}{\partial y'} - 2\Omega u' = \upsilon\frac{\partial^2 w'}{\partial y'^2} + \frac{\sigma\mu_e^2 H_0^2}{\rho\left(1+m^2\right)}\left(m\left(u' - U'\right) - w'\right) - \frac{\upsilon w'}{K_1'} \tag{3}$$

Conservation of energy:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{Q_0}{\rho C_p}\left(T_\infty' - T'\right) - \frac{1}{\rho C_p}\frac{\partial q_r'}{\partial y'} \tag{4}$$

Conservation of Species Concentration (Mass- diffusion):

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} + D_1\left(C' - C_\infty'\right) \tag{5}$$

The boundary conditions are given by

$$u' = 0, w' = 0, T' = T_w', C' = C_w' \quad \text{at } y' = 0 \tag{6a}$$

$$u' \to U'\left(t'\right), w' \to 0, T' \to T_\infty', C' \to C_\infty' \quad \text{as } y' \to \infty \tag{6b}$$

Where the dashes denote the dimensional quantities. Equation (1) gives $v' = v'\left(t'\right)$

The plate is subjected to a variable suction velocity with time so that we can replace $v' = -v_0'\left(1+\varepsilon e^{i\omega' t'}\right)\left(\varepsilon << 1\right)$, where v_0' is the steady suction velocity. For an optically thick fluid, in addition to emission there is also self absorption and usually the absorption co-efficient is wavelength dependent and large so we can adopt the Rosseland approximation for radiative heat flux vector q_r'. Thus q_r' is given by

$$q_r' = -\frac{4\sigma_1}{3K_1}\frac{\partial T'^4}{\partial y'} \tag{7}$$

Where K_1 is Rosseland mean absorption co-efficient and σ_1 is Stefan- Boltzmann constant.

We assume that the temperature difference within the flow are sufficiently small so that T'^4 about the free stream temperature T_∞' and neglecting higher order terms. This results of the following approximations:

$$T'^4 \approx 4T_\infty'^3 T' - 3T_\infty'^4 \tag{8}$$

From (7) and (8) we have

$$\frac{\partial q_r'}{\partial y'} = -\frac{4\sigma_1}{3K_1}\frac{\partial^2 T'^4}{\partial y'^2} = -\frac{16\sigma_1 T_\infty'^3}{3K_1}\frac{\partial^2 T'}{\partial y'^2} \tag{9}$$

Thus the energy equation (4) reduces to

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_P}\frac{\partial^2 T'}{\partial y'^2} + \frac{Q_0}{\rho C_P}\left(T_\infty' - T'\right) + \frac{16\sigma_1 T_\infty'^3}{3K_1 \rho C_P}\frac{\partial^2 T'}{\partial y'^2} \tag{10}$$

Introducing the following non-dimensional quantities:

$$y = \frac{y' v_0'}{\upsilon}, t = \frac{t' v_0'^2}{4\upsilon}, \omega = \frac{4\upsilon\omega'}{v_0'^2}, u = \frac{u'}{U_0'}, w = \frac{w'}{U_0'}, \delta = \frac{Q_0\upsilon^2}{k v_0'^2}, Kr = \frac{D_1\upsilon}{v_0'^2}, U = \frac{U'}{U_0'},$$

$$\theta = \frac{T' - T_\infty'}{T_w' - T_\infty'}, C = \frac{C' - C_\infty'}{C_w' - C_\infty'}, M^2 = \frac{\sigma\upsilon\mu_e^2 H_0^2}{\rho v_0'^2}, Sc = \frac{\upsilon}{D}, \Pr = \frac{\rho\upsilon C_P}{k}, Gr = \frac{\upsilon g\beta\left(T_w' - T_\infty'\right)}{U_0' v_0'^2}, \tag{11}$$

$$Gm = \frac{\upsilon g\beta'\left(C_w' - C_\infty'\right)}{U_0' v_0'^2}, K_1 = \frac{K' v_0'^2}{\upsilon^2}, N = \frac{kK_1}{4\sigma_1 T_\infty'^3}, \lambda = \frac{3N+4}{3N}, K^2 = \frac{\upsilon\Omega}{v_0'^2}$$

Using all these dimensionless quantities, equations (2),(3),(5) and (10) reduces to the following non-dimensional form:

$$\frac{1}{4}\frac{\partial q}{\partial t} - \left(1+\varepsilon e^{i\omega t}\right)\frac{\partial q}{\partial y} - \frac{\partial^2 q}{\partial y^2} + \frac{M^2}{1+m^2}(1-im)(q-U) = \frac{1}{4}\frac{\partial U}{\partial t} + Gr\theta + GcC - q\alpha \tag{12}$$

$$\frac{Sc}{4}\frac{\partial C}{\partial t} - Sc\left(1+\varepsilon e^{i\omega t}\right)\frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} + ScKrC \tag{13}$$

$$\frac{\Pr}{4}\frac{\partial \theta}{\partial t} - \Pr\left(1+\varepsilon e^{i\omega t}\right)\frac{\partial \theta}{\partial y} = \frac{\partial^2 \theta}{\partial y^2} - \delta\theta + \frac{4}{3N}\frac{\partial^2 \theta}{\partial y^2} \tag{14}$$

where $\alpha = 2K^2 + \frac{1}{K_1}, q = qr + i(qi)$

The corresponding boundary conditions are as $y \to \infty$ (15)

$q = 0, \theta = 1, C = 1$ at $y = 0$

Method of solution

$q \to U, \theta \to 0, C \to 0$

To solve the non- linear equations (12)- (14) with boundary conditions (15), we assume that

$$q = (1-q_0) + \varepsilon(1-q_1)e^{i\omega t}, U = 1+\varepsilon e^{i\omega t}, \theta = \theta_0 + \varepsilon\theta_1 e^{i\omega t}, C = C_0 + \varepsilon C_1 e^{i\omega t} \quad (16)$$

Now we substitute equation (16) into equation (12) to (14) and equating the like terms, neglecting higher order terms in ε, we obtain

$$q_0' + q_0' - M_1 q_0 = Gr\theta_0 + GcC_0 - (1-q_0)\alpha \quad (17)$$

$$q_1' + q_1' - \left(M_1 + \frac{i\omega}{4}\right)q_1 = -q_0' + Gr\theta_1 + GcC_1 - (1-q_1)\alpha \quad (18)$$

$$C_0' + ScC_0' + ScKrC_0 = 0 \quad (19)$$

$$C_1' + ScC_1' + Sc\left(Kr - \frac{i\omega}{4}\right)C_1 = -ScC_0' \quad (20)$$

$$\theta_0'\left(1 + \frac{4}{3N}\right) + \Pr\theta_0' - \delta\theta_0 = 0 \quad (21)$$

$$\theta_1'\left(1 + \frac{4}{3N}\right) + \Pr\theta_1' - \left(\delta + \frac{i\omega \Pr}{4}\right)\theta_1 = \Pr\theta_0' \quad (22)$$

The boundary conditions are

At $y = 0$, $q_0 = 1, q_1 = 1, \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0$ (23)

As $y \to \infty$, $q_0 \to 0, q_1 \to 1, \theta_0 \to 0, \theta_1 \to 1, C_0 \to 0, C_1 \to 0$

In equations (17) to (22), the primes denotes the derivatives w.r.to y. Solving equations (17) to (22) subject to the boundary conditions (23), we get

$$\theta_0 = e^{-A_1 y} \quad (24)$$

$$\theta_1 = A_3\left(e^{-A_1 y} - e^{A_2 y}\right) \quad (25)$$

$$C_0 = e^{-A_4 y} \quad (26)$$

$$C_1 = A_6\left(e^{-A_4 y} - e^{-A_5 y}\right) \quad (27)$$

$$q_0 = A_{11} e^{-A_7 y} + A_8 e^{-A_1 y} + A_9 e^{-A_4 y}$$

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(28)

$$q_1 = A_{21} e^{-A_{12} y} + A_{13} e^{-A_7 y} + A_{14} e^{-A_1 y} + A_{15} e^{-A_4 y} + A_{16} e^{-A_1 y} - A_{17} e^{-A_2 y} + A_{18} e^{-A_4 y} - A_{19} e^{-A_5 y} \quad (29)$$

SKIN- FRICTION, THE RATE OF HEAT TRANSFER AND THE RATE OF MASS TRANSFER:

The co-efficient of skin –friction is defined in non- dimensional form as:

$$\tau = \left[\frac{\partial u}{\partial y}\right]_{y=0} = \left(A_7 A_{11} + A_1 A_8 + A_4 A_9\right) + \varepsilon e^{i\omega t}\left(\begin{array}{c} A_{12}A_{21} + A_7 A_{13} + A_1 A_{14} + A_4 A_{15} \\ + A_1 A_{16} + A_2 A_{17} + A_4 A_{18} + A_5 A_{19} \end{array}\right) \quad (30)$$

The non-dimensional rate of heat transfer in terms of Nusselt number Nu is given by

$$Nu = \left[\frac{\partial \theta}{\partial}\right]_{y=0} = -A_1 + \varepsilon e^{i\omega t} A_3\left(-A_1 + A_2\right) \quad (31)$$

The non- dimensional rate of mass transfer in terms of Sherwood number Sh is given by

$$Sh = \left[\frac{\partial C}{\partial y}\right]_{y=0} = -A_4 + \varepsilon e^{i\omega t} A_6 \left(-A_4 + A_5\right) \quad (32)$$

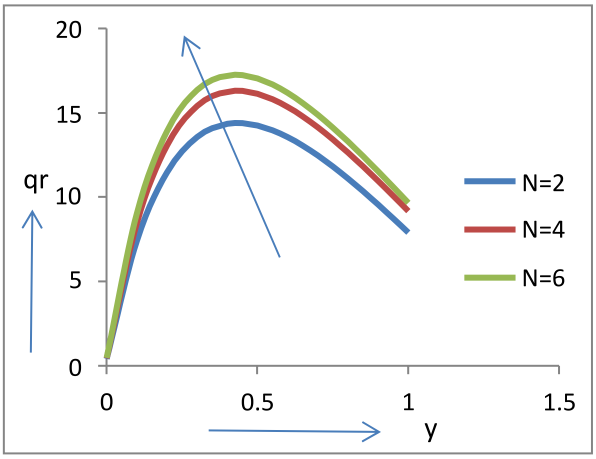

Fig1: Effect of N on primary velocity qr

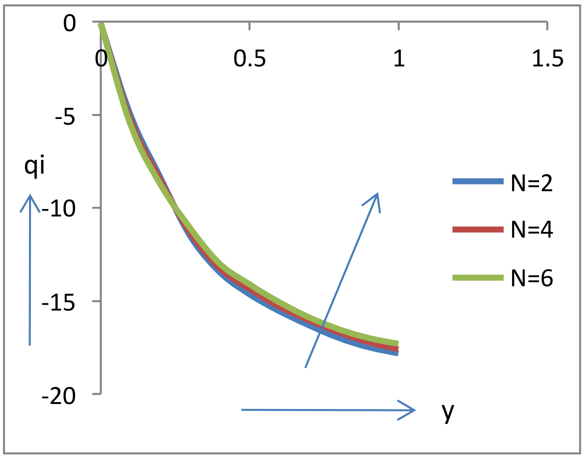

Fig2: Effect of N on secondary velocity qi

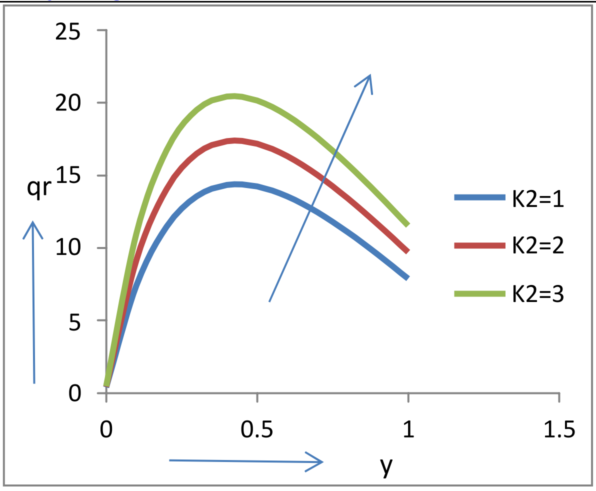

Fig3: Effect of K^2 on primary velocity qr

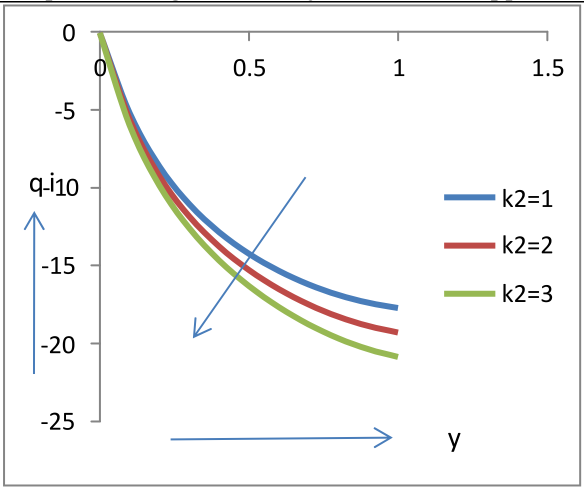

Fig4: Effect of K^2 on secondary velocity qi

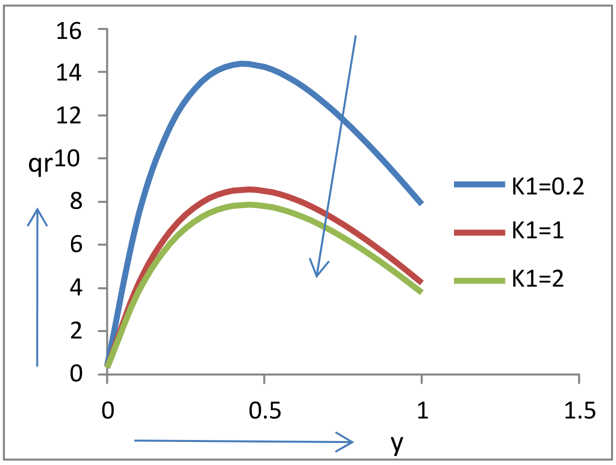

Fig5: Effect of K_1 on primary velocity qr

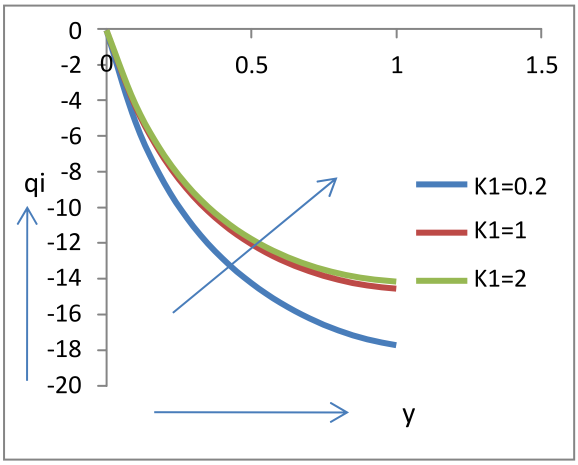

Fig6: Effect of K_1 on secondary velocity qi

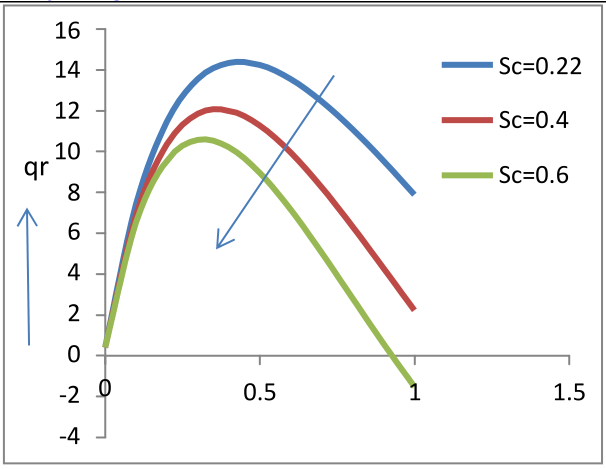

Fig7: Effect of Sc on primary velocity qr

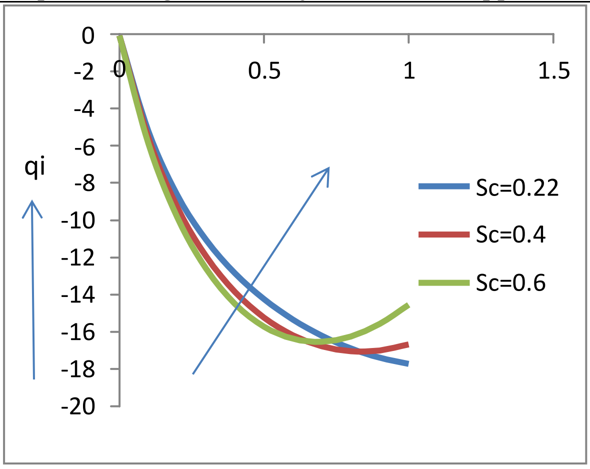

Fig8: Effect of Sc on secondary velocity qi

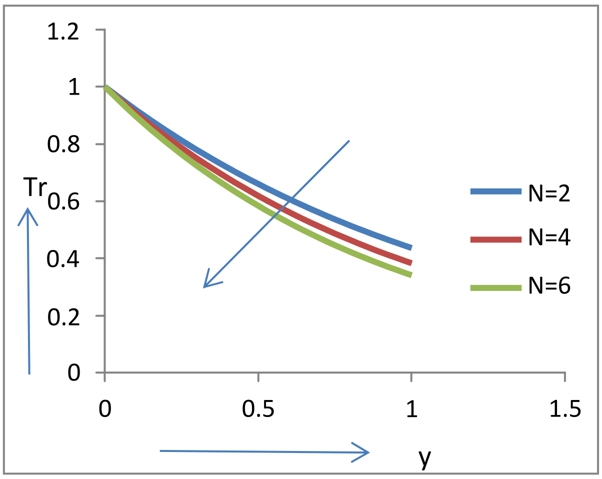

Fig9: Effect of N on primary temperature Tr

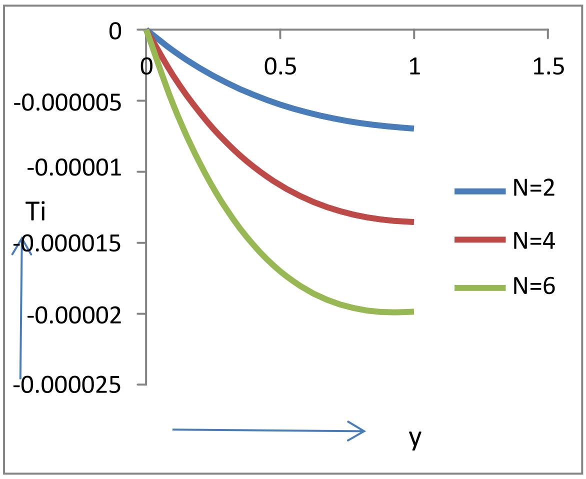

Fig10: Effect of N on secondary temperature Ti

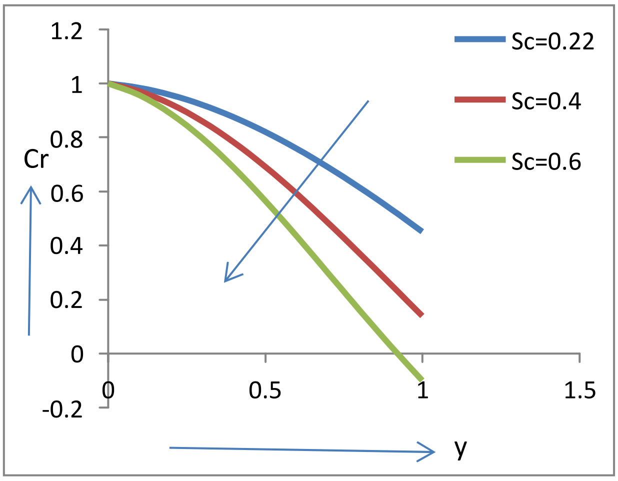

Fig11: Effect of Sc on primary concentration Cr

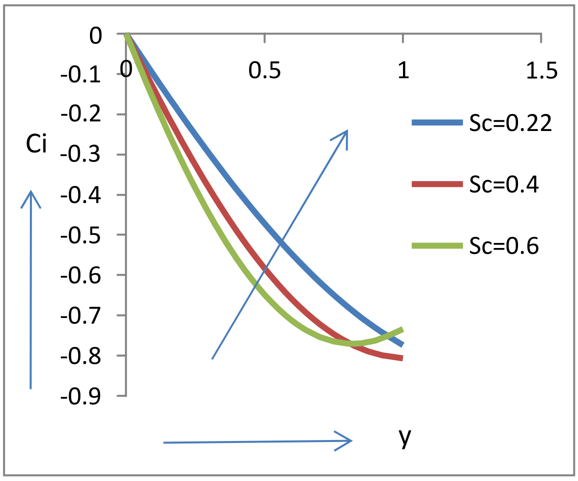

Fig12: Effect of Sc on secondary concentration Ci

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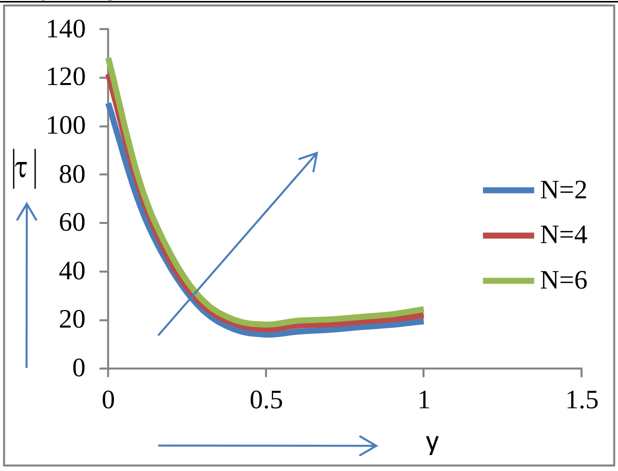

Fig13:Effect of N on magnitude of skin-friction co-effecient $|\tau|$

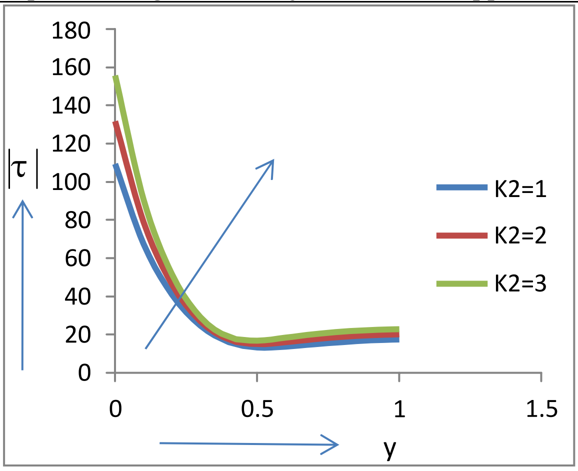

Fig14: Effect of K^2 on magnitude of skin-friction co-effecient $|\tau|$

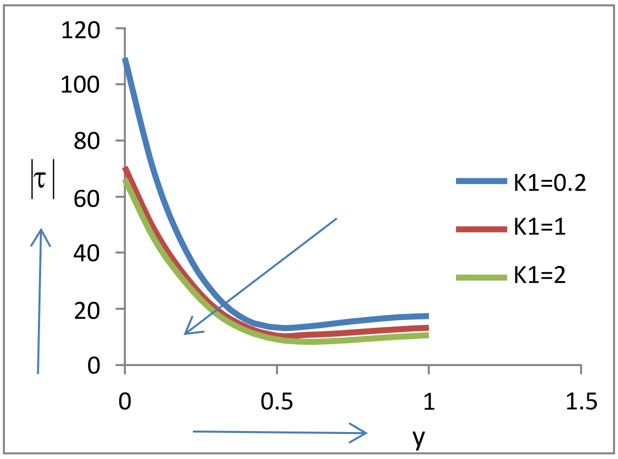

Fig15: Effect of K_1 on magnitude of skin-friction co-effecient $|\tau|$

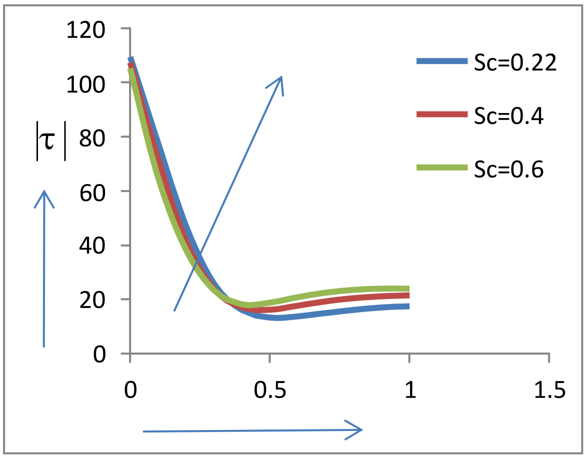

Fig16: Effect of K^2 on magnitude of skin-friction co-effecient $|\tau|$

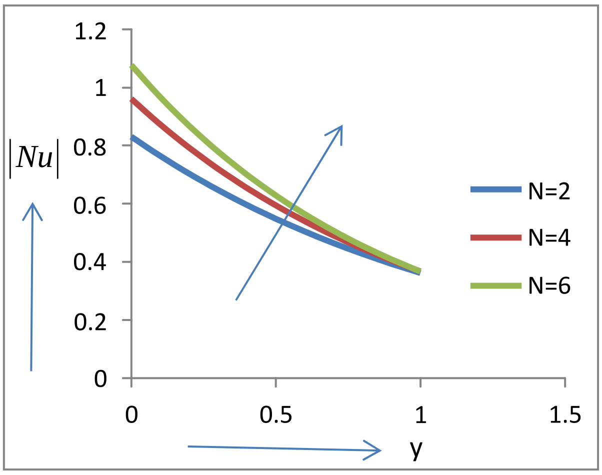

Fig17:Effect of N on magnitude of Nusselt number $|Nu|$

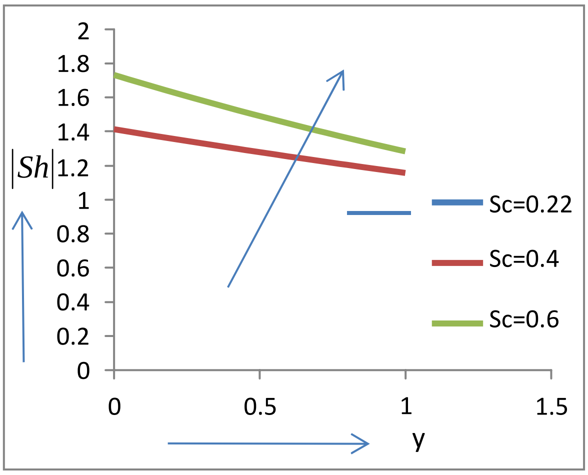

Fig18: Effect of Sc on magnitude of Sherwood number $|Sh|$

Result and discussioin:

In order to get a physical understanding of the problem and for purpose of discussing the results ,numerical calculations have been carried out for the transient primary velocity qr, the secondary velocity qi , the primary temperature Tr , the secondary temperature Ti , the primary concentration Cr , the secondary concentration Ci , the magnitude of skin- friction co-effecient $|\tau|$ the magnitude of Nusselt number $|Nu|$, the magnitude of Sherwood number $|Sh|$ respectively. The effect of materials parameters such as the thermal radiation N , permeability of the porous medium K_1 , rotation K^2 , Schmidt number Sc have been observed . The numerical calculations of these results are presented graphically in figures 1 to 18.

The numerical values of the primary and secondary fluid velocities , computed from the analytical solutions (28) and (29) , are represented graphically versus boundary layer co-ordinate y in figures (1) – (8) for various values of thermal radiation N , rotation parameter K^2 , permeability parameter K_1 and Schmidt number Sc. Figures (1) , (2) illustrate the effects of thermal radiation N on the primary and secondary fluid velocities respectively. It is evident from figures (1) , (2) that, qr and qi increases on increasing N. This implies that N tends to accelerate primary and secondary fluid velocities throughout the boundary layer region. Figures (3), (4) present the influence of rotation K^2 on the primary and secondary fluid velocities respectively. It is clear from figures (3) , (4) that, on increasing rotation parameter K^2, primary velocity qr first increases at a thin layer adjacent to the plate and thereafter decreases comprehensively at $y\rightarrow\infty$ whereas secondary velocity qi decreases on increasing K^2 in the region away from the plate. Figures (5) , (6) depict the effects of porous medium K_1 on primary and secondary fluid velocities respectively. It is noticed from figures (5) , (6) that, qr decreases on increasing permeability parameter whereas it has reverse effect on qi. Figures (7) , (8) demonstrate the influence of Schmidt number Sc on primary and secondary fluid velocities respectively. It is perceived from (7) , (8) that, qr decreases on increasing Sc whereas qi increases on increasing Sc. This implies that mass diffusion tend to accelerate qr and qi fluid velocities throughout the boundary layer region.

The numerical values of the primary and secondary fluid temperatures , computed from the analytical solutions (26) and (27) , are displayed graphically versus boundary layer co-ordinate y in figures (9) , (10) for various values of N. Figures (9) , (10) demonstrate the influence of N on primary and secondary fluid temperature respectively. It is reveal from figures (9) , (10) that, N leads to decrease in Tr and Ti. Physically N causes a fall in Tr and Ti and thereby causes a fall in kinetic energy of the fluid particles. Thus as N increases, Tr and Ti also decreases. Now from figures (9) , (10) , it may be inferred that radiation has a more significant effect on Tr and Ti.Thus N is strong effect on Tr and Ti.

The numerical values of the primary and secondary concentrations, computed from the analytical solutions (24) and (25) , are depicted graphically versus boundary layer co-ordinate y in figures (11) , (12) for various values of Schmidt number Sc. Figures (11) , (12) shows the effect of Sc on Cr and Ci. It is found that Cr decreases and Ci increases with increase in Sc. The Schmidt number Sc express the ratio of momentum to mass diffusivity. The Sc therefore quantities the relative effectiveness of momentum and mass transport by diffusion in primary and secondary concentration boundary layers. As the Schmidt number Sc increases, the mass transfer rate increases and hence Cr decreases whereas Ci increases in a complete turn occurrence is observed.

The numerical values of the magnitude of skin- friction co-effecient $|\tau|$, computed from the analytical solution (30) are presented graphically versus boundary layer co-ordinate y in figures (13)- (16) for various values of N , K^2 , K_1 , Sc. Figures (13)- (16) demonstrate the effect of N , K^2 , K_1 , Sc on the $|\tau|$.It is clear from figures (13), (14), (16), (15) that,the magnitude of skin- friction $|\tau|$ increases on increasing N , K^2 , Sc whereas it decreases on increasing K_1 .

The numerical values of the magnitude of Nusselt number $|Nu|$ computed from the analytical solution (31), is displayed graphically versus boundary layer co-ordinate y in figure (17) for various values of N . It is noticed from figure (17) that, $|Nu|$ increases on increasing N. This implies that, thermal radiation tend to enhance the magnitude of rate of heat transfer $|Nu|$

The numerical values of the magnitude of Sherwood number $|Sh|$ computed from the analytical solution (32), is presented graphically versus boundary layer co-ordinate y in figure (18) for various values of Sc . It is clear from figure (18) that, $|Sh|$ increases on increasing Sc. Now from figure (18) it may be inferred that Schmidt number tend to increase the magnitude of rate of mass transfer $|Sh|$.

Conclusion

An investigation of the effects of rotation and thermal radiation on MHD convective flow along an infinite vertical porous plate exposed to variable suction and heat absorption, is carried out. Exact solutions of the governing equations were obtained using perturbation technique. The conclusions of the study are as follows:

1. Thermal radiation N tends to accelerate both primary and secondary fluid velocities throughout the boundary layer region.

2. Rotation tends to accelerate primary velocity qr whereas it has a reverse effects on the secondary velocity qi in the region away from the plate.

3. Permeability of porous medium K_1 and Schmidt number Sc tends to accelerate the secondary velocity qi throughout the boundary layer region whereas it has reverse effect on qr throughout the boundary layer region.

4. An increase in the thermal radiation N leads to decrease in Tr, Ti.

5. An increase in the Schmidt number Sc leads to decrease in Cr whereas Ci increases on increasing Sc.

6. $|\tau|$ increases on increasing N, K^2, Sc whereas it decreases on increasing K_1.

7. $|Nu|$ and $|Sh|$ increases on increasing N, Sc.

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