Heat and Mass Transfer of MHD flow over a vertical porous plate with Hall current and rotation effects in the presence of magnetic field

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Abstract: Fluid flow over a vertical porous plate in the presence of magnetic field with hall current which is embedded in porous medium. The basic governing equations of the problems are transformed into a system of non -dimensional differential equations, by using Perturbation techniques. Analysis of Velocity, Temperature and concentration of fluid by using the various parameters like Grashof., Prandtl number, chemical reaction and magnetic parameter etc., velocity profile of fluid flow increases by increasing the Grashof, modified Grashof., Hall current parameters which are given in graphically. Temperature of the fluid flow decreases while increase of Prandtl number, viscous dissipation parameters etc., concentration profile are also analysis by using the various parameters. Investigation results are analyzed by using the graph with implementation of mathematical software. The increasing of Schmidt number is decreasing the concentration boundary layer thickness of the flow field. While Chemical reaction parameter increases decrease effects of the rate of mass transfer at the wall.

Keywords: Grashof , Heat Source,Hall Parameter, Magnetic Parameter Chemical parameter.

1.Introduction

Heat and mass transfer of fluid flow with hall effects has attention of many researchers in the present era. Especially, Hall effects play a vital role in many areas like engineering, industrial, bio medical etc., application of fluid flow in plasma , boundary layer in the field of aerodynamics. Strong magnetic field is known as Hall current. Now days Hall current plays a vital role in the field of fluid dynamics. Aboeldahab, E. M. and Elbarbary, E. M [1] studied the effects of hall current on the oscillatory MHD flow past a flat plate. Afify, A. A [2] discussed the effects of radiation on free convective flow and mass transfer past a vertical isothermal surface in the presence of hall current. Bestman, A. R. and Adjepong, S. K [3] analysis unsteady MHD flow over a vertical porous plate under the influence of hall current parameter. Bhattacharyya, K. and Layek, G. C., **[4]**, have studied the Similarity

Solution of MHD Boundary Layer Flow with Diffusion and Chemical Reaction Over a Porous Flat Plate with Suction/Blowing. Chamkha, A. J.,[5] studies the Thermal Radiation and Buoyancy Effects on Hydromagnetic Flow Over an Accelerating Permeable Surface with Heat Source or Sink.

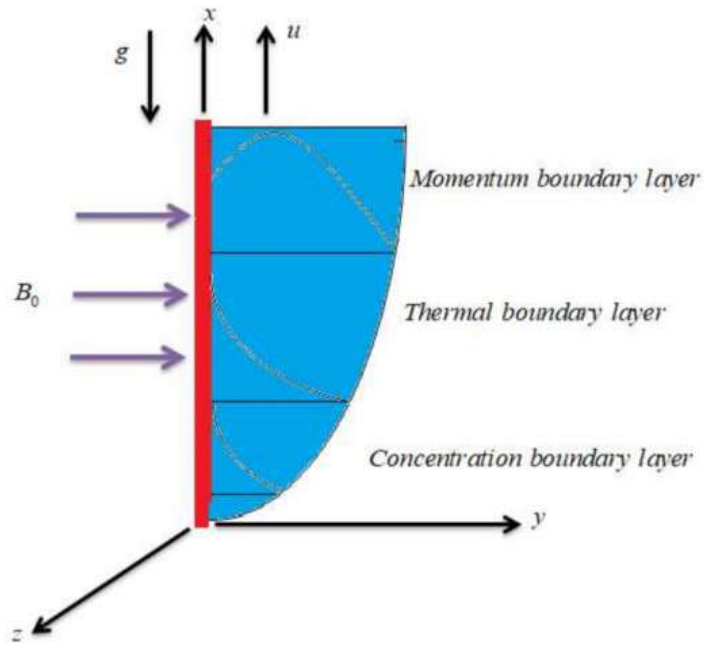
Chamkha, A. J, **[6]** studied the MHD Flow of a Uniformly Stretched Vertical Permeable Surface in the Presence of Heat Generation/Absorption and a Chemical Reaction. Chamkha, A. J., Mohamed, R. A. and Ahmed [7] analyzed the Unsteady MHD Natural Convection from a Heated Vertical Porous Plate in a Micropolar Fluid with Joule Heating, Chemical Reaction and Radiation Effects of the fluid flow. Chandran, P., Sacheti, N. C. and Singh, A. K., [8] studies the Natural Convection Near a Vertical Plate with Ramped Wall Temperature. P.C. Ram, [9] studied the effects of Hall and ion slip currents on free convective heat generating flow in a rotating fluid.

M.A. Seddeek [10] analysis the Effects of Hall and ion-Slip Currents on magneto-micropolar fluid and heat transfer over a non-isothermal stretching sheet with suction and blowing. Z Uddin, M. Kumar,[11] studied the effects of Hall and ion slip effect on MHD boundary layer flow of a micro polar fluid past a wedge. M. Veera Krishna, G.S. Reddy, A.J. Chamkha [12] observed the Hall effects on unsteady MHD oscillatory free convective flow of second grade fluid through porous medium between two vertical plates.

M. Veera Krishna, B.V. Swarnalathamma, A.J. Chamkha [13] has Investigated of Soret, Joule and Hall effects on MHD rotating mixed convective flow past an infinite vertical porous plate. Balamurugan K., Anuradha S.and Karthikeyan R [14] were analyzed the Chemical reaction effects on Heat and Mass Transfer of Unsteady flow over an infinite vertical porous plate embedded in a porous medium with heat source. R. Karthikeyan., Balamurugan K. [15]., have studied the Radiation effects of MHD oscillatory rotation flow through a porous medium bounded by two vertical porous plates in presence of Hall current and dufour effects with chemical reaction

2.Formulation of the Problem

Design of this problem, it can be considered that the flow is unsteady natural convection and mass transfer flow of a viscous incompressible fluid past an infinite vertical porous plate which is embedded in porous medium with heat source. The x’ axis is taken in vertically upward direction along the plate and y’ axis is chosen normal to it. Applying Boussinesq’s approximation the governing equations of the flow field are written as follows:



Continuity Equation:

$$\frac{\partial v'}{\partial y'} = \mathbf{0}\,;\;\; \boldsymbol{v}' = -\boldsymbol{v'}_{\mathbf{0}}(\boldsymbol{Constant}) \tag{1}$$

Momentum Equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} + 2\Omega w' = v\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma \mu^2{}_e B_0{}^2}{\rho(1+m^2)}(u' + mw') + g\beta(T' - T_\infty{}') + g\beta^*(C' - C_\infty{}') - \frac{v}{K'}u' \tag{2}$$

$$\frac{\partial w'}{\partial t'} + v'\frac{\partial w'}{\partial y'} - 2\Omega u' = v\frac{\partial^2 w'}{\partial y'^2} - \frac{\sigma \mu^2{}_e B_0{}^2}{\rho(1+m^2)}(w' - mu') - \frac{v}{K'}w' \tag{3}$$

Energy Equation:

$$u'\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = k\frac{\partial^2 T'}{\partial y'^2} + \frac{\vartheta}{Cp}\left[\left(\frac{\partial u'}{\partial y'}\right)^2 + \left(\frac{\partial w'}{\partial y'}\right)^2\right] + S'(T' - T_\infty{}') \tag{4}$$

Concentration Equation:

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

Boundary Conditions of the problem are:

$$u' = 0, v' = -v_0{}', T' = T_w{}' + \varepsilon(T_w{}' - T_\infty{}')e^{i\omega' t'}, C' = C_w{}' + \varepsilon(C_w{}' - C_\infty{}')e^{i\omega' t'} \;\; at\; y' = 0 \tag{6}$$

$$u' \to 0, T' \to T_\infty{}', C' \to C_\infty{}' \;\; as\; y' \to \infty$$

Now, Introducing the following non- dimensional variables and parameters.

$\boldsymbol{y} = \frac{y' v'_0}{\vartheta}$, $\boldsymbol{t} = \frac{t' {v'_0}^2}{4\vartheta}$, $\boldsymbol{\omega} = \frac{4\vartheta\omega'}{{v'_0}^2}$, $\boldsymbol{u} = \frac{u'}{v'_0}$, $\boldsymbol{w} = \frac{w'}{v'_0}$, $\boldsymbol{\vartheta} = \frac{\eta_0}{\rho}$, $K_p = \frac{{v'_0}^2 K'}{\vartheta^2}$, $T = \frac{T' - T_\infty{}'}{T'_w - T_\infty{}'}$, $C = \frac{C' - C_\infty{}'}{C_w{}' - C_\infty{}'}$ $P_r = \frac{\vartheta}{k'}$

$Gr = \frac{\vartheta g \beta (T'_w - T_\infty{}')}{{v'_0}^3}$, $Gc = \frac{\vartheta g \beta (T'_w - T_\infty{}')}{{v'_0}^3}$, $Sc = \frac{\vartheta}{D}$, $S = \frac{4S'\vartheta}{{v'_0}^2}$, $= \frac{{v'_0}^2}{Cp(T'_w - T_\infty{}')}$, $\boldsymbol{K_r} = \frac{{K_r}'\vartheta}{{\vartheta_0}^2}$,
$M_1 = \frac{M}{1+m^2}(1 - Im)$, $K^2 = \frac{\vartheta\Omega}{{v'_0}^2}$, $\lambda = 2IK^2$ **(7)**

Where $g, \rho, \vartheta, \beta, \beta^*, \omega, \eta_0, k, T', T'_w, T'_\infty, C', C_w', C_\infty', Cp, D, Pr, Sc, Gr, Gc, S, Kp, Ec K_r and M_1$ are respectively the acceleration due to gravity, density, coefficient of kinematic viscosity, volumetric coefficient of expansions for heat transfer,volumetric coefficient of expansions for mass transfer, angular frequency,Coefficient of viscosity, thermal diffusivity, temperature, temperature at the plate, temperature at infinity,Concentration, Concentration at the plate, concentration at infinity, specific heat at constant pressure,molecular mass diffusivity,Prandtl number,Schmidt number, Grashof number for heat transfer, Grahof number for mass transfer, heat source parameter, permeability parameter, Eckert number ,Chemical reaction parameter and Hall Effect Parameter.

Substituting equation (7) in equations (2),(3), and (4) under boundary conditions (6) we get

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} + 2K^2 w = \frac{\partial^2 u}{\partial y^2} - \frac{M}{1+m^2}(u + mw) + GrT + Gc - \frac{1}{Kp}u \tag{8}$$

$$\frac{1}{4}\frac{\partial w}{\partial t} - \frac{\partial w}{\partial y} - 2K^2 u = \frac{\partial^2 w}{\partial y^2} + \frac{M}{1+m^2}(mu - w) - \frac{1}{Kp}w \tag{9}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - \frac{\partial T}{\partial y} = \frac{1}{Pr}\frac{\partial^2 T}{\partial y^2} + \frac{1}{4}ST + Ec\left[\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial z}\right)^2\right] \tag{10}$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - \frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - Krc \tag{11}$$

The Corresponding boundary conditions are:

$$u = 0, T = 1 + \varepsilon e^{i\omega t}, C = 1 + \varepsilon e^{i\omega t} \;\; at \;\; y = 0$$

$$u \to 0, T \to 0, C \to 0 \;\; as\; y \to \infty \tag{12}$$

the Complex Velocity $F = u + iw$, $M_1 = \frac{M}{1+m^2}(1 - im), \lambda = 2IK^2$ we express the Equation (8) and (9) can be combined into a single equation of the form

$$\frac{1}{4}\frac{\partial F}{\partial t} - \frac{\partial F}{\partial y} = \frac{\partial^2 F}{\partial y^2} - (M_1 + \frac{1}{Kp} + \lambda)F + G_r T + G_r c \tag{13}$$

With boundary condition,

$$F = 0, \;\; T = 1 + \varepsilon e^{i\omega t}, C = 1 + \varepsilon e^{i\omega t} \;\; at \;\; y = 0 \;\; ;$$

$$F = 0, T \to 0, C \to 0 \;\; y \to \infty$$

3.Method of Solution:

To solve equations (7), (8) and (9) , we assume $\varepsilon$to be small and the velocity,temperature and concentration distribution of the flow field in the near of the plate can be expressed as

$$F(y,t) = F_0(y) + \varepsilon e^{i\omega t} F_1(y) \quad (14)$$

$$T(y,t) = T_0(y) + \varepsilon e^{i\omega t} T_1(y) \quad (15)$$

$$C(y,t) = C_0(y) + \varepsilon e^{i\omega t} C_1(y) \quad (16)$$

Substituting equations (14) – (16) in equations (7) –(9) respectively, equating harmonic and nonharmonic terms and the neglecting the coefficients of ε^2 then we get

$$F_0'' + F_0' - (M_1 + \frac{1}{Kp} + \lambda)F_0 = -GrT_0 - GcC_0 \quad (17)$$

$$T_0'' + PrT_0' + \frac{PrS}{4}T_0 = -PrEc\left(\frac{\partial u_0}{\partial y}\right)^2 \quad (18)$$

$$C_0'' + ScC_0' - ScK_rC_0 = 0 \quad (19)$$

First Order:

$$F_1'' + F_1' - \left(\frac{i\omega}{4} + \frac{1}{Kp} + M_1 + \lambda\right)F_1 = -GrT_1 - GcC_1 \quad (20)$$

$$T_1'' + PrT_1' - \frac{Pr}{4}(i\omega - S)T_1 = -2PrEc\left(\frac{\partial u_0}{\partial y}\right)\left(\frac{\partial u_1}{\partial y}\right) \quad (21)$$

$$C_1'' + ScC_1' - Sc\left(\frac{i\omega}{4} + K_r\right)C_1 = 0 \quad (22)$$

The Corresponding boundary conditions are

$$y = 0: F_0 = 0, T_0 = 1, C_0 = 1, F_1 = 0, T_1 = 1, C_1 = 1$$

$$y \to \infty: F_0 = 0, T_0 = 0, C_0 = 0, F_1 = 0, T_1 = 0, C_1 = 0 \quad (23)$$

Solving equations (19) & (22) under the boundary condition (23), then we get

$$C_0 = e^{M_2 y} \quad (24)$$

$$C_1 = e^{M_4 y} \quad (25)$$

Using Multi parameter perturbation technique and assuming Ec$\ll$ 1, we take

$$F_0 = F_{00} + EcF_{01} \quad (26)$$

$$T_0 = T_{00} + EcT_{01} \quad (27)$$

$$F_1 = F_{10} + EcF_{11} \quad (28)$$

$$T_1 = T_{10} + EcT_{11} \quad (29)$$

Now using equations (26) –(29) in equations (14),(15),(16) equating the coefficients of like powers of Ec neglecting of Ec^2, we get the following set of differential equations

Zeroth Order:

$$F_{00}'' + F_{00}' - \left(M_1 + \frac{1}{Kp} + \lambda\right) F_{00} = -GrT_{00} - GcC_0 \tag{30}$$

$$F_{10}'' + F_{10}' - \left(\frac{i\omega}{4} + \frac{1}{Kp} + M_1 + \lambda\right) F_{10=} = -GrT_{10} - GcC_1 \tag{31}$$

$$T_{00}'' + PrT_{00}' + \frac{PrS}{4} T_{00} = 0 \tag{32}$$

$$T_{10}'' + PrT_{10}' - \frac{Pr}{4}(i\omega - S)T_{10} = 0 \tag{33}$$

The Corresponding boundary conditions are

$y = 0: F_{00} = 0, T_{00} = 1, F_{10} = 0, T_{10} = 1$

$$y \to \infty: F_{00} = 0, T_{00} = 0, F_{10} = 0, T_{10} = 1 \tag{34}$$

First Order:

$$F_{01}'' + F_{01}' - \left(M_1 + \frac{1}{Kp} + \lambda\right) F_{01} = -GrT_{01} \tag{35}$$

$$F_{11}'' + F_{11}' - \left(\frac{i\omega}{4} + \frac{1}{Kp} + M_1 + \lambda\right) F_{11} = -GrT_{11} \tag{36}$$

$$T_{01}'' + PrT_{01}' + \frac{PrS}{4} T_{01} = -Pr(u_{00}')^2 \tag{37}$$

$$T_{11}'' + PrT_{11}' - \frac{Pr}{4}(i\omega - S)T_{11} = -2Pr\left(\frac{\partial u_{00}}{\partial y}\right)\left(\frac{\partial u_{10}}{\partial y}\right) \tag{38}$$

The Corresponding boundary conditions become,

$y = 0: F_{01} = 0, T_{01} = 0, F_{11} = 0, T_{11} = 0$

$$y \to \infty: F_{01} = 0, T_{01} = 0, F_{11} = 0, T_{11} = 0 \tag{39}$$

Solving equations (35)-(38) subject to the boundary conditions (39) we get

$$F_{00} = A_{10}e^{M_{10}y} + A_{11}e^{M_6 y} + A_{12}e^{M_2 y} \tag{40}$$

$$T_{00} = e^{M_6 y} \tag{41}$$

$$F_{10} = A_{14}e^{M_{12}y} + A_{15}e^{M_8 y} + A_{16}e^{M_4 y} \tag{42}$$

$$T_{10} = e^{M_8 y} \tag{43}$$

Solving equations (32)-(35) subject to boundary conditions (36) we get

$$T_{01} = A_{18}e^{M_{14}y} + B_1 e^{2M_{10}y} + B_2 e^{2M_6 y} + B_3 e^{2M_2 y} + B_4 e^{(M_6+M_{10})y} + B_5 e^{(M_1+M_6)y} + B_6 e^{(M_2+M_{10})}y \tag{44}$$

$$T_{11} = A_{20}e^{M_{16}y} + C_1 e^{(M_{10}+M_{12})y} + C_2 e^{(M_8+M_{10})y} + C_3 e^{(M_4+M_{10})y} + C_4 e^{(M_6+M_{12})y} + C_5 e^{(M_6+M_8)y} + C_6 e^{(M_4+M_6)y} + C_7 e^{(M_2+M_{12})y} + C_8 e^{(M_2+M_8)y} + C_9 e^{(M_2+M_4)y} \tag{45}$$

$$F_{01} = A_{22}e^{M_{18}y} + D_1 e^{M_{14}y} + D_2 e^{2M_{10}y} + D_3 e^{2M_2 y} + D_4 e^{(M_6+M_{10})y} + D_5 e^{(M_2+M_6)y} + D_6 e^{(M_2+M_{10})y} + D_7 e^{2M_6 y} \tag{46}$$

$$F_{11} = A_{24}e^{M_{20}y} + E_1 e^{M_{16}y} + E_2 e^{(M_{10}+M_{12})y} + E_3 e^{(M_8+M_{10})y} + E_4 e^{(M_4+M_{10})y} + E_5 e^{(M_6+M_{12})y} + E_6 e^{(M_6+M_8)y} + E7 e^{(M_4+M_6)y} + E_8 e^{(M_2+M_{12})y} + E_9 e^{(M_2+M_8)y} + E_{10} e^{(M_2+M_4)y} \tag{47}$$

Substituting the values of C_0 and C_1 from equations (24) and (25) in equation(16) the solution for concentration distribution of the flow field is given by

$$C = e^{M_2 y} + \epsilon e^{(i\omega t+M_4)y} \tag{48}$$

3.1 Skin friction: The skin friction at the wall is given by

$$\tau_w = \left(\frac{\partial F}{\partial y}\right)_{y=0} = A_{10}M_{10}+A_{11}M_6+A_{12}M_2+Ec(A_{22}M_{10}+D_1M_6+2D_2M_{10}+2D_3M_2+(M_6+M_{10})D_4+(M_6+M_2)D_5+(M_{10}+M_2)D_6+2M_6D_7)+\epsilon Exp[I\omega t](A_{14}M_{12}+A_{18}M_{87}+A_{16}M_4+ \epsilon Exp[I\omega t]Ec\big(A_{24}M_{12}+E_1M_8+E_2(M_{10}+M_{12})+E_3(M_{10}+M_8)+E_4(M_4+M_6)+E_5(M_6+M_{12})+E_6(M_8+M_6)+E_7(M_6+M_4)+E_8(M_2+M_{12})+E_9(M_2+M_8)+E_{10}(M_2+M_4)\big)$$

3.2 Heat flux: The rate of heat transfer i.e heat flux at the wall in terms of Nusselt Number N_u is given by

$$N_u = \left(\frac{\partial T}{\partial y}\right)_{y=0} = M_6 + Ec(A_{18}M_6 + 2B_1M_{10} + 2B_2M_6 + 2B_3M_2 + B_4(M_6 + M_{10}) + B_5(M_6 + M_2) + B_6(M_2 + M_{10})) + \epsilon Exp[I\omega t](M_8 Ec(A_{20}M_8 + C_1(M_{10} + M_{12}) + C_2(M_{10} + M_8) + C_3(M_4 + M_{10}) + C_4(M_6 + M_{12}) + C_5(M_6 + M_8) + C_6(M_6 + M_4) + C_7(M_2 + M_{12}) + C_8(M_2 + M_8) + C_9(M_2 + M_4)))$$

3.3 Mass flux: The rate of Mass transfer i.e. mass flux at the wall in terms of Sherwood Number S_h is given by

$$S_h = \left(\frac{\partial C}{\partial y}\right)_{y=0} = M_2 + M_4 \epsilon Exp[I\omega t]$$

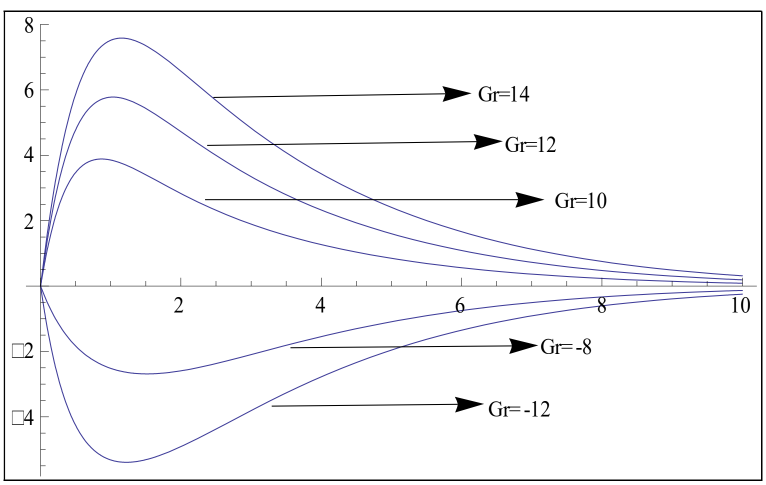
4.Results and discussions:-

The effects of various parameter in heat and mass transfer on unsteady flow of a viscous incompressible fluid past an infinite vertical porous plate embedded in a porous medium with heat source has been studied. The effects of parameters in the fluid flow are thoroughly analyzed and given in the form of graph to easily understand.

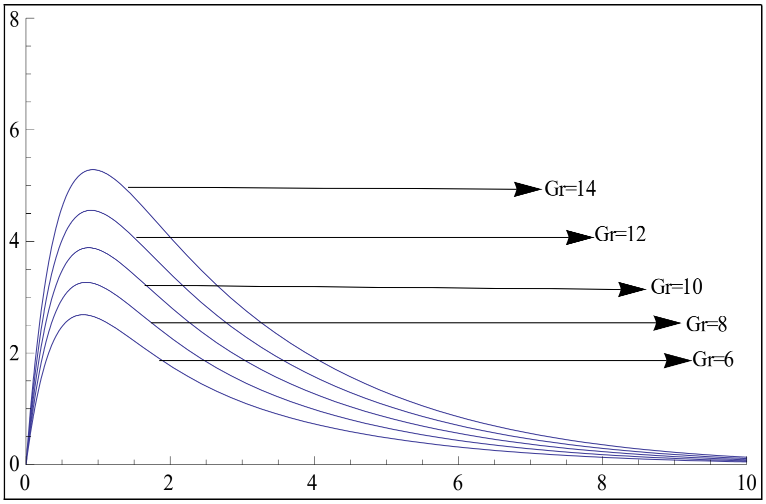
Velocity field: Grashof number can be classified as greater than or less than zero for analysis of heat and mass transfer flow over the vertical porous plate in the presence of magnetic field. Some of the parameters like Grashof number for heat transfer, mass transfer , viscous dissipation heat sources are enhance the velocity profile of the fluid flow. Increases of Magnetic field retards the velocity of the fluid flow.

Temperature Field: - Temperature profiles of the flow field under the influence of effected parameters like Prandtl number, Permeability parameter (Kp),Grashof Number Gr,Heat Sources, Magnetic Parameter M. Temperature profile goes on decrease while growing parameter Prandtl Number (Pr),and Viscous Dissipation (Ec) But the inverse effects exists while increasing Grashof Number Gr.

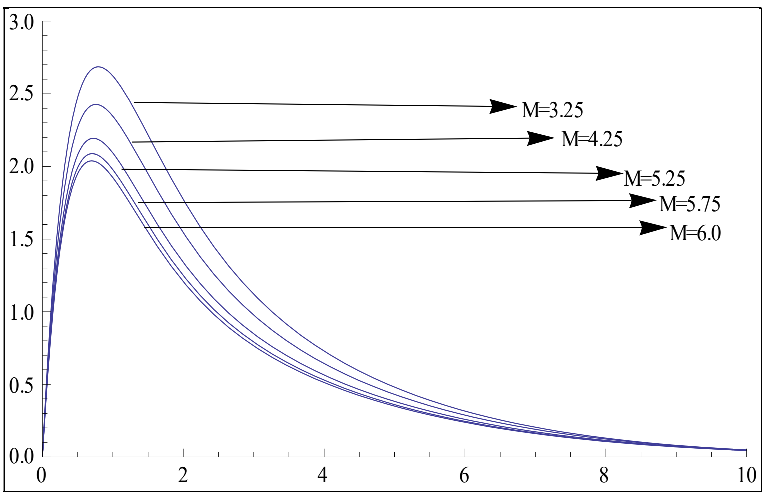
Concentration Field: Schmidt Number and Chemical reaction parameters plays important role in the concentration fluid flow field. The effects of these parameters on the fluid flow field graphically shown. When increases of Schmidt number (Sc) decrease the concentration boundary layer thickness of the flow. The mass transfer is decrease while growing of Chemical reaction parameter (K_r)



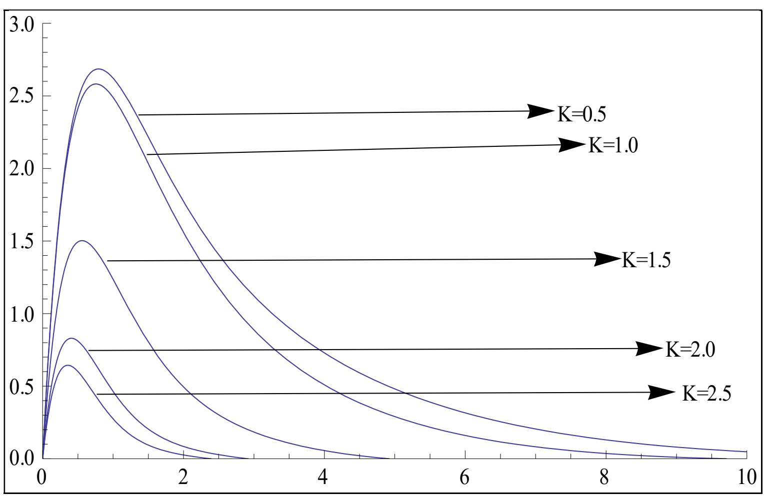
Velocity of fluid flow for various value of Gr



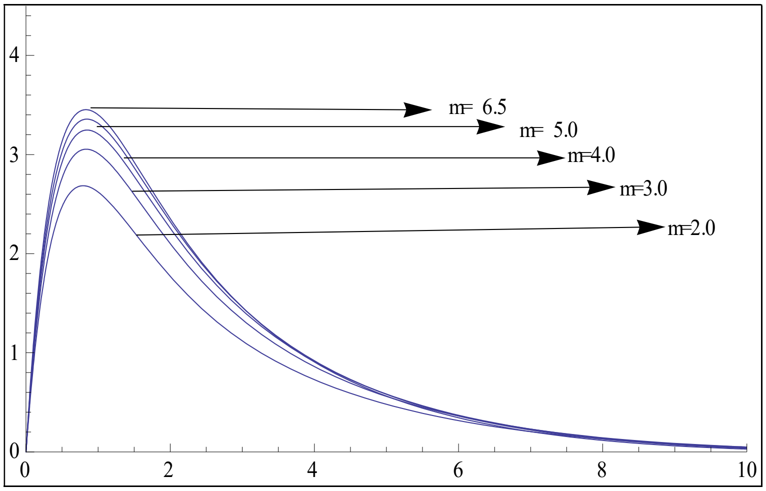
Velocity of fluid for various positive value of Gr



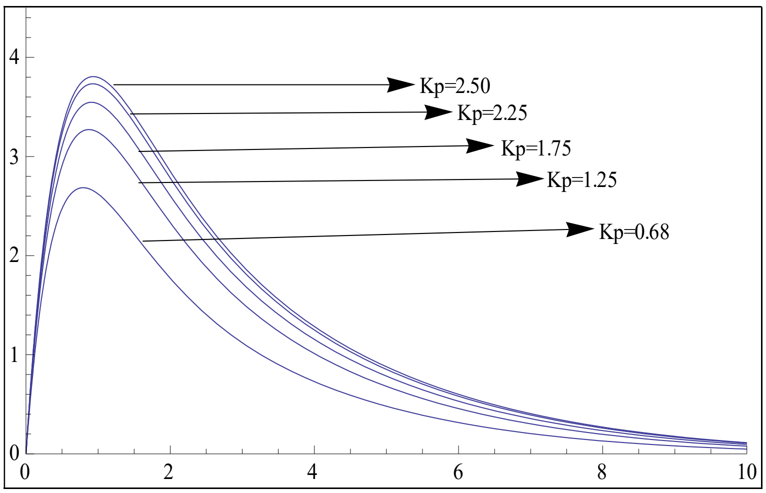
Velocity of fluid for various values of Magnetic field



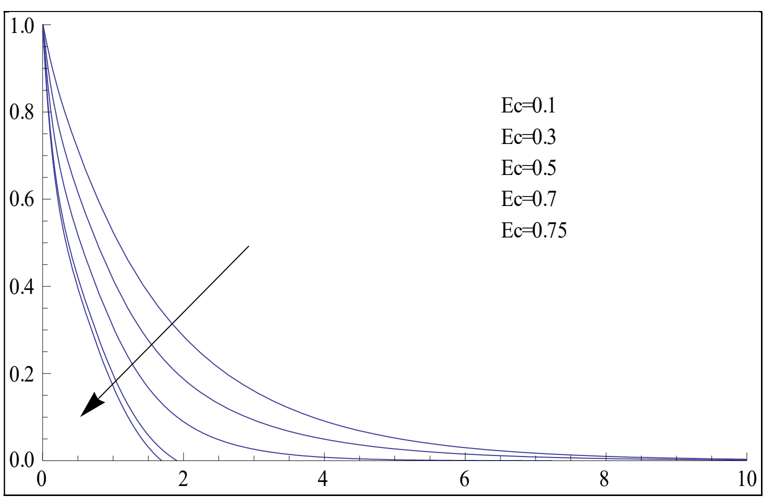
Velocity of fluid for various values of Magnetic field



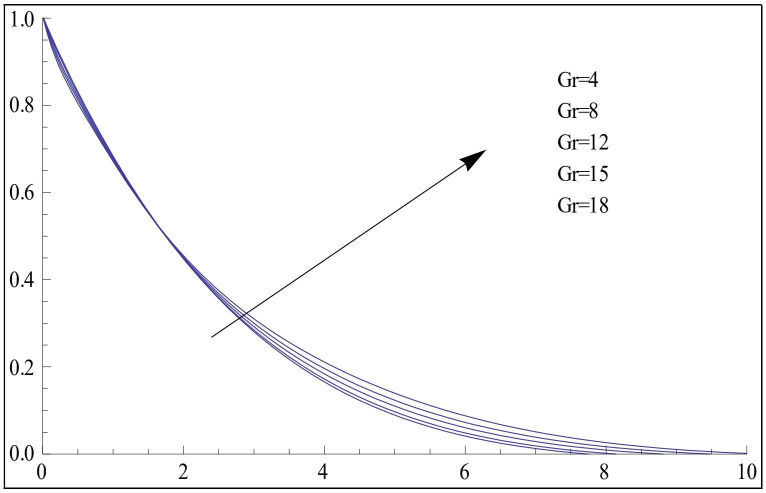
Velocity of fluid for various values of Magnetic field m



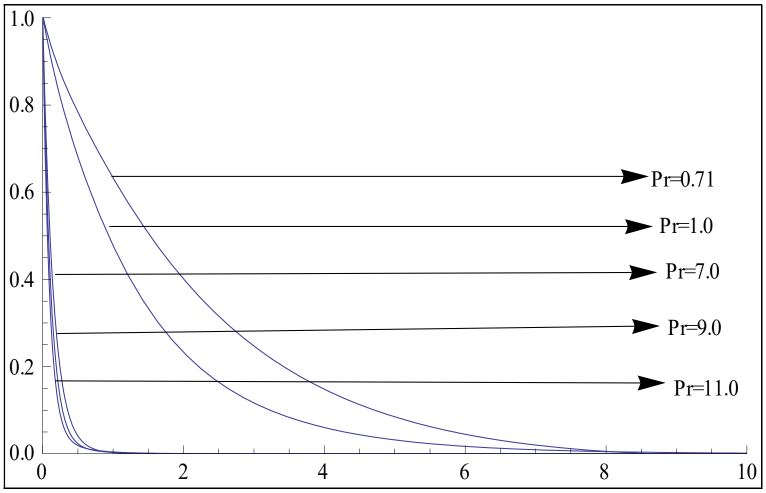
Velocity for various value of Kp



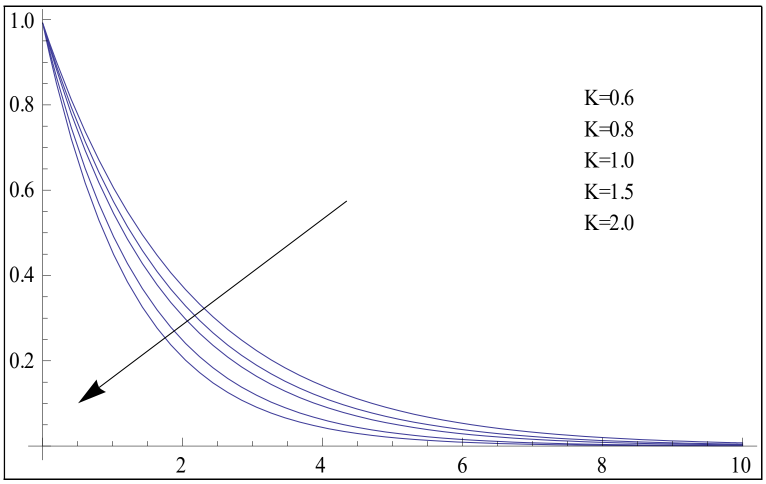
Temperature for various value of Ec



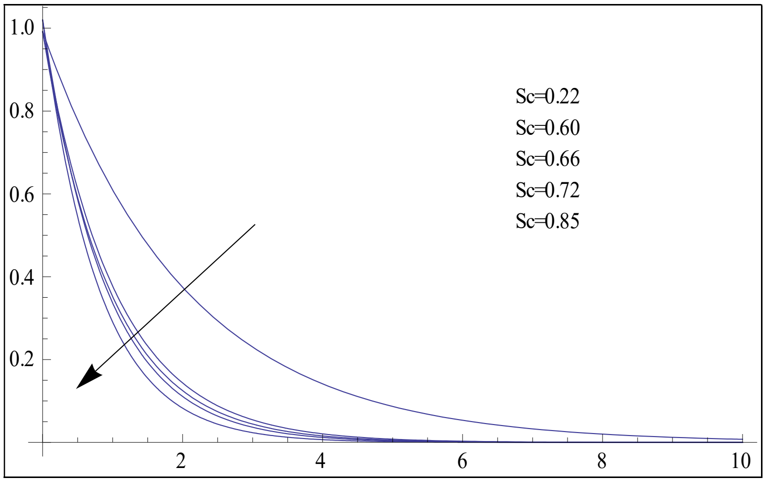
Temperature Distribution for various value of Gr



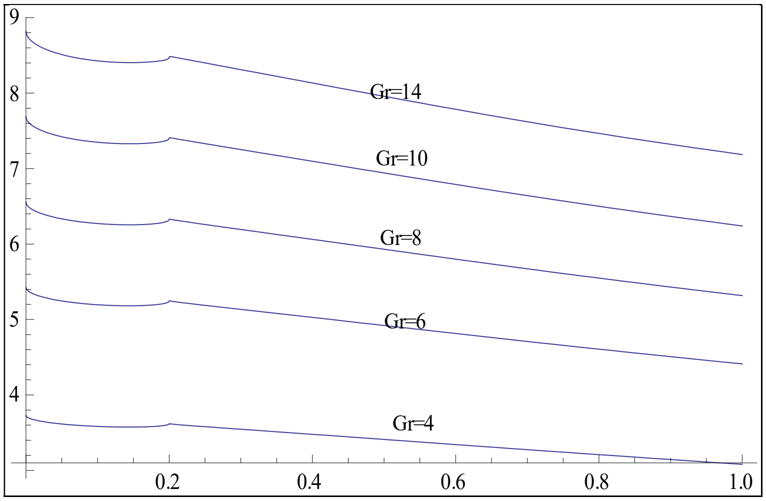
Temperature Distribution for various value of Pr



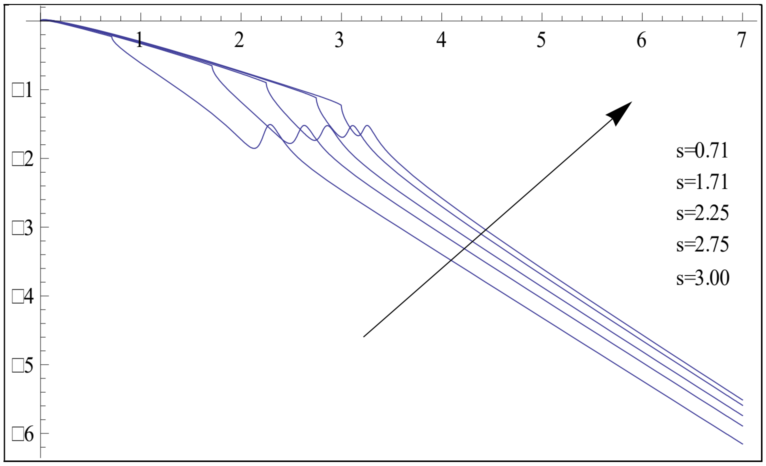
Concentration Distribution for various values of K



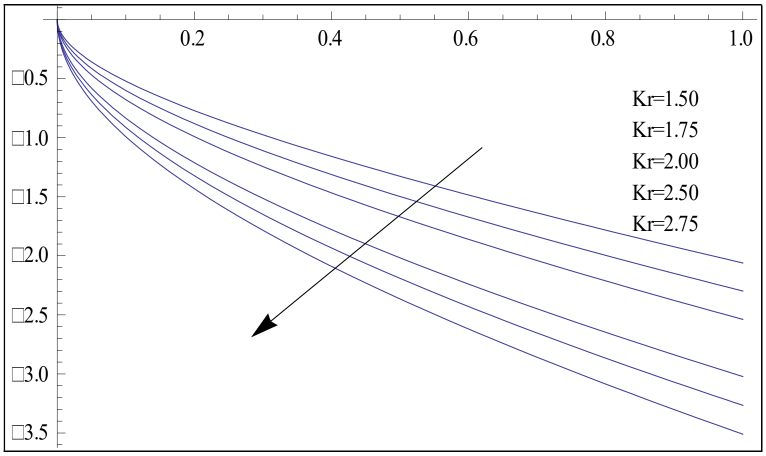
Concentration Distribution for various values of Sc



Skin Friction for various values of Gr



Heat Flux for various values of Heat Source (s)



Mass flux for various values of Kr

Conclusion:

- Grashof Number and Permeability parameters accelerates the transient velocity of the fluid flow.
- Other parameters like Hall current, Grashof number of mass transfer are also enhance the velocity of the fluid flow.
- Increase of Viscous dissipation retards the temperature of the fluid flow.
- Chemical reaction retards the concentration of the fluid flow.
- Skin friction effects are increased while increasing of Grashof number.
- Heat transfer at the wall increases while increase of heat source.

Reference:

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