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MHD Boundary Layer Flow of a Rotating Fluid Past A Vertical Porous Plate

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Abstract

An unsteady magnetohydrodynamci (MHD) convective flow of a viscous incompressible and electrically conducting fluid through porous medium bounded by an infinite vertical porous plate, in a rotating medium is presented. Analytical solutions for the distributions of velocity, temperature and concentration fields are obtained by using a regular perturbation technique. The effects of pertinent parameters on these distributions are studied numerically with the help of graphs. With the aid of the above flow quantities the expressions for skin friction, Nusselt number and Sherwood number are derived.

Keywords: MHD, heat and mass transfer, free convection, chemical reaction, porous medium, rotating system, thermal diffusion and perturbation method.

1. INTRODUCTION

The concept of fluid flow and mass transfer past a porous medium in rotating environment plays very important role in the applications of geophysics, petrochemical engineering, meteorology, oceanography and aeronautics. The stimulus for scientific research on rotating fluid system is basically originated from geophysical and fluid engineering applications. Rotation flow theory is utilized in determining the viscosity of the fluid, in the construction of the turbine and other centrifugal machines. The study of magnetic field effects on free convection Newtonian fluid flow is also important in the study of electrolytes, liquid metals and ionized gasses. Reddy et al. [1] addressed heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink. Raju et al [2] discussed an unsteady MHD radiative, chemically reactive and rotating fluid flow past an impulsively started vertical plate with variable temperature and mass diffusion. Philip et al. [3] investigated on MHD Rotating heat and mass transfer free convective flow past an exponentially accelerated isothermal plate with fluctuating mass diffusion. Harikrishna et al. [4] focused on Hall current effects on unsteady MHD flow in a rotating parallel plate channel bounded by porous bed on the lower half Darcy lap wood model. Reddy et al. [5] commented on natural convection boundary layer flow of a double diffusive and rotating fluid past a vertical porous plate. Again Reddy et al. [6] discussed thermal diffusion and rotational effects on magneto hydrodynamic mixed convection flow of heat absorbing/generating visco-elastic fluid through a porous channel.

The study of heat and mass transfer with the effect of chemical reaction is one of the greatest practical importances to engineers and scientists because of its occurrence in many branches of science and engineering. Reddy et el. [7] discussed chemical reaction and radiation effects on unsteady MHD free convection flow near a moving vertical plate. Reddy et al [8] tested the effect of slip condition, radiation and chemical reaction on unsteady MHD periodic flow of a viscous fluid through saturated porous medium in a planar channel. Reddy et al. [9] also addressed chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux. Seshaiah et al. [10] tested the effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source. Rao et al. [11] addressed an unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption, radiation, chemical reaction and Soret effects. Rao et al. [12] also addressed an unsteady MHD mixed convection of a viscous double diffusive fluid over a vertical plate in porous medium with chemical reaction, thermal radiation and joule heating. Chamkha et al. [13] investigated on unsteady MHD free convection flow past an exponentially accelerated vertical plate with mass transfer, chemical reaction and thermal radiation. Raju et al. [14] studied analytically MHD free convictive, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction. Reddy et al. [15] concentrated on an unsteady MHD free convection flow of a Kuvshinski fluid past a vertical porous plate in the presence of chemical reaction and heat source/sink. Umamaheswar et al. [16] addressed MHD convective heat and mass transfer flow of a Newtonian fluid past a vertical porous plate with chemical reaction, radiation absorption and thermal diffusion. Umamaheswar et al. [17] discussed the effects of Time dependent variable temperature and concentration boundary layer on MHD free convection flow past a vertical porous plate in the presence of thermal radiation and chemical reaction. Raju et al. [18] examined Soret effect due to mixed convection on unsteady magnetohydrodynamic flow past a semi-infinite vertical permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction. Reddy et al. [19] examined thermal diffusion effect on MHD heat and mass transfer flow past a semi-infinite moving vertical porous plate with heat generation and chemical reaction. Reddy [20] et al. [20] studied radiation absorption and chemical reaction effects on MHD flow of heat generating Casson fluid past oscillating vertical porous plate. Reddy et al. [21] investigated on an unsteady MHD free convection flow of a visco-elastic fluid past a vertical porous plate in the presence of thermal radiation, radiation absorption, heat generation/absorption and chemical reaction. Recently Reddy et al. [22] addressed chemical reaction and thermal radiation effects on MHD micropolar fluid past a stretching sheet embedded in a non-Darcian porous medium.

Several researchers have analyzed incomprehensible variety of flows connected to MHD free convective flow through porous media of a rotating/ non-rotating fluid with heat and mass transfer. Reddy et al. [23] studied the effects of unsteady free convective MHD non Newtonian flow through a porous medium bounded by an infinite inclined porous plate. Raju and Varma [24] discussed an unsteady MHD free convection oscillatory Couette flow through a porous medium with periodic wall temperature. Raju et al. [25] discussed MHD thermal diffusion natural convection flow between heated inclined plates in porous medium. Reddy et al. [26] considered MHD free convection heat and mass transfer flow through a porous medium bounded by a vertical surface in presence of Hall current. Reddy et al. [27] investigated heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink. Ravikumar et al. [28] analyzed heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source. Raju et al. [29] examined radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Raju et al. [30] looked at an unsteady MHD thermal diffusive, radiative and free convective flow past a vertical porous plate through non-homogeneous porous medium. Reddy et al. [31] concentrated on unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium. Rao et al. [32] discussed an unsteady MHD mixed convection of a viscous double diffusive fluid over a vertical plate in porous medium with chemical reaction, thermal radiation and joule heating. Raju et al. [33] addressed MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom wall in the presence of viscous dissipation and Joule's heating. Vidyasagar et al. [34] considered unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium. Reddy et al. [35] investigated magneto convective flow of a non-Newtonian fluid through non-homogeneous porous medium past a vertical porous plate with variable suction.

3.2 Formulation of problem

The unsteady free convective flow of a viscous incompressible fluid bounded by a vertical infinite porous surface in a rotating system in the presence of heat source and chemical reaction has been considered. The temperature and concentration on the surface vary with the time about a non-zero constant mean while the temperature as well as concentration of the free stream is taken to be constant. We also consider that the vertical infinite porous plate rotates with the constant angular velocity about an axis which is perpendicular to the vertical plane surface. The Cartesian co-ordinate system is chosen such that x^1, y^1 axes respectively, are in the vertical upward and perpendicular directions on the plane of the vertical porous surface $z^1 = 0$, while z^1-axis is normal to it. The interaction of Coriolis force with the free convection sets up a secondary flow in addition to primary flow and hence the flow becomes three dimensional. With the above frame of reference and assumptions, the physical variables are functions of y^1 and time t^1 only.

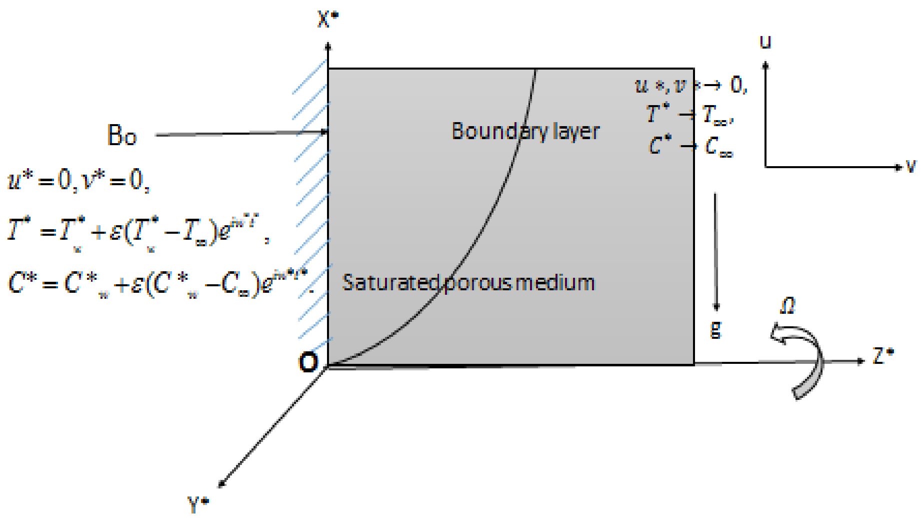

Figure: Flow geometry and coordinate system

Consequently the equations expressing the conservation of mass, momentum, energy and the equation of mass transfer were taken as considered by Reddy et al. [5]. Followed by Reddy et al. [5] and usual Boussinesq approximation, the set of non-dimensional governing equations are given below along with the corresponding boundary conditions:

$$\frac{\partial T}{\partial t} - e^{iwt}\frac{\partial T}{\partial z} = \frac{1}{\Pr}\frac{\partial^2 T}{\partial z^2} - HT \qquad (1)$$

$$\frac{\partial F}{\partial t} - e^{iwt}\frac{\partial F}{\partial z} + 2i\Omega F = G_r T + GcC + \frac{\partial^2 F}{\partial z^2} - (M^2 + \frac{1}{Kp})F \tag{2}$$

$$\frac{\partial C}{\partial t} - e^{iwt}\frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - KcC + S_0\frac{\partial^2 T}{\partial z^2} \tag{3}$$

Hence the boundary conditions are

$$at\ \mathrm{z} = 0: \quad \mathrm{F} = 0, T = e^{iwt}, C = e^{iwt},$$

$$at\ \ \mathrm{z} \to \infty: \ \mathrm{F} \to 0, T \to 0, C \to 0, \tag{4}$$

3. METHOD OF SOLUTION

In order to reduce the system of differential equations (1)-(3) under their boundary conditions (4), to a procedure of ordinary differential equations in non-dimensional form, in view of equation (8) and oscillating plate temperature, the solution form of equations (1), (2) and (3) are

$$F(z,t) = F_0(z)e^{iwt}, T(z,t) = T_0(z)e^{iwt}, C(z,t) = C_0(z)e^{iwt} \tag{5}$$

Which are valid for small amplitude of oscillation. Substituting equation (14) into the system of equations (11)-(13) and equating the harmonic and non-harmonic terms we get

$$\frac{d^2F_0}{dz^2} - (2i\Omega + M^2 + \frac{1}{Kp} + 2iR_0)F_0 = -GrT_0 - GcC_0 \tag{6}$$

$$\frac{d^2T_0}{dz^2} + \Pr\frac{dT_0}{dz} - \Pr(H + iw)T_0 = 0 \tag{7}$$

$$\frac{d^2C_0}{dz^2} + Sc\frac{dC_0}{dz} - (Kc + iw)ScC_0 = -ScS_0\frac{d^2C_0}{dz^2} \tag{8}$$

The boundary conditions (14) using (15) becomes

$$\begin{aligned} &at\ \mathrm{z} = 0: \ \mathrm{F}_0 = 0, T_0 = 1, C_0 = 1 \\ &at\ \mathrm{z} \to \infty: \mathrm{F}_0 \to 0, T_0 \to 0, C_0 \to 0 \end{aligned} \tag{9}$$

The solution of equation (17) using the boundary condition (19) is given by

$$T(z,t) = T_0(z)e^{iwt} = \ e^{-k_1 z}e^{iwt} \tag{9}$$

The solutions of equation (18) using the boundary conditions (19) is given by

$$C(z,t) = C_0(z)e^{iwt} = ((1+k_3)e^{-\sqrt{k_3}z} - k_3 e^{-\sqrt{k_1}z})e^{iwt} \tag{10}$$

$$F_0(z,t) = (-k_4 - k_5)e^{-\sqrt{k_3}z} + k_4 e^{-\sqrt{k_2}z} + k_5 e^{-\sqrt{k_1}z}$$

$$\text{F(z,t)=F}_0(z)e^{iwt} = (-k_4 - k_5)e^{-\sqrt{k_3}z} + k_4 e^{-\sqrt{k_2}z} + k_5 e^{-\sqrt{k_1}z})e^{iwt} \tag{11}$$

Equation (11) reveals that, the steady part of the velocity field has three-layer character, while the oscillating part of the fluid field exhibits a multilayer character. From equations (9) and (10), we observe that in case of considerably slow motion of the fluid the temperature profiles are mainly affected by Prandtl number(P_r) and source parameter (H) and concentration profiles are affected by Schmidt number(S_c) and chemical reaction parameter(K_c) of the fluid respectively. Considering $F_0 = u_0 + iv_0$; now, it is convenient to write the primary and secondary velocity fields, in terms of the fluctuating parts, separate the real part and imaginary part from equation (21) and taking only the real parts as they have physical significance. The velocity distribution of the flow field can be expressed in fluctuating parts as

$$F(z,t) = F_0(z)e^{iwt}$$

$$u + iv = (u_0 + iv_0)(\cos wt + i \sin wt)$$

$$u + iv = u_0 \cos wt - v_0 \sin wt + i(v_0 \cos wt + u_0 \sin wt)$$

Comparing both sides we get

$$u(z,t) = w_0 \left[u_0 \cos wt - v_0 \sin wt) \right]$$

$$v(z,t) = w_0 \left[u_0 \sin wt + v_0 \cos wt) \right] \tag{12}$$

Hence, the expression for the transient velocity profiles, for $wt = \dfrac{\pi}{2}$ is given by

$$u(z, \frac{\pi}{2w}) = -w_0 v_0, v(z, \frac{\pi}{2w}) = w_0 u_0 \tag{13}$$

SKIN FRICTION:

The skin friction at the plate z=0 in terms of amplitude and phase is given by

$$\frac{dF}{dz} = ((k_4 + k_5)\sqrt{k_3} - k_4\sqrt{k_2} - k_5\sqrt{k_1})e^{iwt} \tag{14}$$

The T_{xx} and T_{xy} components of the skin friction at the plate are given by

$$T_{xy} = \frac{\partial u_0}{\partial z}\bigg| z_0 \text{ and } T_{yz} = \frac{\partial v_0}{\partial z}\bigg| z_0$$

RATE OF HEAT TRANSFER:

The rate of heat transfer coefficient at the plate z=0 in terms of amplitude and phase is given by

$$\frac{dT}{\partial y}\bigg| y_0 = \frac{\partial T_0}{\partial z}\bigg| z_0 \; e^{iwt} = -\sqrt{k_1} e^{iwt} \tag{15}$$

RATE OF MASS TRANSFER:

The rate of mass transfer coefficient,,

$$\frac{dC}{\partial z}\bigg| z_0 = \frac{\partial C_0}{\partial z}\bigg| z_0 e^{iwt} = (-(1+k_3)\sqrt{k_2} + k_3\sqrt{k_1})e^{iwt} \tag{16}$$

4. RESULTS AND DISCUSSION

The given problem of unsteady MHD free convective flow with heat and mass transfer influence in a rotating porous medium in the presence of reaction parameter and heat source parameter has been considered. The solution for temperate field, concentration field and velocity field are obtained using the perturbation technique. Effects of different parameters on the flow quantities are presented in figures 2-7. The effect of magnetic parameter on velocity is presented in figure 2, from which we noticed that velocity decreases with an increase in the values of magnetic parameter. This is due to the application of the transverse magnetic field which slowdowns the fluid velocity. This well-known phenomenon is called Lorentz force that condenses the momentum boundary layer. This result is in good agreement with the results of Reddy et al. [5]. Similar effect is noticed from figure 3, in the presence of permeability of the porous medium.

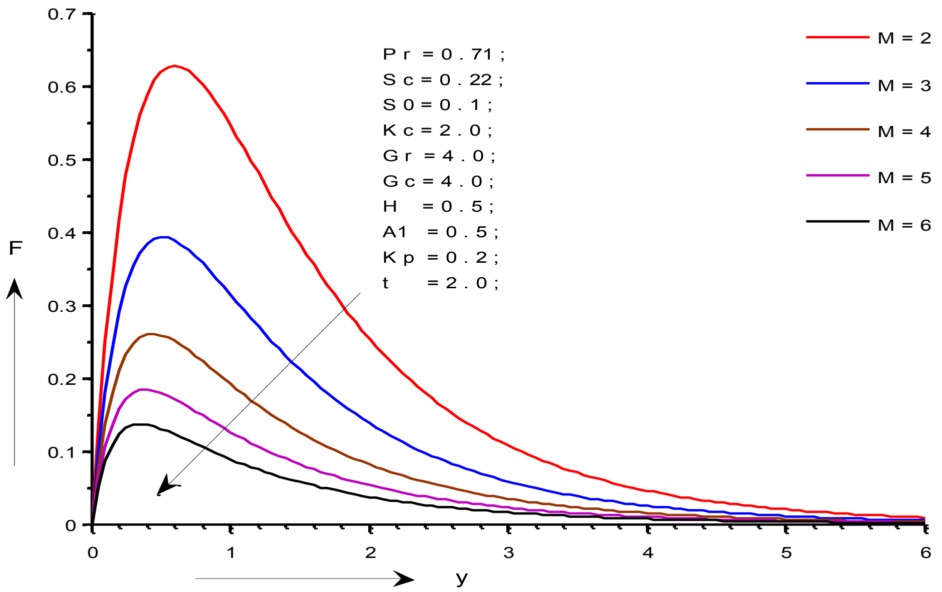

Fig.2 Effect of magnetic parameter (M) on velocity

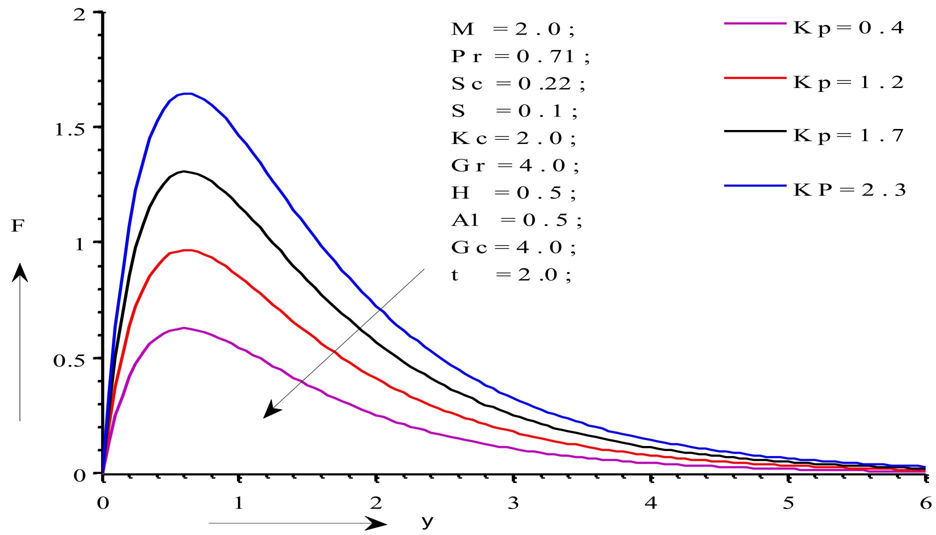

Fig.3. Effect of porosity parameter (Kp) on velocity

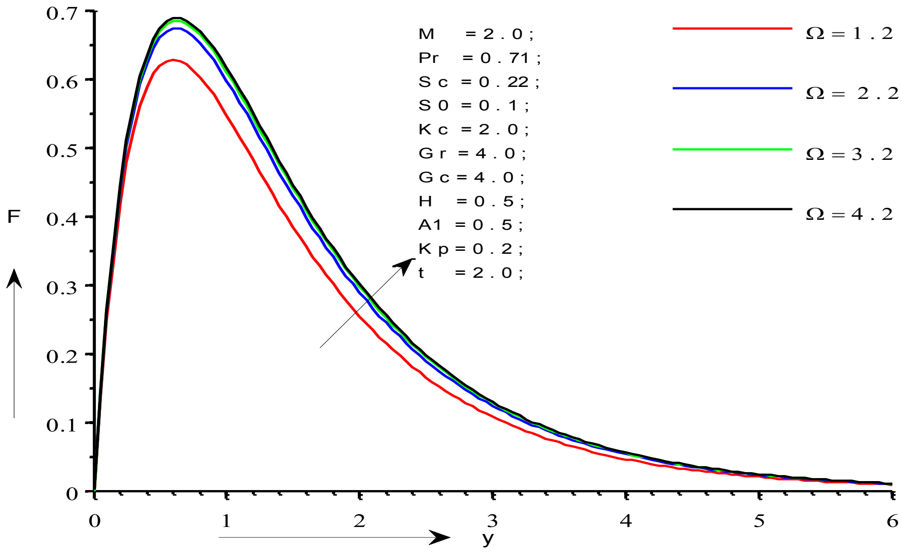

Fig.4. Effect of rotation parameter (Ω) on velocity

In Fig. 4, effect of rotation parameter on velocity is presented. From this figure it is noticed that the velocity profiles increase as the rotation parameter increases. From Fig.5 it is clear that the temperature decreases as the source parameter increases. From Fig.6 it is observed that the concentration reduces as the chemical reaction parameter increases. From Fig.7 it is noted that the concentration increases as the 'S_0' number increases.

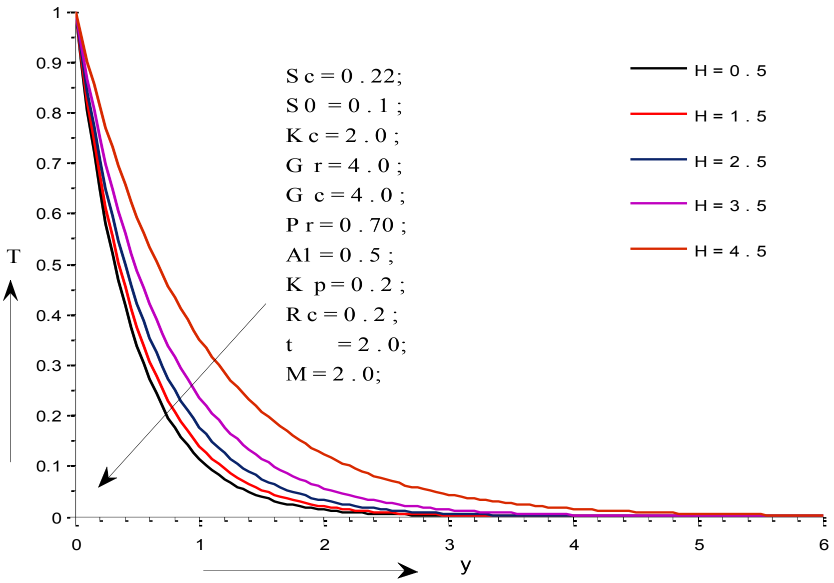

Fig.5. Effect of source Parameter (H) on temperature

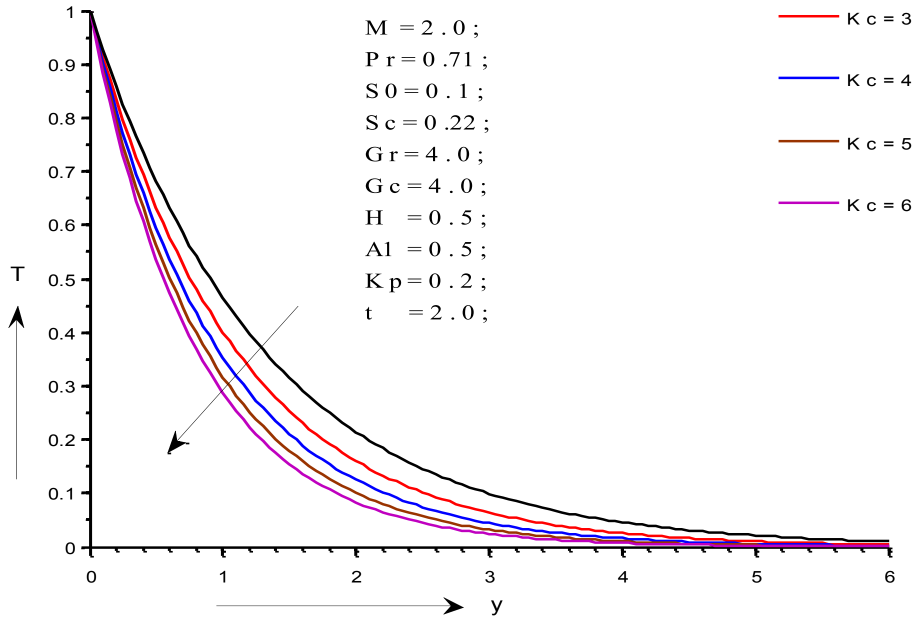

Fig.6. Effect of chemical reaction parameter (Kc) on concentration

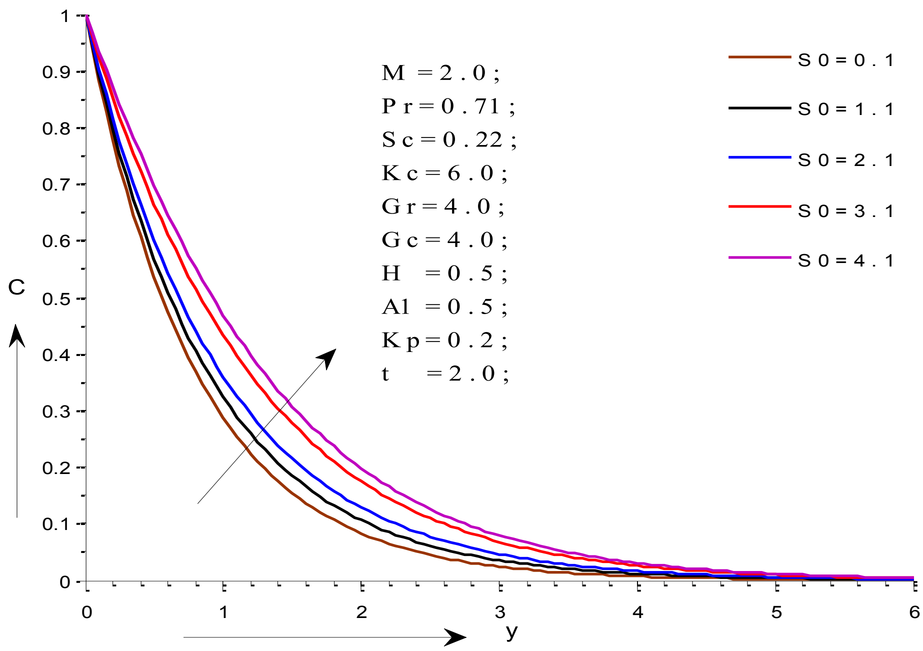

Fig.7. Effect of Soret (S0) on concentration

CONCLUSIONS:

Some of the key conclusions of this study are given below.

- Velocity increases with an increase in rotation parameter where as it shows reverse tendency in the case of magnetic parameter, permeability of the porous medium and suction parameter.
- Thermal boundary layer condenses with an increase in Prandtl number and heat source parameter.
- Concentration boundary layer increases in the presence of Soret number.

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REFERENCES:

[1] T. S. Reddy, O. S. P. Reddy, M. C. Raju, S. V. K. Varma., Heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink, International journal of mathematical archive -3 (8), 2012, 2964-2973

[2] K. V. S. Raju, T. S. Reddy, M. C. Raju, S. V. Ramana & K. J. Pillai, Unsteady MHD radiative, chemically reactive and rotating fluid flow past an impulsively started vertical plate with variable temperature and mass diffusion, Indian Journal of Applied Research, Vol.3, No. 3 , 2013.

[3] J. Philip, M. C. Raju, A. J. Chamkha and S.V. Varma, "MHD Rotating Heat and Mass Transfer Free Convective Flow Past an Exponentially Accelerated Isothermal Plate with Fluctuating Mass Diffusion." International Journal of Industrial Mathematics, Vol. 6, No. 4, 2014 Article ID IJIM-00478, 10 pages, 297-306.

[4] L. Harikrishna, M. Veerakrishna, M.C. Raju, Hall current effects on unsteady MHD flow in a rotating parallel plate channel bounded by porous bed on the lower half Darcy lap wood model, Mathematical sciences International research journal, Vol.4 (2015), 29-39.

[5] L. Rama Mohan Reddy, M. C. Raju, G. S. S. Raju, Natural convection boundary layer flow of a double diffusive and rotating fluid past a vertical

porous plate. Int. J. Appl. Comput. Math. (2016). DOI 10.1007/s40819-n-0174-7.

[6] L. Rama Mohan Reddy, M. C. Raju, G. S. S. Raju, & N. A. Reddy., Thermal diffusion and rotational effects on magneto hydrodynamic mixed convection flow of heat absorbing/generating visco- elastic fluid through a porous channel", Frontiers in Heat and Mass Transfer, Vol.7 (1), 2016. DOI: 10.5098/hmt.7.20

[7] T. S. Reddy, S. V. K. Varma & M. C. Raju; Chemical reaction and radiation effects on unsteady MHD free convection flow near a moving vertical plate, Journal on Future Engineering & Technology, Vol. 7,No. 4, 11-20, May - July 2012.

[8] T. S. Reddy, M. C. Raju & S.V. K. Varma, " The effect of slip condition, Radiation and chemical reaction on unsteady MHD periodic flow of a viscous fluid through saturated porous medium in a planar channel, Journal on Mathematics, Vol.1, No.1, 2012, pp. 18-28.

[9] T. S. Reddy, M. C. Raju & S. V. K. Varma , Chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux, Journal of computational and Applied research in Mechanical Engineering, Vol. 3 (1), 53-62, 2013.

[10] B. Seshaiah, S. V. K.Varma, M. C. Raju, The effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source, International Journal of Scientific Knowledge, Vol.3 No.2, pp. 13-24, 2013.

[11] B. M. Rao, G.V. Reddy, M. C. Raju, S.V. K. Varma, Unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption, radiation, chemical reaction and Soret effects, International Journal of Engineering Sciences & Emerging Technologies, October 2013. Volume 6, Issue 2, pp: 241-257

[12] B. M. Rao, G. V. Reddy, M. C. Raju, "Unsteady MHD mixed convection of a viscous double diffusive fluid over a vertical plate in porous medium with chemical reaction, Thermal radiation and joule heating", International Journal of Applied Mathematics & Statistical Sciences (IJAMSS); Vol.2(5), 2013, 93-116.

[13] A. J. Chamkha, T. S. Reddy, M. C. Raju, and S.V.K. Varma, "Unsteady MHD Free Convection Flow Past an Exponentially Accelerated Vertical Plate with Mass Transfer, Chemical Reaction and Thermal Radiation." International Journal of Microscale and Nanoscale Thermal and Fluid Transport Phenomena, Vol.5, no.1, 2014, pp. 57-75.

[14] M. C. Raju, N. Ananda Reddy, S. V. K. Varma, "Analytical study of MHD free convictive, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction", Ain Shams Engineering Journal, Vol. 5 (4), 2014, 1361-1369. DOI:

10.1016/j.asej.2014.07.005

[15] S. Harinath Reddy, M. C. Raju, E. Keshava Reddy, Unsteady MHD free convection flow of a Kuvshinski fluid past a vertical porous plate in the presence of chemical reaction and heat source/sink, International Journal of Engineering Research in Africa Vol. 14 (2015) pp. 13-27, doi:10.4028/www.scientific.net/JERA.14.13.

[16] M.Umamaheswar, M. C. Raju and S. V. K. Varma, MHD convective heat and mass transfer flow of a Newtonian fluid past a vertical porous plate with chemical reaction, radiation absorption and thermal diffusion, International Journal of Engineering Research in Africa Vol. 19 (2016), 37-56, doi:10.4028/www.scientific.net/JERA.19.37.

[17] M. Umamaheswar, M. C. Raju, S. V. K. Varma, Effects of Time Dependent Variable Temperature and Concentration Boundary Layer on MHD Free Convection Flow Past a Vertical Porous Plate in the Presence of Thermal Radiation and Chemical Reaction, Int. J. Appl. Comput. Math. DOI 10.1007/s40819-015-0124-9. 2016

[18] M. C. Raju, A. J. Chamkha, J.Philip, S.V.K.Varma, Soret effect due to mixed convection on unsteady magnetohydrodynamic flow past a semi-infinite vertical permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction, International Journal of Applied and Computational Mathematics(2016). DOI 10.1007/s40819-016-0147-

[19] P. G. Reddy., Raju M.C., Mamatha B. and Varma S.V.K. (2016) Thermal Diffusion Effect on MHD Heat and Mass Transfer Flow past a Semi Infinite Moving Vertical Porous Plate with Heat Generation and Chemical Reaction, Applied Mathematics, 7, 638-649. http://dx.doi.org/10.4236/am.2016.77059

[20] S.H. Reddy, M. C. Raju, E. Keshava Reddy, Radiation absorption and chemical reaction effects on MHD flow of heat generating Casson fluid past Oscillating vertical porous plate, Frontiers in Heat and Mass Transfer (FHMT), 7, 21 (2016). DOI: 10.5098/hmt.7.21

[21] L. Rama Mohan Reddy, M. C. Raju, G. S. S. Raju., Unsteady MHD free convection flow of a visco-elastic fluid past a vertical porous plate in the presence of thermal radiation, radiation absorption, heat generation/absorption and chemical reaction, International Journal of Applied Science and Engineering, Vol.14 (2), 2016, 69-85.

[22] L. Ramamohan Reddy, M. C. Raju, G. S. S. Raju and S. M. Ibrahim," Chemical reaction and thermal radiation effects on MHD micropolar fluid past a stretching sheet embedded in a non-Darcian porous medium", Journal of Computational and Applied Research in Mechanical Engineering, Vol. 6. No. 2, pp. 27-46 , 2017. DOI: 10.22061/jcarme.2017.582

[23] N. A. Reddy, M. C. Raju and S.V. K. Varma., "Effects of unsteady free convective MHD non Newtonian flow through a porous medium bounded by

an infinite inclined porous plate", Mapana J Sci. Vol. 9, No.2, 2010, 6-20.

[24] M. C. Raju, S. V. K. Varma, Unsteady MHD free convection oscillatory Couette flow through a porous medium with periodic wall temperature, Journal on Future Engineering and Technology, July2011, Vol.6, No.4. Pp.7-12.

[25] M. C. Raju, S.V. K.Varma, N. A. Reddy., "MHD Thermal diffusion Natural convection flow between heated inclined plates in porous medium", Journal on Future Engineering and Technology.Vol.6, No.2, pp.45-48, 2011

[26] T. S. Reddy, O. S. P. Reddy, M. C. Raju and S. V. K. Varma, MHD free convection heat and mass transfer flow through a porous medium bounded by a vertical surface in presence of Hall current, Advances in Applied Science Research, 2012, 3 (6):3482-3490.

[27] T. S. Reddy, O. S. P. Reddy, M. C. Raju, S. V. K. Varma., Heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink, International journal of mathematical archive -3 (8), 2012, 2964-2973

[28] V. Ravikumar, M. C. Raju, G. S. S. Raju ., Heat and mass transfer effects on mhd flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source, International Journal of Contemporary Mathematical sciences, Vol.7, No.32 , 2012, pp. 1597-1604.

[29] M. C. Raju, S.V.K Varma, N. Ananda Reddy., "Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface", Journal of Future Engineering and Technology, Vol. 7, No: 2, pp. 7-12 2012.

[30] K. V. S. Raju, M. C. Raju, S.V. Ramana, G. S. S. Raju, Unsteady MHD thermal diffusive, radiative and free convective flow past a vertical porous plate through non-homogeneous porous medium, International Journal of Advancements in Research & Technology, Vol. 2(7), 170-181, 2013.

[31] T. S. Reddy, M. C. Raju & S. V. K. Varma, Unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium, JAFM, Vol.6, no.3, pp. 443-451, 2013.

[32] B. M. Rao, G. V. Reddy, M. C. Raju, "Unsteady MHD mixed convection of a viscous double diffusive fluid over a vertical plate in porous medium with chemical reaction, Thermal radiation and joule heating", International Journal of Applied Mathematics & Statistical Sciences (IJAMSS); Vol.2(5), 2013, 93-116.

[33] K. V. S. Raju, T. S. Reddy, M. C. Raju, P.V. Satyanarayana, and S.V. Ramana, "MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom wall in the presence of viscous dissipation and Joule's heating", Ain Sham's engineering Journal (Elsevier) (2014), 5 (2), 543-551.DOI: 10.1016/j.asej.2013.10.007

[34] B. Vidyasagar, M. C. Raju, S.V. K.Varma, S.V. Ramana, Unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium, Review of Advances in Physics Theories and Applications, 2014, 1(3): 48-62.

[35] S.H. Reddy, M. C. Raju, E. Keshava Reddy, Magneto Convective Flow of a Non-Newtonian Fluid through Non-Homogeneous Porous Medium past a Vertical Porous Plate with Variable Suction, Journal of Applied Mathematics and Physics, 4, 233-248, 2016. http://dx.doi.org/10.4236/jamp.2016.42031