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EFFECT OF CHEMICAL REACTION ON VELOCITY OF MHD FLOW OF A VISCOUS CONDUCTING FLUID IN A POROUS CHANNEL

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Abstract: This paper presents an analytical method of solution to Hall effect on hydromagnetic free convection flow in a vertical porous channel with mass transfer and chemical reaction. The exact solutions of equations of motion, heat transfer and mass transfer are obtained by complex variable technique. The expressions for primary velocity and secondary velocity are also derived. The variations in fluid velocity are displayed graphically. Primary velocity rises with increase in the Schmidt number (S_c),permeability parameter(K_1^*) and modified Grashof number for mass diffusion (G_c) ,but remains unaffected with increase in reaction rate constant($\mathbf{R}^*$).The secondary velocity rises with increase in Reynolds number(**R**) and mass diffusion Grashof number but falls with increase in Reaction rate constant and permeability parameter

Keywords: MHD Free convection, Reynold number, Grashof number, Prandtl number, Schmidt number.

1. Introduction

The study of the effect of chemical reaction on velocity of an electrically conducting fluid through a porous channel have drawn considerable attentions of several researchers owing to its importance in various scientific and technological applications such as high temperature casting and levitation, thermo-nuclear fusion, furnace design, glass production, solar power technology etc. When heat and mass transfer occurs simultaneously in a moving fluid the relation between the fluxes and the driving potentials are of intricate nature. It has been found that an energy flux can be generated not only by temperature gradient but also by composition gradients [8,12,17,18,19]. In a fluid saturated porous medium MHD natural convection flow of an electrically conducting fluid is also exploited in crystal formation successfully [3].

Many researchers across the globe have been investigating in this field of free convection flow owing to its above mentioned wide applications. Sacheti et al. [12] studied hydromagnetic free convection flow of a viscous incompressible fluid. Soundalgekar [19], Ramankumari and Reddy [10] discussed free convective flow with mass transfer in the presence of magnetic field. Sattar and Alam [14], Datta and Majumdar [1] analysed the effect of Hall current on a steady hydromagnetic free convective flow. Hydromagnetic natural convection flow with heat and mass transfer of a chemically reacting and heat absorbing fluid past an accelerated moving vertical plate with ramped temperature and ramped surface concentration through a porous medium was investigated by Seth et al. [15], Rashidi et al. [11] analyzed free convective heat and mass transfer for MHD fluid flow over a permeable vertical stretching sheet in the presence of the radiation and buoyancy effects. Dufour and Soret effects on steady MHD convective flow of a fluid in a porous medium with temperature dependent viscosity were investigated by Omowaye et al. [7]. Ibrahim and Suneetha [6] studied heat source and chemical effects on MHD convection flow embedded in a porous medium with Soret, viscous and Joules dissipation. Unsteady MHD free convection flow with Hall effect of a radiating and heat absorbing fluid past a moving vertical plate with variable ramped temperature was investigated by Seth et al. [16]. Durga Prasad et al. [2] discussed the heat and mass transfer analysis for the MHD flow of nanofluid with radiation absorption. Effects of Hall current, rotation and Soret effects on MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium was analyzed by Sarma and Pandit [13]. El-Aziz and Yahya studied heat and mass transfer of unsteady hydromagnetic free convection flow through porous medium past a vertical plate with uniform surface heat flux. Recently, Garg and Deepti [4] considered Hall effect on primary velocity only, without considering the effect on secondary velocity. Similarly, Garg and Shipra [5] have given the exact solution flow near a moving vertical plate in the presence of heat source/sink but the effect of porosity on velocity of flow and effect of chemical reaction on concentration were not being analyzed. Rajput and Kumar [9] studied the effects of radiation and chemical reaction on MHD flow in the variable state but not after the steady state. Zigta [20] analyzed the effects of chemical reaction and viscous dissipation on flow velocity in presence of oscillating plates but not in presence of fixed plates with porosity [20].

In the above mentioned investigations, researchers have not considered mass transfer including chemical reaction and Hall effects simultaneously. However, process involving both heat and mass transfer occurs not only due to the temperature differences but also due to concentration differences or the combination of the two. In many physical situations, the temperature differences as well as concentration differences or the combination of the two plays important role. The objective of the present study is therefore, to consider the simultaneous effect of chemical reaction and the Hall current on mass transfer in a MHD free convective flow in a porous vertical channel.

2. Mathematical Formulation and its Solution

Consider the free convection flow of an electrically conducting fluid in a vertical porous channel where the plates are separated by a distance h from each other. We consider X-axis parallel to the plates and Y-axis normal to it. There is a uniform suction V_0 on the wall $y = 0$ and a uniform injection V_0 on the wall $y = h$. A uniform magnetic field H_0 acts normally to the channel neglecting the induced magnetic field, we can write the magnetic field as:

$$\vec{H} = (0, H_y, 0) \tag{1}$$

This assumption is justifiable only when the magnetic Reynold number is very small (Cowling [1957]).

Using Maxwell's equation div $\vec{H} = 0$

We have $H_y = H_0$ (2)

From the equation of conservation of electric charge we have

$$\text{div } \vec{J} = 0 \tag{3}$$

Neglecting polarization effect we take

$$\vec{E} = 0 \tag{4}$$

The generalized Ohm's law taking Hall current into account is given by

$$\vec{J} + \frac{\omega_e \tau_e}{B_0}\left(\vec{J} \times \vec{B}\right) = \sigma\left(\vec{E} + \vec{q} \times \vec{B}\right) \tag{5}$$

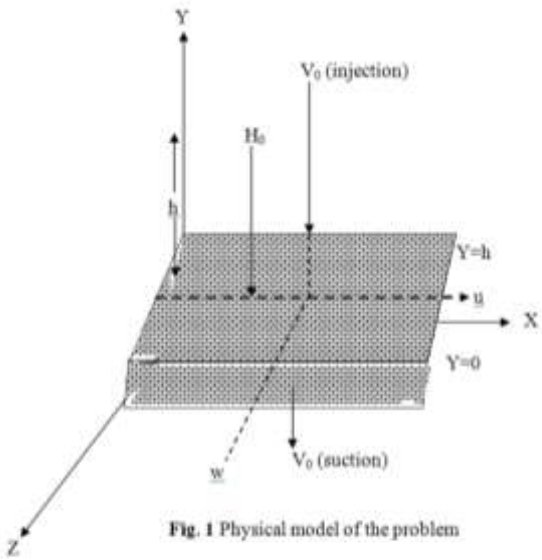

Fig. 1 Physical model of the problem

Equation of continuity div $\vec{q} = 0$ gives $v\dfrac{\partial v}{\partial y} = 0$, $-v_0$

Hence $v = \text{const} = -v_0$, $v_0 > 0.$ (6)

Now using equation (3) and equation (6) we get

$$\vec{J} = (J_x, J_z)\ 0\ ,$$
$$\vec{q} = (u, -\mathrm{v}_0, w) \quad (7)$$

Using equation (7) in equation (5) we have

$$J_x = \frac{\sigma B_0^2}{1+m^2}(mu - w)$$

$$J_z = \frac{\sigma B_0^2}{1+m^2}(u + mw) \quad (8)$$

For a fully developed steady free convection flow, the equations of motion, heat transfer and mass transfer may now be written as

$$-v_0 \frac{du}{dy} = \nu \frac{d^2u}{dy^2} - \frac{\sigma B_0^2 (u + mw)}{\rho(1+m^2)} + g\beta(T - T_2) + g\beta^*(C' - C_2) - \frac{\nu}{k'}u \quad (9)$$

$$-v_0 \frac{dw}{dy} = \nu \frac{d^2w}{dy^2} + \frac{\sigma B_0^2 (mu - w)}{\rho(1+m^2)} - \frac{\nu}{k'}w \quad (10)$$

$$-v_0 \frac{dT}{dy} = \frac{k}{\rho C_p}\frac{d^2T}{dy^2} \quad (11)$$

$$-v_0 \frac{dc'}{dy} = D\frac{d^2c'}{dy^2} + \lambda^* \quad (12)$$

where $\lambda^* = -k^*(c')^n$

For first order reaction $n = 1$

So $v_0 \dfrac{dc'}{dy} = D\dfrac{d^2c'}{dy^2} - k^*(C' - C_2)$ (13)

The boundary condition are

$$\left.\begin{array}{l} u=0\ ,\ w=0\ ,\ T=T_1\ ,\ C'=C_1 \text{ at } y=0 \\ u=0\ ,\ w=0\ ,\ T=T_2\ ,C'=C_2 \text{ at } y=h \end{array}\right\} \quad (14)$$

On introducing the following dimensionless variables and dropping the dashes

$$R^* = \frac{k^* h}{v_0} \eta = \frac{y}{h}\ ,\ u' = \frac{u}{v_0}\ ,\ w' = \frac{w}{v_0}\ ,\ \theta = \frac{T-T_2}{T_1-T_2}\ ,\ C = \frac{C'-C_2}{C_1-C_2}\ ,\ k_1^* = \frac{k' v_0^2}{\nu^2} \quad (15)$$

The equation (9) – (13) can be written as

$$\frac{1}{R}\frac{d^2u}{d\eta^2} + \frac{du}{d\eta} - \left(\frac{RM}{1+m^2}\right)(u+mw) + RG\theta + RG_cC - \frac{R}{K_1^*}u = 0 \quad (16)$$

$$\frac{1}{R}\frac{d^2w}{d\eta^2} + \frac{dw}{d\eta} + \frac{RM}{(1+m^2)}(mu-w) - \frac{R}{K_1^*}w = 0 \quad (17)$$

$$\frac{1}{RP_r}\left(\frac{d^2\theta}{d\eta^2}\right) + \frac{d\theta}{d\eta} = 0 \quad (18)$$

$$\frac{d^2C}{d\eta^2} + RS_c\frac{dc}{d\eta} - RS_cR^*C = 0 \quad (19)$$

where $R = \frac{v_0 h}{\nu}$ and $S_c = \nu / D$ (20)

Modified boundary conditions are

$$\left.\begin{array}{l} u=w=0\ ,\ \theta=1\ ,\ C=1 \text{ at } \eta=0 \\ u=w=0\ ,\ \theta=0\ ,C=0 \quad \text{at}\ \eta=h \end{array}\right\} \quad (21)$$

Solutions of equation 18 without viscous dissipation will be as followed,

Let soln. be $\theta = Ae^{\alpha\eta}$

The general solution of the equation

$$\theta = A_1 + A_2 e^{-RP_r\eta} \quad (22)$$

Putting the boundary condition, we have the solution

$$A_2 = \frac{1}{1-e^{-RP_r}}$$

$$\Rightarrow A_1 = 1 - \frac{1}{1-e^{-RP_r}} = \frac{-e^{-RP_r}}{1-e^{-RP_r}}$$

Hence,

$$\Rightarrow \theta = \frac{e^{-RP_r\eta} - e^{-RP_r}}{1-e^{-RP_r}} = \frac{e^{+RP_r(1-\eta)} - 1}{e^{RP_r} - 1} = \frac{1-e^{RP_r(1-\eta)}}{1-e^{RP_r}} \tag{23}$$

Similarly solutions to equation 19 is given as follows,

Let $C = Be^{\gamma\eta}$

So the general solution is

$C = B_1 e^{\gamma_1\eta} + B_2 e^{\gamma_2\eta}$

Applying the modified boundary conditions at $\eta = 0$, $C = 1$ we have

$B_1 + B_2 = 1$ and at $\eta = 1$, $C = 0$

$\Rightarrow B_1 e^{\gamma_1} + B_2 e^{\gamma_2} = 0$

Eliminating B_2, the solution is

$$\Rightarrow C = \frac{\left[1 - e^{(\gamma_2-\gamma_1)}\, e^{(\gamma_1-\gamma_2)\eta}\right] e^{\gamma_2\eta}}{(1-e^{\gamma_2-\gamma_1})} \tag{24}$$

Now adding *i* times of equation 17 to equation 16 we have

$$\frac{d^2}{d\eta^2}(u+iw) + R\frac{d}{d\eta}(u+iw) - \frac{R^2M}{1+m^2}(u+mw-imu+iw)$$

$$-\frac{R^2}{K_1^*}(u+iw) = -R^2(G\theta + G_cC) \tag{25}$$

Let $\psi = u + iw$

$$\Rightarrow \frac{d^2\psi}{d\eta^2} + R\frac{d\psi}{d\eta} - \left\{\frac{M(1-im)}{1+m^2} + \frac{1}{K_1^*}\right\} R^2\psi = -R^2\left(G\theta + G_cC\right) \tag{26}$$

Let $\frac{d^2\psi}{d\eta^2} + R\frac{d\psi}{d\eta} - E_0\psi = -\left\{E_1\theta + E_2C\right\}$ (27)

where $E_0 = \left\{ \frac{M(1-im)}{1+m^2} + \frac{1}{K_1^*} \right\} R^2$ (28)

$E_1 = R^2 G$; $E_2 = R^2 G_c$

The auxiliary equation is

$$m^2 + Rm - E_0 = 0$$

Let $m_1 = \frac{-R + \sqrt{R^2 + 4E_0}}{2}$ and (29)

$$m_2 = \frac{-R - \sqrt{R^2 + 4E_0}}{2} \quad (30)$$

So, the complementary function for $\psi = C_1 e^{m_1 \eta} + C_2 e^{m_2 \eta}$ and the particular integral

$$\text{PI} = \frac{-(E_1\theta + E_2 C)}{D^2 + RD - E_0} \quad (31)$$

Let $\theta = E_3 - E_3\, e^{RP_r(1-\eta)}$

and $C = E_4 e^{\gamma_2 \eta} - E_4 E_5 e^{\gamma_1 \eta}$

where $E_3 = \frac{1}{1 - e^{RP_r}}$, $E_4 = \frac{1}{1 - e^{(\gamma_2 - \gamma_1)}}$, $E_5 = e^{(\gamma_2 - \gamma_1)}$ (32)

So

$$\text{PI} = E_1 E_3 \left\{ \frac{1}{E_0} + \frac{e^{RP_r(1-\eta)}}{(R^2 P_r^2 - R^2 P_r - E_0)} \right\} + E_2 E_4 \left\{ \frac{E_5 e^{\gamma_1 \eta}}{\gamma_1^2 + R\gamma_1 - E_0} - \frac{e^{\gamma_2 \eta}}{\gamma_2^2 + R\gamma_2 - E_0} \right\} \quad (33)$$

Hence the solution of equation 27 is

$$\psi = C.F. + P.I. = C_1 e^{m_1 \eta} + C_2 e^{m_2 \eta} + E_6 + E_7 \quad (34)$$

where $E_6 = E_1 E_3 \left\{ \frac{1}{E_0} + \frac{e^{RP_r(1-\eta)}}{(R^2 P_r^2 - R^2 P_r - E_0)} \right\}$ (35)

$$E_7 = E_2 E_4 \left\{ \frac{E_5 e^{\gamma_1 \eta}}{(\gamma_1^2 + R\gamma_1 - E_0)} - \frac{e^{\gamma_2 \eta}}{(\gamma_2^2 + R\gamma_2 - E_0)} \right\} \quad (36)$$

$\psi = u + iw$

at $\eta=0$, $u = w = 0 \Rightarrow \psi = 0$, $\theta = 1$, $C = 1$

at $\eta=1$, $u = w = 0 \Rightarrow \psi = 0$, $C = 0$, $\theta = 0$ (37)

$$\Rightarrow C_1 = -\frac{(Y + Xe^{m_2})}{e^{m_1} - e^{m_2}} \quad C_2 = \frac{Xe^{m_1} + Y}{e^{m_1} - e^{m_2}} \tag{38}$$

So, $$\psi = \frac{-(Y + Xe^{m_2})}{e^{m_1} - e^{m_2}} e^{m_1\eta} + \frac{Y + Xe^{m_1}}{e^{m_1} - e^{m_2}} e^{m_2\eta} + E_6 + E_7 \tag{39}$$

where

$$X = \frac{E_2E_4}{\gamma_2^2 + R\gamma_2 - E_0} - \frac{E_1E_3}{E_0} - \frac{e^{RP_r}E_1E_3}{R^2P_r^2 - R^2P_r - E_0} - \frac{E_2E_4E_5}{\gamma_1^2 + R\gamma_1 - E_0} \tag{40}$$

$$Y = \frac{E_1E_3}{E_0} + \frac{E_1E_3}{R^2P_r^2 - R^2P_r - E_0} + \frac{E_2E_4E_5e^{\gamma_1}}{\gamma_1^2 + R\gamma_1 - E_0} - \frac{E_2E_4e^{\gamma_2}}{\gamma_2^2 + R\gamma_2 - E_0}$$

$$\gamma_1 = \frac{-RS_c + \sqrt{R^2S_c^2 + 4RR^*S_c}}{2} \quad \gamma_2 = \frac{-RS_c - \sqrt{R^2S_c^2 + 4RR^*S_c}}{2} \tag{41}$$

$$G = \frac{g\beta\nu(T_1 - T_2)}{V_0^3} \ , \ G_c = \frac{g\beta^*\nu(C_1 - C_2)}{V_0^3} \quad P_r = \frac{\rho C_p \nu}{K} \tag{42}$$

Separating the real and imaginary parts of ψ which is the solution of equation 27, the expressions for primary and secondary velocity are obtained.

4. Results and Discussion

Behavior of MHD free convection viscous flow in a vertical porous channel with Hall current effect, mass transport and chemical reaction has been analysed on the basis of graphs and tables pertaining to various fluid parameters.

Figure 2 exhibits the primary velocity profiles for different values of R, G, G_c, R^* and K_1^*, keeping the other parameters constant. It is observed that the primary velocity decreases with increase in Reynolds number. Flow reversal is marked here. Primary velocity remains unaffected with the change in the value of reaction rate parameter. The primary velocity increases with increase in permeability parameter. If the thermal Grashof number (*G*) becomes more negative, then the primary velocity falls. The primary velocity acquires positive values when the thermal Grashof number (*G*) turns from negative to positive (curves V and VI). With increase in modified Grashof number (G_c) for mass diffusion, the primary velocity increases. (Curves VI and VII).

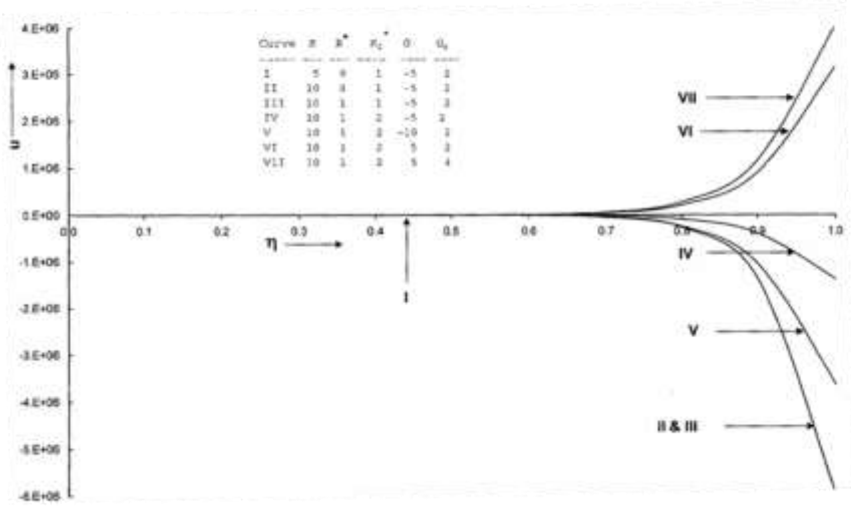

Fig. 2 Primary velocity profile for different values of R, G_D R^*, K_1^* when $P_r = 0.025$, $S_c = 0.24$, $m = 0.5$, $M = 4$

Figure 3 shows the primary velocity profiles for different values of m, M, P_r and S_c, keeping other parameters fixed. With increase in Hall parameter the primary velocity decreases. (Curves I and II). With increase in magnetic parameter (*M*) there is significant amount of fall in the primary velocity (curves II and III). There is a small decrease in primary velocity with increase in the Prandtl number (curves III and IV). From curves IV and V it is clear that primary velocity rises by a very small amount with increase in the Schmidt number (S_c).

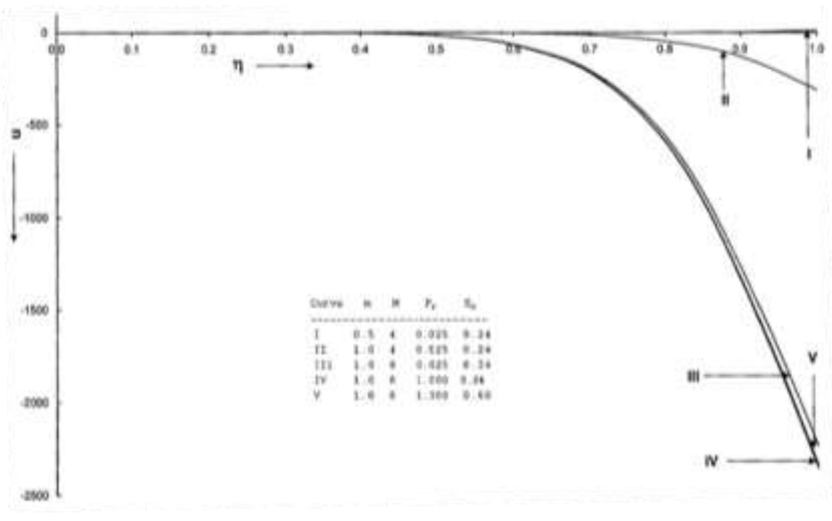

Fig. 3 Primary velocity profile for different values of m, M, P_r, S_c when $R = 5$, $R^* = 1.0$, , $G = -5$, $G_c = 2$

The behaviour of secondary velocity for different values of R, G, G_c, R^* and K_1^* is depicted in Figure 4. From curves I and II, it is clear that increase in Reynolds number increases the secondary velocity.

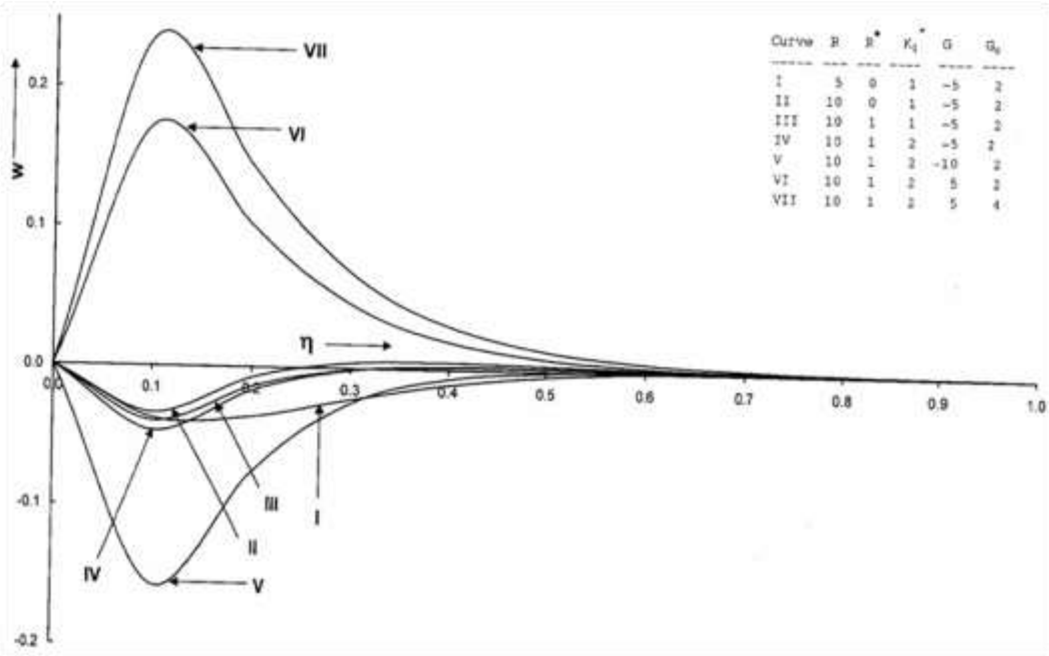

Fig. 4 Secondary velocity profile for different values of R, G, G_c, R^*, when $P_r = 1.0, S_c = 0.6, m = 0.5, M = 4$

With increase in reaction rate constant the secondary velocity decreases which is evident from curves II and III. From curves III and IV, it is cleared that increase in permeability parameter reduces the secondary velocity. There is significant amount of fall in secondary velocity with increase in the value of thermal Grashof number (*G*). When thermal Grashof number takes positive values, secondary velocity becomes positive and hence flow reversal is marked. Secondary velocity rises by significant amount with increase in mass diffusion Grashof number as evident from curves VI and VII. As the distances from the plate increase the magnitude of secondary velocity increases, attains peak value and then falls to zero.

Figure 5 explains the nature of secondary velocity profiles for various values of m, M, P_r and S_c, keeping other parameters fixed.

As distance from the plate increases the secondary velocity decreases, attains minimum value and then increases turning from negative to positive value for $0.3 < \eta < 0.4$. Therefore flow reversal is observed. Profiles I and II reveals that increase in Hall parameter decreases the secondary velocity. There is further reduction in magnitude of secondary velocity with increase in the value of Hartmann number (curves II and III).

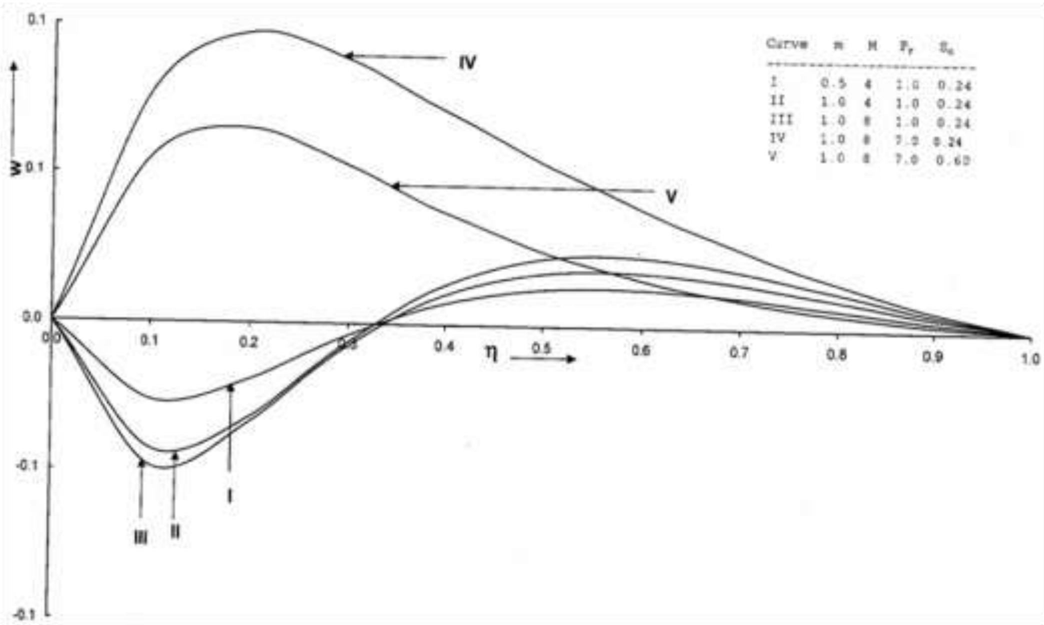

Fig. 5 Secondary velocity profile for different values of m, M, P_r, S_c when $R = 5$, $R^* = 1.0$, $G = -5$, $G_c = 2$

There is a flow reversal for secondary velocity with increase in Prandtl number (Profiles III and IV). It is marked that the secondary velocity decreases with increase in the value of Schmidt number.

4. Conclusions

Hall effect on hydromagnetic free convection flow in a vertical porous channel with mass transfer and chemical reaction has been solved by complex variable technique. The expressions for primary velocity, secondary velocity, temperature, concentration, skin friction are also derived. The variations in fluid velocity, temperature and concentration are displayed graphically whereas numerical values of skin frictions are presented in tabular form for various values of flow parameters. The conclusions from the above analysis are summarized below:

(i) The primary velocity increases with increase in permeability parameter.

(ii) With increase in Hall parameter the primary velocity decreases.

(iii) Increase in Hall parameter decreases the secondary velocity.

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References

[1] Datta, N. and Mazumder, B.S. (1974). MHD source flow between two parallel porous disks one of which is rotating, Ind J Phys, **48**, 1105-1116.

[2] Durga Prasad, P., Kiran Kumar, R.V.M.S.S. and Varma, S.V.K. (2018). Heat and mass transfer analysis for the MHD flow of nanofluid with radiation absorption, Ain Shams Eng J, **4**,801-813.

[3] El-Aziz, Md. A. and Yahya, A.S. (2016). Perturbation analysis of unsteady boundary layer slip flow and heat transfer of Casson fluid past a vertical permeable plate with Hall current, Appl Math Comput, **307**, 146-164.

[4] Garg, B.P. and Deepti. (2019). Chemical reaction effects on radiative MHD mixed convection flow from a vertical flat plate with ohmic heating and viscous dissipation in slip flow regime, Journal of Rajasthan Academy of Physical Sciences, **18**, 65-82.

[5] Garg, B.P. and Shipra. (2019). Exact solution of MHD free convective and mass transfer flow near a moving vertical plate in the presence of heat source/sink, Journal of Rajasthan Academy of Physical Sciences, **18**, 25-44.

[6] Ibrahim, S.M. and Suneetha, K. (2016). Heat source and chemical effects on MHD convection flow embedded in a porous medium with Soret, viscous and Joules dissipation, Ain Shams Eng J, **7**, 811-818.

[7] Omowaye, A.J., Fagbade, A.I. and Ajayi, A.O. (2015). Dufour and soret effects on steady MHD convective flow of a fluid in a porous medium with temperature dependent viscosity: Homotopy analysis approach, J Nigerian Math Soc, **34**, 343-360.

[8] Pattanaik, J.R., Dash, G.C. and Singh, S. (2017). Radiation and mass transfer effects on MHD flow through porous medium past an exponentially accelerated inclined plate with variable temperature, Ain Shams Eng J, **8**, 67-75.

[9] Rajput, U.S. and Kumar, G. (2019). Effects of radiation and chemical reaction on MHD flow past a vertical plate with variable temperature and mass diffusion, Journal of Naval Architecture and Marine Engineering, **16**, 99-108.

[10] Ramankumari, C.V. and Reddy, N.B. (1994). Mass transfer effect on unsteady MHD free convection flow past a vertical porous plate with variable suction, J Energy Heat and Mass Transfer, **16**, 279-287.

[11] Rashidi, M. M., Rostami, B., Freidoonimehr, N and Abbasbandy, S. (2014). Free convective heat and mass transfer for MHD fluid flow over a permeable vertical stretching sheet in the presence of the radiation and buoyancy effects, Ain Shams Eng J, **5**, 901–912.

[12] Sacheti, N.C., Chandran, P. and Singh, A.K. (1994). An exact solution for unsteady magnetohydrodynamic free convection flow with constant heat flux, Int Commun Heat Mass, **21**, 131-142.

[13] Sarma, D. and Pandit, K.K. (2018). Effects of Hall current, rotation and Soret effects on MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium, Ain Shams Eng J, **4**, 631-646.

[14] Sattar, Md. A. and Alam, Md. M. (1995). MHD free convective heat and mass transfer flow with Hall current and constant heat flux through a porous medium, IJPAM, **26**, 157-167.

[15] Seth, G.S., Hussain, S.M. and Sarkar, S.(015). Hydromagnetic natural convection flow with heat and mass transfer of a chemically reacting and heat absorbing fluid past an accelerated moving vertical plate with ramped temperature and ramped surface concentration through a porous medium, J Egypt Math Soc, **23**, 197–207.

[16] Seth, G.S., Kumbhakar, B. and Sharma, R. (2016). Unsteady MHD free convection flow with Hall effect of a radiating and heat absorbing fluid past a moving vertical plate with variable ramped temperature, J Egyptian Math Soc, **24**, 471-478.

[17] Seth, G.S., Sarkar, S. and Hussain, S.M. (2014). Effects of Hall current, radiation and rotation on natural convection heat and mass transfer flow past a moving vertical plate, Ain Shams Eng J, **5**, 489–503.

[18] Seth, G.S., Sarkar, S. and Hussain, S.M. (2014). Effects of Hall current, radiation and rotation on natural convection heat and mass transfer flow past a moving vertical plate, Ain Shams Eng J, **5**. 489–503.

[19] Soundalgekar, V.M. (1979). Effects of Mass Transfer and Free-Convection Currents on the Flow Past an Impulsively Started Vertical Plate, J. Appl. Mech, **46**, 757-764.

[20] Zigta, Binyam. (2019).Thermal Radiation, Chemical Reaction and Viscous Dissipation Effects on Unsteady MHD Flow of Viscoelastic Fluid Embedded in a Porous Medium, Budapest International Research in Exact Sciences (BirEx) Journal, **1**, 35-57.