

Effect of Chemical Reaction on MHD Micropolar Fluid Flow on a Vertical Surface through Porous Media with Heat Source

R.Mohapatra¹, H.Pattanayak², S.R.Mishra³

Lecturer, Dept. of Mathematics, I.H.S.E, Siksha 'O' Anusandhan University, Bhubaneswar, Odisha, India¹

Visiting Professor, Institute of Mathematics and Application, Bhubaneswar, Odisha, India²

Assistant Professor, Department of Mathematics, I.T.E.R, Siksha 'O' Anusandhan University, Bhubaneswar, Odisha, India³

ABSTRACT: The steady magnetohydrodynamic (MHD) mixed convection stagnation point flow of an incompressible and electrically conducting micropolar fluid past a vertical flat plate through a porous medium is investigated in this paper. The effects of heat generation / absorption and chemical reaction have been taken into account during the present study. Numerical solutions are obtained by using Runge-Kutta fourth order scheme with shooting technique. The skin friction and rate of heat and mass transfer at the bounding surface are also calculated. It is interesting to note that the results of the previous authors are in good agreement with the results of the present study tabulated which is evident from the tabular values. Further, the novelty of the present analysis is to account for the effects of first order chemical reaction in a flow of reactive diffusing species in the presence of heat source/sink.

KEY WORDS: Micropolar fluid; heat generation/absorption; chemical reaction; Porous medium; Shooting technique.

I. INTRODUCTION

The thermal buoyancy generated due to heating/cooling of a vertical plate has a large impact on flow and heat transfer characteristics. Convection heat transfer in the fluid flow is a phenomenon of great interest from both theoretical and practical point of views because of its vast applications in many engineering and geophysical fields. Combined forced and natural convection over a flat plate has been widely studied from both theoretical and experimental standpoint over the past few decades. The applications of several engineering problems in the real world on the convective flows with variable viscosity and thermal conductivity of many fluids which vary with the temperature play a vital role in porous media.

Nomenclature

a, b, c	Constants	B_0	constant magnetic field
C	fluid concentration	C_p	specific heat capacity
C_w	concentration at the plate	C_∞	uniform concentration
C_f	skin friction coefficient	D	coefficient of mass diffusivity
g	acceleration due to gravity	Gr	local thermal Grashof number
Gc	local solutal Grashof number	j	micro-inertia density
Kc	chemical reaction parameter		

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Kc^*	dimensional reaction coefficient	k	thermal conductivity
K	material parameter	l	characteristic length
Nu	local Nusselt number	M_n	mass flux
M	magnetic parameter	N	microrotation vector
Pr	Prandtl number	q_w	heat flux
Re_x	local Reynolds number	S	Source parameter
Sc	Schmidt number	Sh	Sherwood number
t	non-dimensional time	T	temperature
T_∞	reference temperature		
u, v	dimensional velocity component along x and y direction		
U	non-dimensional free stream velocity	(x, y)	coordinates
Greek symbol:			
α	thermal diffusivity	$f(\eta)$	dimensionless stream function
β_c, β_T	volumetric expansion coefficient for concentration and thermal expansion		
η	similarity variable	θ	dimensionless temperature
ϕ	dimensionless concentration	ρ	density of fluid
μ	dynamic viscosity	ν	kinematic viscosity
κ	vortex viscosity	σ	electrical conductivity
λ_2	solutal buoyancy parameter	λ_1	thermal buoyancy parameter
ω	angular velocity	γ	spin gradient viscosity
$\psi(x, y)$	stream function	τ_w	wall shear stress
Subscripts:			
w	quantities at the wall		
∞	quantities at the free stream.		

As a result which drawn from the flow of fluids with constant viscosity is not applicable for those fluids that flow with the temperature dependent on viscosity, in particular at high temperature. A fluid that flows with variable viscosity has a wide range of applications in chemical and biochemical industries and also useful in many fluid flow problems. Books on Porous media by Nield and Bejan [1] and Vafai [2] stand evident to the fact that convective flows in porous media are of vital importance to these processes.

Porous media are widely used in high temperature heat exchanges, turbine blades, jet nozzles, etc. In practice cooling of porous structure is achieved by forcing the liquid or gas through capillaries of solid. Actually, they are used to insulate a heated body to maintain its temperature. Porous media are considered to be useful in diminishing the natural free convection which would otherwise occur intensely on a vertical heated surface. In order to make heat insulation of surface more effective it is necessary to study the free convection flow through porous medium and to estimate its effect in heat and mass transfer. Study of origin of flow through porous media is heavily based on Darcy's experimental law. By using Darcy's law, Yamamoto and Yoshida [3] considered suction and injection flow with convective acceleration through a plane porous wall specifically for the flow outside a vortex layer. The effect of a magnetic field on free convection and mass transfer flow through porous medium with constant suction and constant heat flux was discussed by Acharya et.al [4]. Gupta [5] studied laminar free convection flow of an electrically

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

conducting fluid past a vertical plate with uniform surface heat flux and variable wall temperature in presence of a magnetic field.

Muthucumaraswamy and Ganesan [6] have analyzed the effect of a chemical reaction on the unsteady flow past an impulsively started semi-infinite vertical plate, which is subject to uniform heat flux. Samad and Mohebujjaman [7] have studied about MHD heat and mass transfer free convection flow along a vertical stretching sheet in presence of magnetic field with heat generation. Reddy and Reddy [8] discussed MHD free convection flow with variable viscosity and thermal diffusivity along a moving vertical plate embedded in a porous medium. MHD Free convective heat transfer flow past vertical plate embedded in a porous medium with effects of variable fluid properties in the presence of heat source is studied by Rani and Palli [9].

The study of stagnation point flow towards a solid surface in moving fluid traced back to Hiemenz in 1911. He was the pioneer to analyze two-dimensional stagnation-point flow on stationary plate using a similarity transformation to reduce the Navier-Stokes equations to non-linear ordinary differential equations. Since then many investigators have extended the idea to different aspect of the stagnation-point flow problems in various way. Adhikari and .Maiti [10] discussed about MHD micropolar fluid flow towards a vertical surface in presence of heat source/sink under radiative heat flux. Chaudhary and Jha [11] studied the effects of chemical reactions on MHD micropolar fluid flow past a vertical plate in slip-flow regime. Reddy et al.[12] studied the MHD stagnation point flow of a micropolar fluid over a stretching surface with heat source/sink, chemical reaction and viscous dissipation.

The flow and heat transfer characteristics over a stretching sheet in the presence of a uniform magnetic field has also been studied by Ishak et al. [13] and Prasad et al. [14]. The above investigations considered the flow solely caused by a stretching sheet immersed in an otherwise quiescent fluid.

Harris et al. [15] studied the mixed convection boundary-layer stagnation point flow on a vertical surface in a porous medium with slip. Recently, Aziz [16] studied the boundary layer slip flow over a flat plate with constant heat flux condition at the surface and in this paper the local similarity was appeared in the slip boundary condition. Very recently, a numerical investigation of unsteady mixed convection boundary-layer flow near the two-dimensional stagnation point on a vertical permeable surface embedded in a fluid-saturated porous medium with thermal slip was reported by Rohni et al. [17].

The hydro magnetic convection with heat and mass transfer in porous medium has been studied due to its importance in the design of MHD generators and accelerators in geophysics, in design of underground water energy storage system, soil-sciences, astrophysics, nuclear power reactors and so on. Magneto hydrodynamics is currently undergoing a period of great enlargement and differentiation of subject matter. The interest in these new problems generates from their importance in liquid metals, electrolytes and ionized gases. Because of their varied importance, these flow have been studied by several authors-notable amongst them are Liao[18] and Jang[19]. Babu and Reddy [20] examined the effect of mass transfer on MHD mixed convective flow from a vertical surface with Ohmic heating and viscous dissipation.

In recent years, the dynamic of micropolar fluids, originated from the theory of Eringen has been popular area of research. The theory of micro rotation fluids, first studied by Eringen[21,22] displays the effects of local rotary inertia and couple stresses, can explain the flow behavior due to the microscopic effects arising from the local structure and micro motions of the fluid elements in which the classical Newtonian fluids theory is inadequate. These fluids contain dilute suspensions of rigid micro molecules with individual motions which support stress and body moments and are influenced by spin-inertia. The theory of micro polar fluids and its extension to thermomicropolar fluids[23] forms suitable non-Newtonian fluid models which can be used to analyze the behavior of exotic lubricants, polymeric, colloidal suspensions, ferro-liquids etc.

The study of stagnation point flow towards a vertical plate has received a great attention of research interest due to its wide applications in industries and practical applications. Some of the applications are cooling of electronic devices by fans, solar central receivers exposed to wind currents, cooling of nuclear reactors during emergency shutdown, and many hydrodynamic processes. Aman et al [24] have study MHD stagnation point flow of a micropolar fluid toward a vertical plate with a convective surface boundary condition.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

The novelty of the present study is to account for the effect of porous medium, heat source/sink and first order chemical reaction of a reactive species on the flow, heat and mass transfer characteristics of MHD mixed convective micropolar fluid past a vertical surface. The results of Ishak et al. [25], Lok et al. [26], Ramachandran et al. [27] and Rashad et al.[28] have been discussed as special cases of the present study.

II. MATHEMATICAL ANALYSIS

A steady, two- dimensional viscous flow of an incompressible, electrically conducting fluid near a stagnation point on a vertical heated plate through porous medium is considered. It is assumed that the velocity of the flow external to the boundary layer $U(x)$, the temperature $T_w(x)$ of the plate and concentration $C_w(x)$ at the plate are proportional to the distance x from the stagnation point, i.e. $U(x) = ax$, $T_w(x) = T_\infty + bx$ and $C_w(x) = C_\infty + cx$, where a, b and c are constants, $T_w(x) > T_\infty$ with T_∞ being the uniform temperature of the fluid and $C_w(x) > C_\infty$ with C_∞ being the uniform concentration of the fluid. A uniform magnetic field of strength B_0 is assumed to be applied in the positive y -direction normal to the plate. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field is negligible. The level of concentration of foreign mass is assumed to be low, so that the Soret and Dufour effects are negligible. The model of first order chemical reaction has been considered following Bhattacharyya[29]. Under the usual boundary layer approximation, the governing equations are

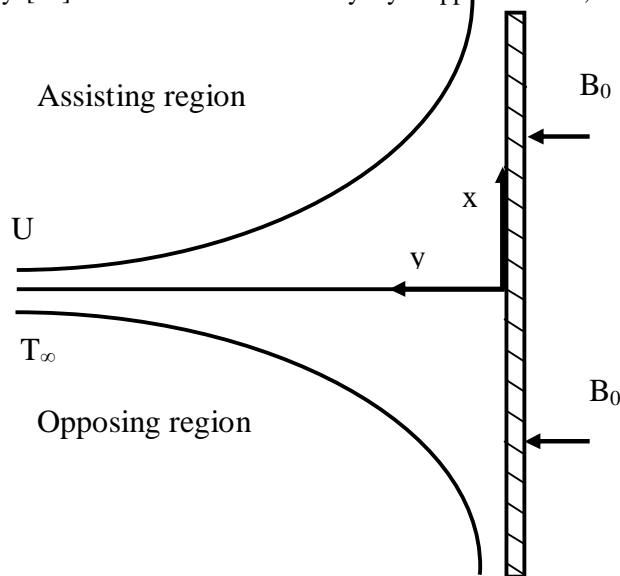


Fig.1 Physical model and coordinate system

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = U \frac{dU}{dx} + (\mu + \kappa) \frac{\partial^2 u}{\partial y^2} + \kappa \frac{\partial N}{\partial y} + \sigma B_0^2 (U - u) + \frac{\mu}{k_p^*} (U - u) \pm \rho g \beta_T (T - T_\infty) \pm \rho g \beta_c (C - C_\infty) \tag{2}$$

$$\rho j \left(u \frac{\partial N}{\partial x} + v \frac{\partial N}{\partial y} \right) = \gamma \frac{\partial^2 N}{\partial y^2} - \kappa \left(2N + \frac{\partial u}{\partial y} \right) \tag{3}$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} + S' (T - T_\infty) \tag{4}$$

$$u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - k_c^* (C - C_\infty) \tag{5}$$

The boundary conditions for the velocity, temperature and concentration fields are

$$\left. \begin{aligned} u = 0, v = 0, N = -\frac{1}{2} \frac{\partial u}{\partial y}, T = T_w(x), C = C_w(x), \quad \text{at } y = 0 \\ u \rightarrow U(x), N \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty \quad \text{as } y \rightarrow \infty \end{aligned} \right\} \tag{6}$$

where $\gamma = (\mu + \kappa / 2) j = \mu(1 + K / 2) j$, and $K = \kappa / \mu$.

The continuity equation (1) is satisfied by the Cauchy-Riemann equations

$$u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x} \tag{7}$$

where $\psi(x, y)$ is the stream function.

In order to transform equations (2) to (5) into a set of ordinary differential equations, the following similarity transformations and dimensionless variables are introduced.

$$\left. \begin{aligned} \eta = \left(\frac{a}{v} \right)^{1/2} y, f(\eta) = \frac{\psi}{(av)^{1/2} x}, \omega(\eta) = \frac{N}{a \left(\frac{a}{v} \right)^{1/2} x}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \\ \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, M = \frac{\sigma B_0^2}{\rho a}, P_r = \frac{v}{\alpha}, \lambda_1 = \frac{Gr}{Re_x^2}, Gr = \frac{g \beta_T (T_w - T_\infty) x^3}{v^2}, k_p = \frac{k_p^*}{a} \\ Gc = \frac{g \beta_c (C_w - C_\infty) x^3}{v^2}, \lambda_2 = \frac{Gc}{Re_x^2}, l = \frac{v}{a}, Re_x = \frac{Ux}{v}, S = \frac{S'}{a}, S_c = \frac{v}{D}, k_c = \frac{k_c^*}{a} \end{aligned} \right\} \tag{8}$$

In view of equations (7) and (8), the equations (2)- (5) transform into

$$(1 + K) f''' + ff'' - f'^2 + K\omega' - (M + k_p) f' + \lambda_1 \theta + \lambda_2 \phi = 0 \tag{9}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

$$\left(1 + \frac{K}{2}\right)\omega'' + f\omega' - f'\omega - K(2\omega + f'') = 0 \tag{10}$$

$$\theta'' + Pr(f\theta' - f'\theta) + PrS\theta = 0 \tag{11}$$

$$\phi'' + Sc(f\phi' - f'\phi) - Sck_c\phi = 0 \tag{12}$$

subject to boundary conditions

$$\left. \begin{aligned} f(\eta) = 0, f'(\eta) = 0, \omega(\eta) = -\frac{1}{2}f''(\eta), \theta(\eta) = 1, \phi(\eta) = 1, \quad \text{at } \eta = 0 \\ f'(\eta) \rightarrow 1, \omega(\eta) \rightarrow 0, \theta(\eta) \rightarrow 0, \phi(\eta) \rightarrow 0 \quad \text{as } \eta \rightarrow \infty \end{aligned} \right\} \tag{13}$$

where the primes denote differentiation with respect to η

III. PHYSICAL QUANTITIES OF INTEREST

The physical quantities of interest are the skin friction coefficient C_f and the local Nusselt number Nu , and Sherwood number Sh which are defined as

$$C_f = \frac{\tau_w}{\rho U^2 / 2}, Nu = \frac{xq_w}{k(T_w - T_\infty)}, Sh = \frac{xM_n}{D(C_w - C_\infty)} \tag{14}$$

where k is the thermal conductivity.

The wall shear stress τ_w , the heat flux q_w and mass flux M_n are given by

$$\left. \begin{aligned} \tau_w &= \left[(\mu + \kappa) \frac{\partial u}{\partial y} + \kappa N \right]_{y=0} \\ q_w &= -k \left(\frac{\partial T}{\partial y} \right)_{y=0} \\ M_n &= -D \left(\frac{\partial C}{\partial y} \right)_{y=0} \end{aligned} \right\} \tag{15}$$

Using the similarity variables (7), we obtain

$$\frac{1}{2}C_f Re_x^{1/2} = \left(1 + \frac{K}{2}\right)f''(0), \quad \frac{Nu}{Re_x^{1/2}} = -\theta'(0), \quad \frac{Sh}{Re_x^{1/2}} = -\phi'(0) \tag{16}$$

IV. SOLUTIONS OF THE PROBLEM

The set of coupled nonlinear governing boundary-layer equations (9) - (12) together with the boundary conditions (13) equations (9) and (12) are solved numerically using Runge-Kutta method along with shooting technique. First of all, higher order nonlinear differential equations are converted into simultaneous nonlinear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique. The resultant initial value problem is solved by employing Runge-Kutta fourth order method. The step size $\eta = 0.001$ is used to obtain the numerical solution with five decimal place accuracy as the criterion of convergence. From the process of

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

numerical computation, the skin-friction coefficient, the Nusselt number which are respectively proportional to $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ are also sorted out and their numerical values are presented in the tables 1-3 respectively.

V. RESULTS AND DISCUSSION

The discussion of flow, heat and mass transfer characteristics in various physical situations of parameters as follows. In all the figures bold lines represent the assisting and dotted lines represent opposing flows. For assisting flow we have assumed $\lambda_1 = 1, \lambda_2 = 1$ and $\lambda_1 = -1, \lambda_2 = -1$ for opposing flow for all the Figs. 2-15.

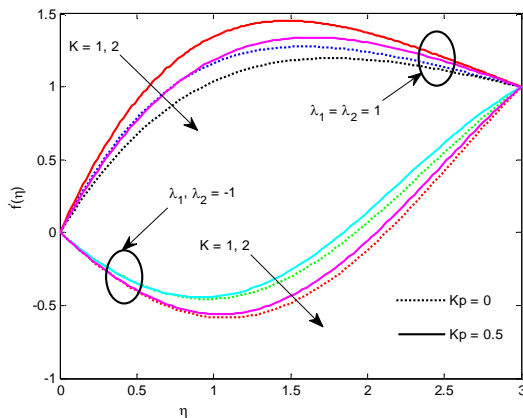


Fig.2 Velocity profile for Pr=1, M = 1, S = 0, Kc = 0

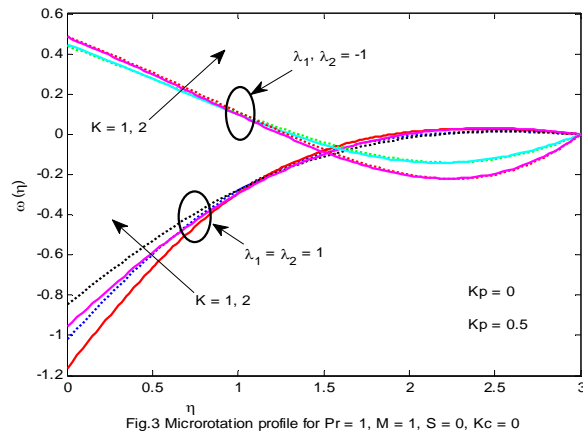


Fig.3 Microrotation profile for Pr= 1, M = 1, S = 0, Kc = 0

The present study is interesting due to the interaction of interaction of λ_2 , the mass buoyancy parameter. The results are compared with that of Ishak et al. [25] and Lok et al.[26] and Rashad et al.[28] for $\lambda_2 = 0, S = 0, k_c = 0$ and $\lambda_2 = S = k_c = M = 0$ and $\lambda_2 = S = k_c = M = Kp = 0$ respectively. Further, the result of Ramchandran [27] can also be derived with the absence of magnetic field ($M = 0$) and porous matrix ($Kp = 0$).

The illustration of the material constant K ($K \neq 0$) on velocity profiles are shown in Fig.2 for both the absence of Kp ($Kp = 0$) and presence of Kp ($Kp = 0.5$). It is seen that for both the absence / presence of porous matrix the velocity profile $f'(\eta)$ decreases with increasing value of material constant K for both assisting ($\lambda_1 > 0, \lambda_2 > 0$) and opposing ($\lambda_1 < 0, \lambda_2 < 0$) flows. The maximum velocity occurs in the flow field near the plate and the present result is in good agreement with the results of Rashad et al.[28] and Ramchandran [27]. For micropolar case ($K = 1.0, 2.0$) with ($Kp = 0$) the result is also in good agreement with that of Ishak et al. [25].

Fig. 3 presents the angular velocity profile in response to an increasing non-Newtonian property of the fluid under study for both the absence / presence of porous matrix. It is interesting to note that angular velocity remains negative in the boundary layer for the case of assisting flow and the profiles intersect each other at $\eta = 1.5$ (approx.).

The angular velocity profile increases with the increasing value of material parameter for both opposing and assisting flows cases in the absence / presence of Kp . This indicates that these layers present transition state after which the opposite effect i.e. $|\omega|$ increases with an increasing K till the free stream state is attained ($\eta > 3.0$). Further, it is remarked that transition state is accelerated in case of opposing flow.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

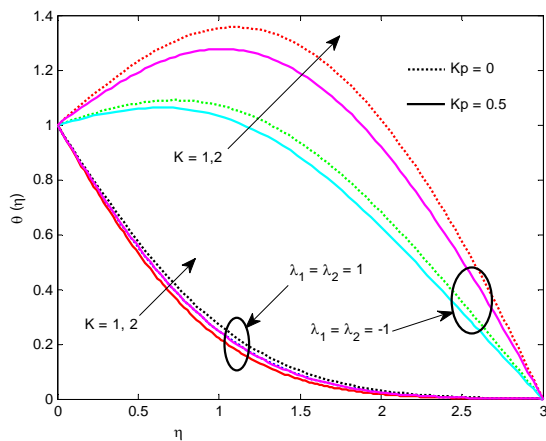


Fig.4 Temperature profile for $Pr = 1, M = 1, S = 0, Kc = 0$

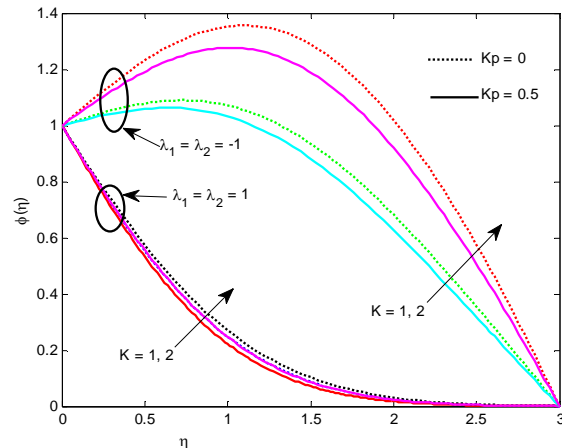


Fig.5 Concentration Profile for $Pr = 1, M = 1, S = 0, Kc = 0$

Figs. 4 and 5 present the variation of K on temperature and concentration distribution respectively in both the absence / presence of Kp . It is evident that for assisting flow thermal boundary layer is thicker than the opposing flow and it is further increased with increasing value of material constant (K) in both the profiles irrespective of the value of porous matrix. The similar effect is observed in both the cases of temperature and concentration distribution in the flow domain barring the elegance of the effects of the material property of the fluid.

The variation of magnetic field on the velocity profile is shown in Fig. 6. It is evident that an increase in magnetic field strength in both the absence / presence of Kp , enhance the velocity at all points and it is further accelerated in case of assisting flow. It is interesting to note that in case of assisting flow the profiles are significant where as the back flow is occur in case of opposing case. It is due to the opposing characteristic of $\lambda_1 = -1, \lambda_2 = -1$. The resistive force has contributed to enhance the velocity which may be attributed to the interplay of the effects of buoyancy force, heat source, chemical reaction and porous parameter.

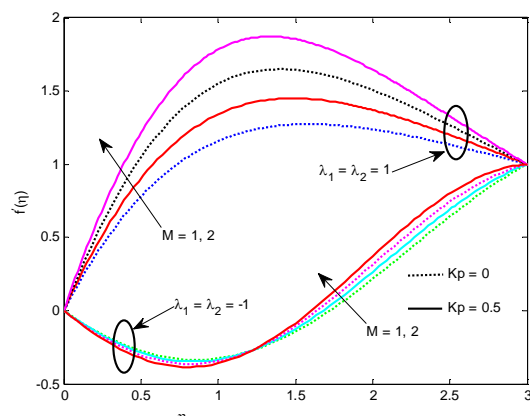


Fig.6 Velocity profile for $Pr = 1, K = 1, S = 0.5, Kc = 1$

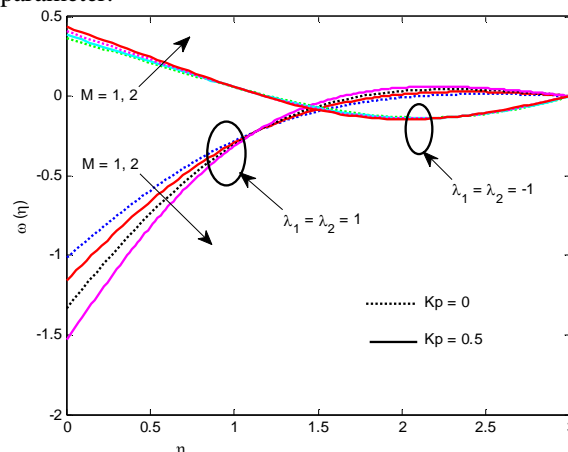


Fig. 7 Microrotation profile for $Pr = 1, K = 1, S = 0.5, Kc = 1$

Fig 7 exhibits the effect of magnetic field on angular velocity. The effect of magnetic field is opposite to that of material property of the fluid in case of assisting flow where as opposing flow enhance it in both the absence / presence of Kp . One peculiarity is remarked in Fig. 7 that assisting flow accelerate the profile from negative to positive where as opposing flow decelerate it to meet the adequate boundary conditions which is an exception i.e. transition layers almost coincide for two flows. To be specific, as the magnetic field generates a force of

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

electromagnetic origin, which is a resistive force, as a result of which the angular velocity decreases in the opposing flow. Further, the shifting of point in opposing flow is affected due to combined effect of both the opposing forces. One is buoyancy and other one is electromagnetic in origin.

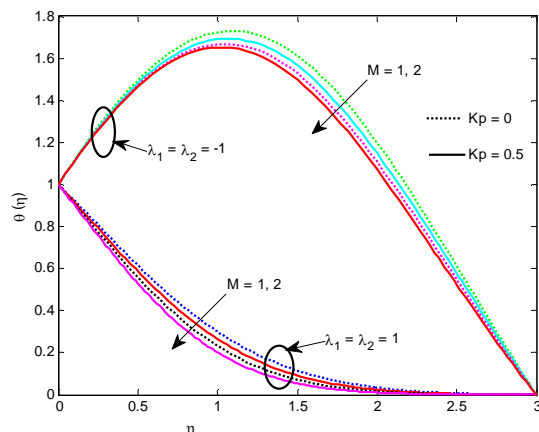


Fig.8 Temperature profile for $Pr = 1, K = 1, S = 0.5$

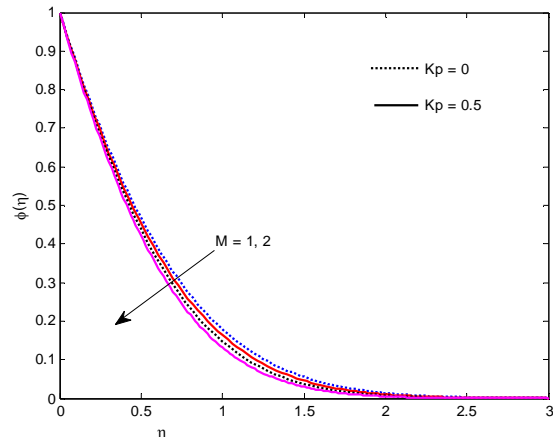


Fig.9 Concentration profile for $Kc = 1, Sc = 1, M = 1, K = 1, S = 0.5$

Figs. 8 and 9 show the effect of magnetic parameter on temperature and concentration respectively in both the presence / absence of Kp when $Pr = 1.0$ which bears an important physical characteristic of balancing the kinematic viscosity and diffusive property of the fluid in flow. The magnetic field is depicted the profiles for both assisting and opposing cases irrespective of the absence / presence of Kp . The presence of source parameter, $S = 0.5$, has also a significant role on temperature profile to diminish it.

An interesting property of Prandtl number is well exhibited in Figs. 10-12, where assisting flow and opposing flow have opposite effect on velocity, angular velocity and temperature profiles for the both the absence / presence of porous matrix.

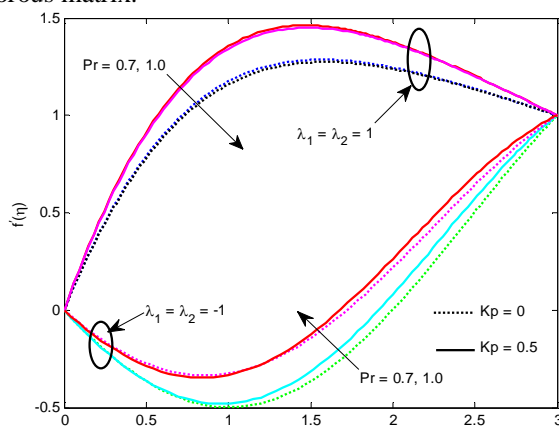


Fig.10 Velocity profile for $M = 1, k = 1, S = 0.5, Kc = 1$

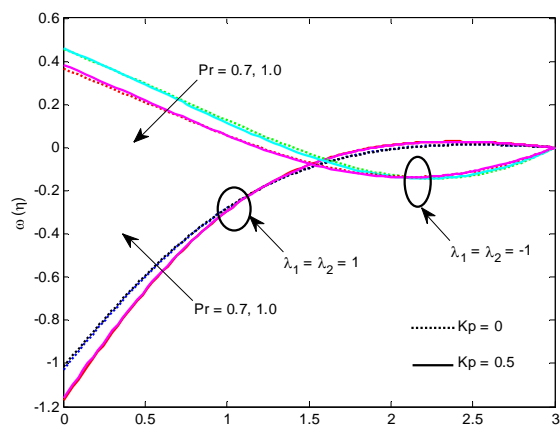


Fig.11 Microrotation profile for $M = 1, K = 1, S = 0.5, Kc = 1$

It is evident from Fig.10 that increase in Pr decelerate the velocity in case of assisting flow and accelerate it in case of opposing. This may be attributed due to predominance of diffusive property of the fluid as $Pr \leq 1$. Whereas from Fig. 11 it is observed that an increasing value of Pr angular velocity profile accelerate in case of assisting and decelerate in case of opposing i.e. under the dominating effect of diffusivity, temperature decreases at all points in opposing flows. Assisting flow retards the temperature profiles at all points with an increasing value of Prandtl number but opposing flow enhances it (see Fig.12).

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

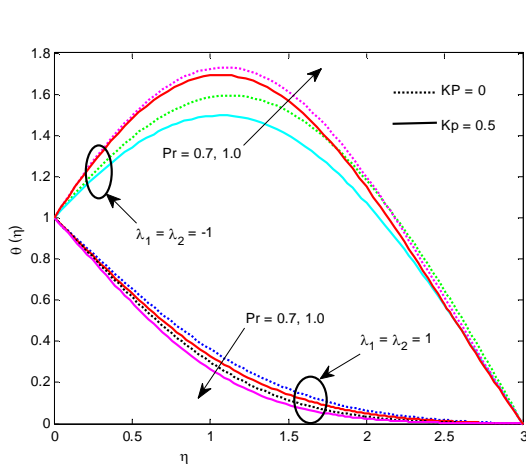


Fig.12 Temperature profile for $M = 1, K = 1, S = 0.5$

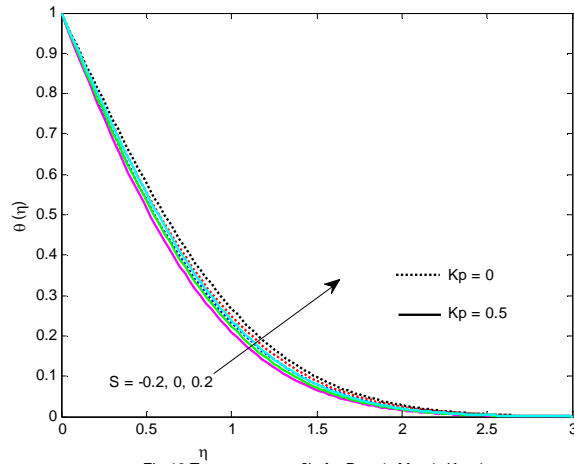


Fig.13 Temperature profile for $Pr = 1, M = 1, K = 1$

Fig.13 exhibits the presence of source on the temperature distribution in both the presence / absence of porous matrix. This clearly indicates that an increase in source strength, from sink to source, enhances the temperature in all the layers in micropolar fluid flow in buoyancy assisting flow.

From Fig.14, a heavier species, i.e. with increasing Sc , leads to a decrease in concentration level in the fluid layers with the interaction of chemical reaction parameter $Kc = 1$ in both the absence / presence of Kp .

Fig.15 exhibits the effect of chemical reaction parameter for destructive reaction, $Kc = 0$ without reaction and $Kc < 0$ constructive reaction. Reaction parameter shows a retarding effect on concentration distribution as the reaction proceeds from constructive to destructive state irrespective of the absence / presence of porous matrix.

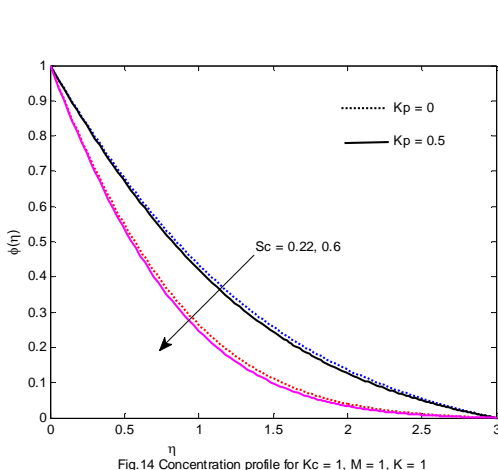


Fig.14 Concentration profile for $Kc = 1, M = 1, K = 1$

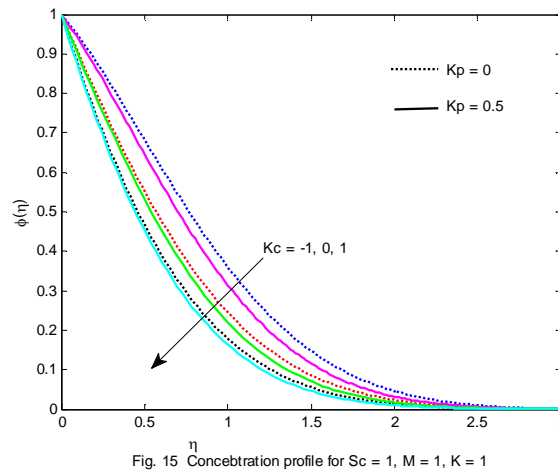


Fig.15 Concentration profile for $Sc = 1, M = 1, K = 1$

At last, the local skin friction coefficient in terms of $f''(0)$, local Nusselt number i.e. the wall temperature gradient $-\theta'(0)$ and local Sherwood number i.e. the wall concentration gradient $-\phi'(0)$ for various values of physical parameters are shown in Tables 1-3 for the absence / presence of porous matrix.

Table-1: Values of $f''(0)$ for $M = 0, K = 0$ and $\lambda_1 = 1$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Pr	λ_2	S	Sc	Kc	Kp	Present result	Ramachandran et al.[27]	Lok et al.[26]	Ishak et al.[25]
0.71	0	0	0	0	0	1.703458	1.7063	1.706376	1.7063
1	0	0	0	0	0	1.6593	-	-	1.6755
7	0	0	0	0	0	1.523	1.5179	1.517952	1.5179
0.71	1	0	0	0	0	2.277315	-	-	-
0.71	1	0.5	0	0	0	2.303127	-	-	-
0.71	1	0.5	0.22	0	0	2.241924	-	-	-
0.71	1	0.5	0.22	1	0	2.211975	-	-	-
0.71	1	0.5	0.22	1	0.5	2.187391	-	-	-
1	1	0.5	0.22	1	0.5	2.682169	-	-	-
0.71	1	1	0.22	1	0.5	2.247983	-	-	-
0.71	1	0.5	0.6	1	0.5	2.136722	-	-	-
0.71	1	0.5	0.22	2	0.5	2.189371	-	-	-

Table-1 contributes the following facts in respect of skin friction:

An increase in the value of Pr decreases the skin friction in the absence of buoyancy effect, heat source, chemical reaction but the presence of buoyancy force (assisting flow) and heat source enhance it in both presence / absence of porous parameter. It is interesting to note that presence of foreign species ($Sc \neq 0$) decreases the skin friction even in the presence of buoyancy, heat source effects, chemical reaction and both the presence / absence of porous parameter. Diffusion of foreign species reduces the skin friction, which is desirable. Moreover, presence of destructive reaction decreases it further. One striking result is to note that when $Pr = 7.0$ for aqueous medium, presence of foreign species, heat source and buoyancy force increases the skin friction substantially whereas the absence of these, skin friction is quite low.

Table-2 presents the rate of heat transfer coefficient for different values of physical parameters. Rate of heat transfer increases in the presence of buoyancy (solutal) but it reduces in the presence of heat source in gaseous medium ($Pr < 1$) in both presence / absence of porous matrix. However, in aqueous medium rate of heat transfer is higher than gaseous medium but it is interesting to note that the combined effect of solutal buoyancy and heat source reduces the rate of heat transfer in aqueous medium substantially.

Following facts are evident from Table-3. Heavier species with solutal buoyancy increases the rate of mass transfer. The species considered are hydrogen ($Sc = 0.22$) and water vapour ($Sc = 0.66$) in air medium for both destructive and constructive reaction rates. In the absence as well as presence of porous matrix the rate is enhanced further with a destructive reaction but with constructive reactive species it decreases significantly.

Thus, it is concluded that lighter diffusive species favoring constructive reaction are suitable for reducing mass transfer rate at the bounding surface

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Table-2: Values of $-\theta'(0)$ for $M = 0, K = 0$ and $\lambda_1 = 1$

Pr	λ_2	S	Kp	Present result	Ramachandran et al.[27]	Lok et al.[26]	Ishak et al.[25]
0.71	0	0	0	0.766214	0.7641	0.764087	0.7641
0.71	1	0	0	0.841207	-	-	-
0.71	1	0.5	0	0.658995	-	-	-
1	0	0	0	0.871279	-	-	0.8708
1	1	0	0.5	0.954632	-	-	-
1	1	0.5	0.5	0.731922	-	-	-
7	0	0	0	1.722327	1.7224	1.722775	1.7225
7	1	0	0.5	3.352978	-	-	-
7	1	0.5	0.5	0.044526	-	-	-

Table-3: Values of $-\phi'(0)$ for $M = 0, K = 0$ and $\lambda_1 = 1$

Sc	λ_2	Kc	Kp	Present result
0.22	0	0	0	0.509327
0.22	1	0	0.5	0.536987
0.22	1	1	0	0.684392
0.22	1	-1	0.5	0.363025
0.6	0	0	0	0.716942
0.6	1	0	0.5	0.760028
0.6	1	1	0	1.042296
0.6	1	-1	0.5	0.393093

VI. CONCLUSIONS

- Velocity profile $f'(\eta)$ decreases with increasing value of material constant K for both assisting ($\lambda_1 > 0, \lambda_2 > 0$) and opposing ($\lambda_1 < 0, \lambda_2 < 0$) flows where as reverse effect is encountered for angular velocity profile.
- The magnetic field is depicted the temperature and concentration profiles for both assisting and opposing cases irrespective of the absence / presence of Kp .
- Increase in Pr decelerate the velocity in case of assisting flow and accelerate it in case of opposing.
- An increase in source strength, from sink to source, enhances the temperature in all the layers in micropolar fluid flow.
- Reaction parameter shows a retarding effect on concentration distribution.
- Diffusion of foreign species reduces the skin friction, which is desirable.
- Rate of heat transfer increases in the presence of buoyancy (solutal) but it reduces in the presence of heat source.
- Heavier species with solutal buoyancy increases the rate of mass transfer.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

REFERENCES

- [1] D.A. Nield, A. Bejan, Convection in Porous Media, Third ed., Springer, New York, 2006.
- [2] K.Vafai, Handbook of Porous Media, second ed., Taylor & Francis, Newyork, 2005.
- [3] K. Yamamota and Z. Yoshida, J. phys. Soc. Japan 37(1974) 774-779.
- [4] M. Acharya, G. C. Dash and L.P. Singh, Magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, Indian J. pure appl. Math. ,31(1) (2000)1-18.
- [5] A.S. Gupta ,Laminar free convection flow of an electrically conducting fluid from a vertical plate with uniform surface heat flux and variable wall temperature in the presence of a magnetic field, Z Angew Math Phys, 13(1963)324-333.
- [6] R.Muthucumaraswamy, and P. Ganesan, ,On impulsive motion of a vertical plate with heat flux and diffusion of chemically reactive species, Forsch. Ingenieurwes, 66(2000) 17-23.
- [7] M.A. Samad and M. Mohebujjaman , MHD heat and mass transfer free convection flow along a vertical stretching sheet in presence of magnetic field with heat generation , Research Journal of Applied Sciences, Engineering and Technology 1(3)(2009)98-106.
- [8] P.Bala Anki Reddy, N. Bhaskar Reddy, MHD Free convection flow with variable viscosity and thermal diffusivity along a moving vertical plate embedded in a porous medium, Acta Technica corviniensis- Bulliten of Engineering Tome-VI, 3(2013) 86-90.
- [9] T. Raja Rani, Rajendar Palli, MHD Free Convective Heat Transfer Flow Past Vertical Plate Embedded in a Porous Medium with Effects of Variable Fluid Properties in the Presence of Heat Source, Proceedings of the World Congress on Engineering 2(2014).
- [10] A. Adhikari and A.K.Maiti, MHD micropolar fluid flow towards a vertical surface in presence of heat source/sink under radiative heat flux, Journal of the International Mathematical Virtual Institute , 4 (2014)1-25.
- [11] R. C. Chaudhary and A. K. Jha, Effects of chemical reactions on MHD micropolar fluid flow past a vertical plate in slip-flow regime, Applied Mathematics and Mechanics, 29 (9) (2008)1179-1194
- [12] K. Surya Narayana Reddy, M. Sreedhar Babu, S. Vijaya Kumar Varma, N. Bhaskar Reddy, MHD Stagnation Point Flow of A Micropolar Fluid over a Stretching Surface with Heat Source/Sink, Chemical Reaction and Viscous Dissipation, International Journal of Engineering Inventions, 3(10) (2014) 15-26.
- [13] A. Ishak, R. Nazar and I. Pop, Mixed convection stagnation point flow of a micropolar uid towards a stretching sheet , Mechanica 43(2008) 411-418.
- [14] K.V. Prasad, D.Pal, , P.S. Datti, , MHD power-law fluid flow and heat transfer over a non-isothermal stretching sheet,Communications in Nonlinear Science and Numerical Simulations, 14(2009) 2178-2189.
- [15] S.D Harris, D.B Ingham, I.Pop ,Mixed convection boundary-layer flow near the stagnation point on a vertical surface in a porous medium Brinkman model with slip. Transp Porous Media, 77(2009) 267-85.
- [16] A.Aziz ,Hydrodynamic and thermal slip flow boundary layers over a flat plate with constant heat flux boundary condition. Commun Nonlinear Sci Numer Simul 15(2010)573-580.
- [17] A.M.Rohni , S.Ahmad, I.Pop, J.H. Merkin, Unsteady mixed convection boundary-layer flow with suction and temperature slip effects near the stagnation point on a vertical permeable surface embedded in a porous medium. Transp Porous Media, 92(2012)1-14.
- [18] S.J. Liao, On the analytic solution of magnetohydrodynamic flows of non-Newtonian fluids over a stretching sheet, J Fluid Mech, 488 (2003)189-212.
- [19] Jaesung Jang, Seung S.Lee, Theoretical and experimental study of MHD (magnetohydrodynamic) micropump, 80(1)(2000)84-89.
- [20] V. Sri Hari Babu and G. V. Ramana Reddy, Mass transfer effects on MHD mixed convective flow from a vertical surface with Ohmic heating and viscous dissipation, Advances in Applied Science Research, 2(4)(2011)138-146.
- [21] A.C. Eringen, Theory of Micropolar Fluids, Jr. Math. Mech., 16(1966)1-18.
- [22] A.C. Eringen, Theory of Thermomicropolar Fluids, Jr. Math. Appl., 38(1972)480-495.
- [23] S.K. Jena and M.N. Mathur, Similarity solution for laminar free convection ow of thermomicropolar fluid past a non-isothermal vertical at plate, Int. Jr. Engg. Sci19(1981)1431-1439.
- [24] Fazlina Aman, Anuar Ishak and Ioan Pop, MHD Stagnation Point Flow of a Micropolar Fluid Toward a Vertical Plate with a Convective Surface Boundary Condition, Bull. Malays. Math. Sci. Soc. (2) 36(4) (2013)865-879.
- [25] Anuar Ishak, Roslinda Nazar, Ioan Pop, Magnetohydrodynamic(MHD) flow of a micropolar fluid towards a stagnation point on a vertical surface, Computers and Mathematics with applications, 56(2008) 3188-3194.
- [26] Y.Y. Lok., N. Amin., D.Campean I.,Pop ,Steady mixed convection flow of a micropolar fluid near the stagnation point on a vertical surface, Int.J. Numerical Methods Heat Fluid Flow, 15 (2005)654-670.
- [27] N. Ramachandran , T.S. Chen, B.F. Armaly , Mixed convection in a stagnation flows adjacent to vertical surfaces, ASME J. Heat Transfer,110(1988) 373-377.
- [28] A.M. Rashad ,S. Abbasbandy, Ali J. Chamkha , Mixed convection flow of a micropolar fluid over a continuously moving vertical surface immersed in a thermally and solutally stratified medium with chemical reaction, Journal of Taiwan Institute of Chemical Engineers, 45(2014)2163-2169.
- [29] K. Bhattacharyya , Dual solutions in boundary stagnation-point flow and mass transfer with chemical reaction past a stretching/shrinking sheet, International Communications in Heat and Mass Transfer, 38 (2011)917-922.