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Hydromagnetic Boundary Layer Forced Convective Flow of Micropolar Fluid with Heat Generation/Absorption

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ABSTRACT: The numerical investigation deals with the effect of velocity, temperature and concentration of a micropolar fluid past a constantly moving permeable plate with in the boundary layer of the flow. In the present work, energy equation is considered together with the magnetic field, heat generation/absorption, and radiative heat flux. The system partial differential equations which governs the flow have been transformed into the system of ordinary differential equation. using shooting technic and solved numerically by fourth order Runge-Kutta method. The results are shown graphically for different values of heat generation/ absorption, magnetic parameter, and temperature dependent viscosity parameter. Effect of variable viscosity over skin friction, microrotation, and rate of mass transfer are examined and it shows that these parameters highly depend on variable viscosity. Mass transfer rate also depend on chemical reaction parameter.

KEYWORDS: MHD, Forced convection, Boundary layer, Micropolar.

I. INTRODUCTION

Recent developments in many engineering processes such as metallurgy, casting, compact heat exchangers, filtration of liquid metals, cooling of nuclear reactors and fusion control, geothermal systems, accelerators and flow meters leads to develop the research on the flow and heat transfer of electrically conducting fluids.

In literature, there are many studies on the heat transfer effects on flow of electrically conducting fluid in the presence of magnetic field in different aspects. O.A. Bég.et.al [2] focused on buoyancy-induced viscoelastic flow in a porous medium with magnetic field effects. O.A. Bég.et.al [3] performed the effect of mixed convective flow in a porous medium in the presence of magneto-hydro dynamic field with transpiration and viscous (Eckert) heating.

Toshivo Tagawa et al. [4] note that MHD heat transfer can be divided into two. 1. The heating is an incidental by product of electromagnetic field; e.g. MHD generators, pumps, etc. 2. The primary use of electromagnetic fields is to control the heat transfer. A. Raptis, N. Kafousias[5] analyzed the steady two - dimensional flow, of an electrically conducting fluid through a porous medium.

Also recent growth in many engineering processes such as extrusion of polymer and plastic sheets, process of crystal growth, etc. makes a flow of micropolar fluid in the boundary layer on a constantly moving surface as an important area of research. The theory of micropolar fluid was first originated by Eringen [6]. Micropolar fluid contains rigid, randomly oriented particles dispersed in a viscous medium. Some examples of such fluids are liquid crystals, animal fluid, and some polymeric fluids. Later, many studies have examined the effect of heat transfer of micropolar fluid past continuously moving plate [7,8,9].

Combined heat and mass transfer effect in moving fluid with chemical reaction is also important in view of several physical problems. Recently Loganathan and Golden Stepha [10],[11] deliberated the problem on heat and mass transfer effects of forced convective flow of micropolar fluid in the presence of chemical reaction and radiation.

Numerous factors existing in convective flows may lead to heat generation, which in turn highly influences the rate of heat and mass transfer of the flow. Moreover, in many applications of geo-physics and energy-related engineering problems such as removal of heat in nuclear fuel debris, exothermic chemical reactions in packed-bed reactor, etc., internal heat generation/absorption plays a vital role.



Associated to the already obtainable research materials, so far no research has been made to investigate the problem of heat generation/absorption and mass transfer effects on flow of electrically conducting micropolar fluid past a constantly moving porous plate with first-order chemical reaction and variable viscosity. Hence, the objective of the present paper is to study the effects of heat generation/absorption and chemical reaction on a MHD micropolar fluid past continuously moving porous plate with radiation.

II. FORMULATION OF THE PROBLEM

A problem is described as follows, a 2-D., incompressible forced convective heat and mass transfer flow on a constantly moving flat permeable plate with a constant velocity U_0 in a micropolar fluid medium at rest.

The plate is kept along the x-axis and y-axis is normal to it. The surface of the plate is sustained at a uniform temperature and concentration T_w and C_w respectively.

The following properties of the fluid are taken into account

i) The fluid viscosity is taken to be a variable linearly with temperature and is given by $\mu = \mu_f (1 + \gamma_f (\theta - 1/2))$.

ii) Viscous dissipation, Radiative heat flux, $q_r = -\frac{4\sigma_1}{3k'} \frac{\partial T^4}{\partial y}$ and temperature-dependent heat generation/absorption are added in the energy equation.

With respect to the fluid properties mentioned above, equations governing the boundary layer flow are given by

Continuity equation

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

Momentum equation

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{1}{\rho} \frac{\partial}{\partial y} \left((\mu + s) \frac{\partial u}{\partial y} \right) + k_1 \frac{\partial \sigma}{\partial y} - \frac{\alpha B^2(x)}{\rho} u \tag{2}$$

Angular Momentum equation

$$\gamma_s \frac{\partial^2 \sigma}{\partial y^2} - 2\sigma - \frac{\partial u}{\partial y} = 0 \tag{3}$$

Energy equation

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial y^2} + \frac{\gamma}{c_p} \left(\frac{\partial u}{\partial y} \right)^2 + \left(\frac{16\sigma_1 T_\infty^3}{3k' \rho c_p} \right) \frac{\partial^2 T}{\partial y^2} - \frac{Q}{\rho c_p} (T - T_\infty) + \left(\frac{\alpha B^2(x)}{\rho c_p} \right) u^2 \tag{4}$$

Species concentration equation

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

Subjected to the boundary conditions;

$$\begin{aligned} u = U_0, \quad v = V_w, \quad T = T_w, \quad \sigma = 0, \quad C = C_w \quad \text{at } y = 0 \\ u = 0, \quad T = T_\infty, \quad \sigma = 0, \quad C = C_\infty, \quad \text{as } y \rightarrow \infty \end{aligned} \tag{6}$$

Where, $k_1 = \frac{s}{\rho}$ is the coupling constant, $B(x) = \frac{B_0}{\sqrt{2x}}$ the magnetic conduction, and $Q(x) = \frac{Q_0}{x}$ is the heat absorption/generation and other physical quantities and variables are given in the nomenclature



Now considered the following dimensionless similarity variables

$$\eta = y\sqrt{\frac{U_0}{2\gamma x}}, \psi = \sqrt{2\gamma U_0 x} f(\eta)$$

$$\sigma = \sqrt{\frac{U_0^3}{2\gamma x}} g(\eta), \theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty} \quad (7)$$

$$K = \frac{k_1}{\gamma}, G = \frac{U_0 \gamma_s}{\gamma x}, Pr = \frac{\gamma \rho c_p}{k}, N = \frac{k'k}{4\sigma_1 T_\infty^3}, Ec = \frac{U_0^2}{c_p (T_w - T_\infty)},$$

$$F_w = -V_w \sqrt{\frac{2x}{\gamma U_0}}, R = -R_c \left(\frac{2x}{U_0} \right), A = \frac{2Q_0}{\rho c_p U_0}$$

$$M = \frac{\alpha B_0^2}{\rho U_0}$$

where $f(\eta)$ and $g(\eta)$ are dimensionless stream functions, in sight of equation (7), equations (2)-(5) are converted to the following system of ordinary differential equations

$$(1 + \gamma_f(\theta - 0.5) + K)f''' + ff'' + \frac{K}{2}g' + \gamma_f\theta'f'' - M(f')^2 = 0 \quad (8)$$

$$Gg'' - 4g - 2f'' = 0 \quad (9)$$

$$(3N + 4)\theta'' + 3PrN\theta' + 3NPrEc(f'')^2 + 3NPrA\theta + 3MEcPrN(f')^2 = 0 \quad (10)$$

$$\phi'' + Scf\phi' + ScR\phi = 0 \quad (11)$$

The equivalent initial and boundary conditions in non-dimensional quantities are given by

$$\eta = 0: f(0) = F_w, f'(0) = 1, \theta(0) = 1, g(0) = 0, \phi(0) = 1$$

$$\eta = \infty: f'(\infty) = 0, \theta(\infty) = 0, g(\infty) = 0, \phi(\infty) = 0 \quad (12)$$

The parameters G, R, A, and F_w correspond to local effects, i.e., relating to specific values of x. Therefore (8)–(11) are ordinary differential equations, which are locally similar together with the boundary conditions (12).

The interesting physical parameters are local skin-friction coefficient, local Nusselt number, and local Sherwood number which can be defined as follows

$$C_f = \frac{2\tau_w}{\rho U_0^2}, Nu_x = \frac{xq_w}{k(T_w - T_\infty)}, Sh_x = \frac{xq_M}{D(C_w - C_\infty)}$$

Where

$$\tau_w = \left[(\mu + s) \frac{\partial u}{\partial y} + s\sigma \right]_{y=0}, q_w(x) = \left[\left(-k - \frac{16\sigma_1 T_\infty^3}{3k'} \right) \left(\frac{\partial T}{\partial y} \right) \right]_{y=0}, q_M(x) = -D \left(\frac{\partial C}{\partial y} \right)_{y=0}$$

Using similarity variable (7), we get

$$C_f Re_x^{1/2} = \sqrt{2} f''(0), Nu_x Re_x^{-1/2} \left(\frac{3N}{3N + 4} \right) = \frac{-\theta'(0)}{\sqrt{2}}, Sh_x Re_x^{-1/2} = \frac{-\phi'(0)}{\sqrt{2}}$$

III. NUMERICAL SOLUTION

The equations (8), (9), (10), and (11) with the boundary condition (12) are solved by using fourth order Runge-Kutta method along with Nactsheim–Swigert shooting technique (Adams and Rogers, [1]) for the parameter F_w , K, N, Pr, Sc, G, R, and γ_f . In the B.C (14), there are four asymptotic boundary conditions and therefore there are four unknown

surface condition $f''(0)$, $g'(0)$, $\theta'(0)$, and $\phi'(0)$. Using Nactsheim-Swigert technique we get the values of surface conditions (Adams and Rogers,[1]). Finally the equation (10) – (13) with boundary condition (14) solved by set up a computer program for the procedure mentioned above along with fourth order Runge-Kutta method. A step size of $\Delta\eta = 0.01$ was selected to satisfy the convergence criterion of 10^{-4} in all cases



IV. EXPERIMENTAL RESULTS

In this section, the numerical solution is given as graph in figure 1-17 to explain the effect of various physical parameters such as G, K, N, Sc, R, A, γ_f and Pr. The heat transfer parameter $-\theta'(0)$ is compared with those of [10] and it has tremendous agreement with them.

Table 1: Observation with respect to El-Arabawy[10]

Prandtal number	El-Arabawy[10]	Current work
0.73	0.4270	0.49815
7	1.6986	1.77469
10	2.060 29	2.13903
20	2.97190	3.06067
50	4.76887	4.88467

The non-dimension velocity component for few values of heat generation/absorption parameter A=2.0, 0.0, -2.0, variable viscosity $\gamma_f = 0.8, 0.0, -0.8$ and magnetic parameter $M = 0.0, 0.2, 0.6, 0.8$ are shown in the figures from fig.(1).to fig.(3).

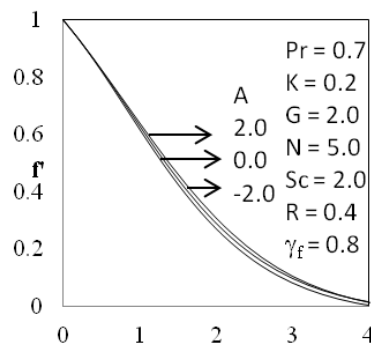


Fig 1: Effect of Velocity for different values of heat absorption and generation parameter

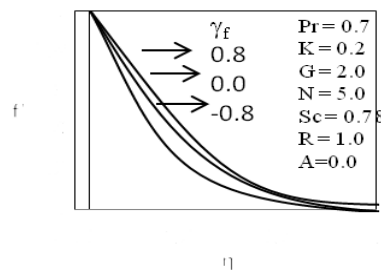


Fig 2: Effect of Velocity for different variable viscosity

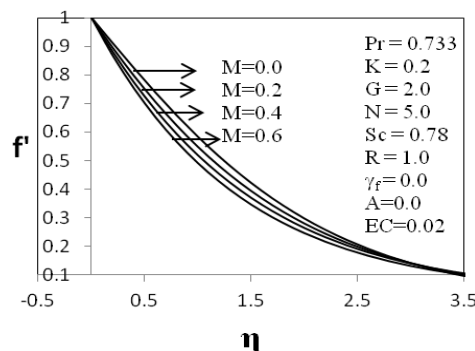


Fig 3: Effect of Velocity for different values of M

The non-dimensional velocity component for few values of heat generation/absorption parameter $A=2.0, 0.0, -2.0$, is portrayed in fig. (1). It is observed that the velocity field gradually increases, for increasing value of A . Since the presence of heat source ($A>0$) creates more energy in the boundary layer which will lead to rise in temperature. As expected, this rise in temperature will lead to increase of flow field, but heat absorption ($A<0$) will produce opposite effect. This can be clearly seen in fig.(1).

Fig (2) here describes the non-dimensional velocity component for different values of $\gamma_f = 0.8, 0.0, -0.8$ and reveals that the velocity in the boundary layer rises with increasing value of γ_f . The dimensionless velocity component for different values of magnetic parameter $M = 0.0, 0.2, 0.6, 0.8$ with is shown in fig. (3). It shows that velocity in the boundary layer decreases for increasing value of M .

Angular velocity profiles for various heat generation/absorption parameter A , suction or injection parameter F_w , and magnetic parameter M are shown in the figures from fig.(4).to fig.(6).

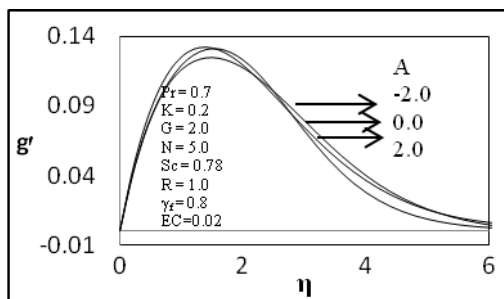


Fig 4: Micro rotation profile for different values of heat absorption and generation paramete

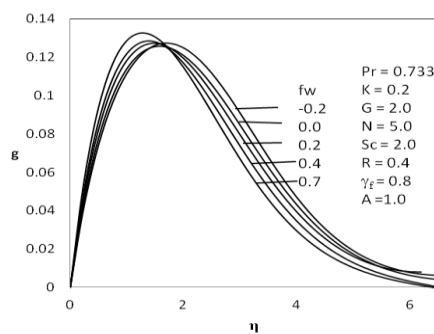


Fig 5: Micro rotation profile for different values of suction and injection

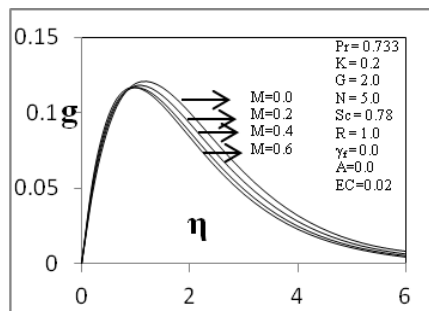


Fig 6: Micro rotation profile for different values of M

From fig.(4), it is noticed that angular velocity increases with increasing value of A . Angular velocity profiles for various F_w are presented in the fig (5). It shows that close to the surface of the plate, the angular velocity of the



microelements rises with the rise in F_w . Since the rotation of the micro elements induced close to the surface of the plate due to increase of suction velocity. After a small distance from the surface of the plate where kinematic viscosity is dominant, these profiles overlap and then decrease with the increase of F_w . In fig. (6), the angular velocity is found to be increased with the increase of magnetic parameter M . The non-dimensional temperature component for few values of heat generation/absorption parameter $A=2.0, 0.0, -2.0$, variable viscosity $\gamma_f = 0.8, 0.0, -0.8$ and magnetic parameter $M = 0.0, 0.2, 0.6, 0.8$ are shown in the figures from fig.(7).to fig.(10).

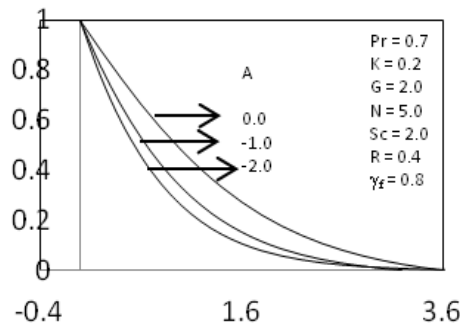


Fig 7: Temperature effect for different values of heat absorption and generation parameter

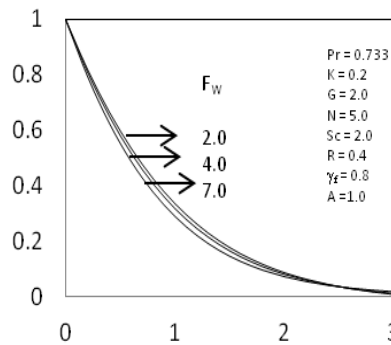


Fig 8: Temperature effect for different values of suction and injection

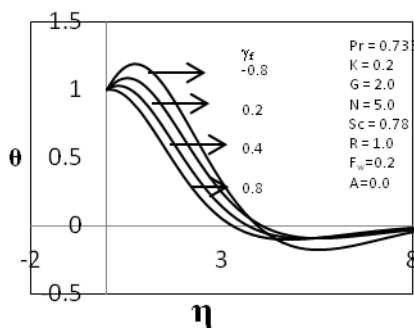


Fig 9: Temperature effect for different viscosity

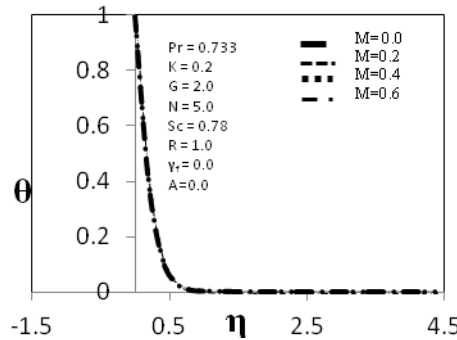


Fig 10:Effect of Temperature for different values of M

The effects of heat generation/absorption parameter A on the temperature profile are shown in fig. (7). Similar to velocity field, $A > 0$ have a affinity to rise the thermal boundary layer thickness and ($A < 0$) have a affinity to diminish the thermal boundary layer thickness effect The effects of suction or injection parameter Fw on the temperature profile are exposed in fig. (8). Fig. (9) displays the temperature profile for different values of $\gamma_f = 0.8, 0.0, -0.8$. It is

detected that the temperature decreases with increasing value of γ_f . The non-dimensional temperature component for different values of magnetic parameter $M = 0.0, 0.2, 0.6, 0.8$ is depicted in fig. (10). It shows that temperature of the fluid in the boundary layer decreases for increasing value of M.

The non-dimensional concentration component for different values of suction or injection parameter Fw, time dependent variable viscosity $\gamma_f = 0.8, 0.0, -0.8$ and magnetic parameter $M = 0.0, 0.2, 0.6, 0.8$ are shown in the figures from fig.(11).to fig.(13).

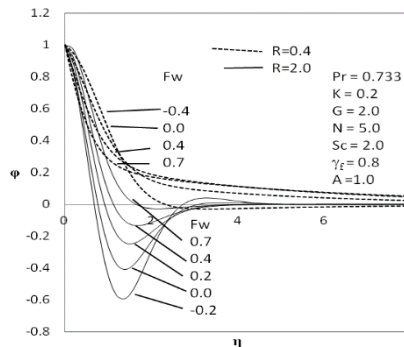


Fig 11:Effect of Concentration for different values of suction and injection

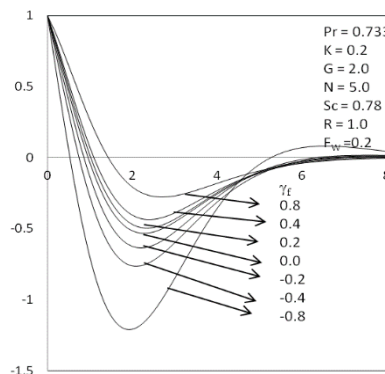


Fig12: Effect of Concentration for different viscosity

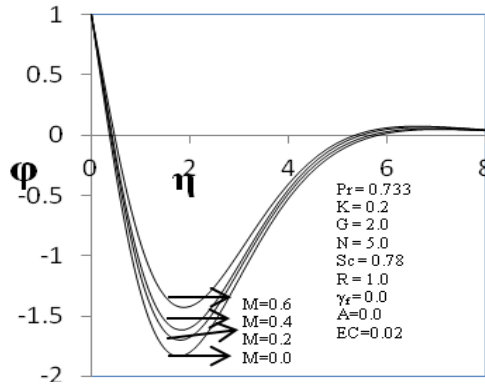


Fig 13: Effect of Concentration for different values of M

The effects of suction or injection parameter F_w on concentration of the fluid within the boundary layer is shown graphically for higher as well as lesser values of R in fig. (11). It is observed that in case of smaller R , for increasing F_w , the concentration of the fluid drops but the reverse effect is produced for larger value of R . Fig. (12) displays the concentration sketch for different value of γ_f . It shows that concentration of the fluid in the boundary layer rises with increasing value of γ_f , The dimensionless concentration component for different values of magnetic field parameter $M = 0.0, 0.2, 0.6, 0.8$ is portrayed in fig. (13). It shows that concentration of the fluid in the boundary layer increases for increasing value of M .

Effect on temperature of the fluid with in the boundary layer for different values of Pr , is shown in fig.(14). It displays that the temperature declines with increasing value of Pr .

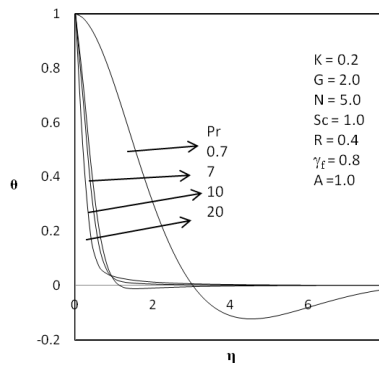


Fig 14: Temperature effect for different values of Pr

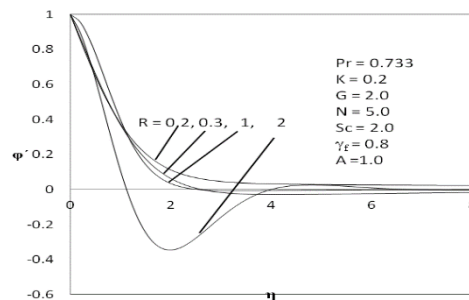


Fig 15: Effect of Concentration for different R

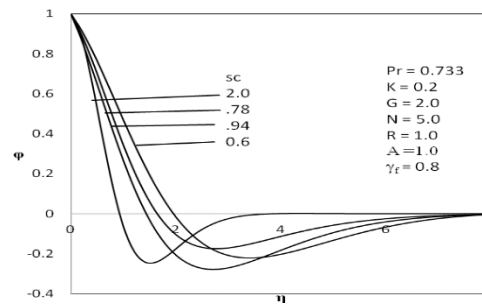


Fig 16: Effect of Concentration for different values of Sc

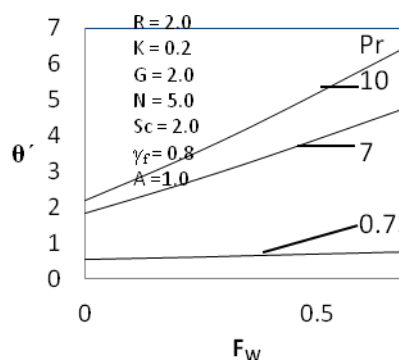


Fig 17: Heat transfer parameter for different values of Pr

Effect on concentration of the fluid for different values of chemical reaction parameter R, is shown in fig. (15) In fig.(15), it is observed that with the increasing values of R, the concentration of the fluid within the boundary layer drops.

Effect on concentration of the fluid for different values Schmidt number Sc, is also placed in fig. (16). It is also detected that with the increasing value of Sc, the concentration of the fluid drops. Increasing Sc means the species diffusion diminishes and viscous force rises which cause a fall in concentration as expected.

Fig. (17) shows the effects of Prandtl number on the heat transmission for various values of Fw. It is detected that heat transfer rises quite quickly with increasing Pr.

V. CONCLUSION

The numerical investigation has been carried out on the effect of velocity, temperature and concentration of a micropolar fluid past a constantly moving permeable plate with in the boundary layer of the flow. Computation is carried out for the prescribed parameters such as heat generation/absorption A, suction/injection Fw, magnetic parameter M and temperature-dependent viscosity. More over the effect of the above mentioned parameters on velocity, temperature and concentration of the fluid within the boundary layer are presented graphically.

Finally it concludes that;

- The velocity, temperature, of the fluid within the boundary layer increases when the heat generation/absorption parameter increases.
- An increase in heat generation/absorption parameter, magnetic parameter, and suction/injection parameter leads to increase in angular velocity of the microelements very close to the surface of the plate.
- The temperature and concentration of the fluid within the boundary layer decreases when both suction/injection parameter and magnetic parameter increase.
- The temperature within the boundary layer decline, for increasing value of temperature-dependent viscosity parameter,
- The velocity of the fluid within the boundary layer increases for increasing value of temperature-dependent viscosity parameter.



- The temperature decreases due to increase in Prandtl number and concentration declines as the Schmidt number increases.
- An increase in chemical reaction parameter decreases the concentration within the boundary layer. Moreover, the negative concentration was observed for larger values of chemical reaction parameter.
- The heat transfer parameter increases with the increasing values of Prandtl number while rate of mass transfer decreases with increasing Schmidt number.

NOMENCLATURE

C	species concentration
D	binary diffusion coefficient
N	radiation parameter
T	temperature
q_r	radiative heat flux
C _p	specific heat
E _c	Eckert number
k	thermal conductivity
K ₁	coupling constant
G	micro rotation parameter
Pr	Prandtl number
Q	heat generation or absorption
A	dimensionless heat generation or absorption
R _C	chemical reaction parameter
R	dimensionless chemical reaction parameter
Sc	Schmidt number
s	gyro viscosity
f	dimensionless stream function
g	dimensionless micro rotation
u	velocity in x direction
v	velocity in y direction
U ₀	velocity of the plate
V _w	non zero velocity component of the wall
x	distance along the surface
y	distance normal to the surface

Greek Symbols

η	similarity Variables
μ_f	reference viscosity
μ	dynamic viscosity
γ_s	spin gradient viscosity
ρ	density of the fluid.
σ	micro rotation component
α	electrical conductivity
σ_1	Stefan-Boltzmann constant
θ	dimensionless temperature
ϕ	dimensionless concentration

Subscripts

W	condition on the wall
∞	free stream condition

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