Combined Influence of Hall Current and Soret Effect on Convective Heat and Mass Transfer Flow past a Vertical Porous Plate in a Rotating Fluid and Dissipation with Convective Boundary Conditions

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Abstract

In this Paper, we analyse the effect of thermo-diffusion ,and dissipation on convective heat and mass transfer flow of viscous electrically conducting rotating fluid in a vertical rotating plate in the presence of transverse magnetic field under convective boundary conditions with partial slip.. By employing finite element technique the equations governing the flow, heat and mass transfer have been solved. The velocity, temperature and concentration distributions are analysed for different parametric values. The shear stress and rate of heat and mass transfer on the boundary are evaluated numerically for different variations.

Keywords : Hall Current, Heat and Mass transfer, Chemical Reaction, Porous Plate, Rotating fluid, Soret effect.

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1.INTRODUCTION

The motion of rotation fluids enclosed with in a body or vice versa, was given by Green span, discussed these problems relating to the boundary layers and their interaction in rotating flows and gave so many examples relating to such interaction. The rotating viscous flow equation yields a layer known as Eckman boundary layer after the Swedish oceanographer Eckman who discovered it. Attempts to observe the structure of the Eckman layer in the surface layers of the sea have been successful. Eckman layers are easy to produce and observe in the laboratory. Such boundary layers or similar ones are required to connect principally geotropic flow in the interior of the fluid to the horizontal boundaries where conditions like a prescribed horizontal stress or no slip on a solid bottom are given. In a similar way other kinds of various boundaries have been studies so as to connect geotropic flow to vertical boundaries (for example a vertical well along which the depth varies) on which boundary conditions consistent with geotropic flow are given. Mahendra Mohan [29] has discussed the free and forced convections in rotating Hydromagnetic viscous fluid between two finitely conduction parallel plates maintained at constant temperature gradients. In view of many scientific and engineering applications of fluids flow through porous media, different authors have been studied [Mahendra Mohan and Srivastava [30], Rao et.al. [39] Sarojamma and Krishna[ 41], Krishna et.al. [27],Seth and Ghosh [43],Agarwal and Dhanpal [5],Ghosh [17],El-Mistikawy et.al. [33a],Hazim Ali Attia [19] the combined free and forced convection flow of an incompressible viscous fluid in a parallel plates channel bounded below by a permeable bed and rotating with a constant angular velocity about an axis perpendicular to the length of the plates.
In the last several years considerable attention has been given to the study of the Hydromagnetic thermal convection due to its numerous applications in geophysics and astrophysics. It is well known that in the geothermal region, gases are electrically conduction and that they undergo the influence of magnetic fluid. Several authors [Gill and Casali [18], Jana [24], Yen [43], Mohanti [35], have theoretically investigated the natural convection effects in forced horizontal flows and considered the effect of wall conductance as convective horizontal channel flow. Circar and Mukherjee [12] have analyzed the effect of mass transfer and rotation on flow past a porous plate in a porous medium with variable suction in a slip flow regime. Balasubramanyam [7] and Reddy [28] have investigated convective heat and mass transfer flow in horizontal rotating fluid under different conditions. Several authors Singh and Mathew [49], Muthucumaraswamy and Ganesan [32], Deka et al. [15], Muthucumaraswamy [31], Muthucumaraswamy and Meenakshisundaram [28], Chamkha [10], Chamkha [11], Raptis and Perdikis [39], Ibrahim et al. [20], Indudhar et al. [21], Cheena Kesaviah et al. [11] have studied on oscillatory free convective MHD flow in a rotating vertical porous channel with heat sources.

When heat and mass transfer occur simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of more intricate nature. Mass fluxes can be created by temperature gradients and this is the Soret effect or thermo-diffusion effect. Several authors Adrian Postelnicu [1], Sreevani et al. [51], Barletta [8] and Zanchini [56], Barletta [5], Zanchini [56] and Sreevani [51], Sivaiah et al. [50], Indudhar et al. [22], Madhusudhan Reddy et al. [28], Kamalakar et al. [25], Rajasekhar et al. [40], Muthucumaraswamy et al. [33], Jafarunnisa [23], Alam et al. [6], Srirangavani [52], Jayasudha [58] have studied thermo-diffusion and diffusion thermo effects on combined heat and mass transfer through a porous medium under different conditions. Recently Madhaviilatha et al. [27a] have discussed the effect of non-linear density-temperature and concentration on rotating convective heat and mass transfer fluid flow past a porous stretching sheet with Soret and Dufour effects. Sukanya et al. [57] have discussed combined influence of Hall Currents and Soret effect on convective heat and mass transfer flow past vertical porous stretching plate in rotating fluid and dissipation with constant heat and mass flux and partial slip.

In all these investigations, the effects of Hall currents are not considered. However, in a partially ionized gas, there occurs a Hall current when the strength of the impressed magnetic field is very strong. These Hall effects play a significant role in determining the flow features. Sato [46], Yamanishi [55], Sherman and Sutton [48] have discussed the Hall effects on the steady hydromagnetic flow between two parallel plates. These effects in the unsteady cases were discussed by Pop [30]. Debnath [11] has studied the effects of Hall currents on unsteady hydromagnetic flow past a porous plate in a rotating fluid system and the structure of the steady and unsteady flow is investigated. Alam et al., [3] have studied unsteady free convective heat and mass transfer flow in a rotating system with Hall currents, viscous dissipation and Joule heating. Taking Hall effects in to account Krishna et al., [27] have investigated Hall effects on the unsteady hydromagnetic boundary layer flow. Rao et al., [39] have analyzed Hall effects on unsteady Hydromagnetic flow. Siva Prasad et al., [48a] have studied Hall effects on unsteady MHD free and forced convection flow in a porous rotating channel. Recently Seth et al., [43] have investigated the effects of Hall currents on heat transfer in a rotating MHD channel flow in arbitrary conducting walls. Sarkar et al., [44] have analyzed the effects of mass transfer and rotation and flow past a
porous plate in a porous medium with variable suction in slip flow region. Anwar Beg et al. have discussed unsteady magnetohydrodynamics Hartmann-Couette flow and heat transfer in a Darcian channel with Hall current, ionslip, Viscous and Joule heating effects. Ahmed has discussed the Hall effects on transient flow past an impulsively started infinite horizontal porous plate in a rotating system. Sukanya et al. have investigated the mixed convective heat and mass transfer flow past a porous stretching surface with constant heat and mass flux.

2. FORMULATION OF THE PROBLEM

We consider a steady hydromagnetic heat and mass transfer flow of a viscous electrically conducting along a porous infinite vertical plate \( y=0 \) in a rotating system. The flow is also assumed to be moving with a uniform velocity \( U_\infty \), which is in the \( x \)-direction, is taken along the plate in the upward direction and the \( y \)-axis is normal to it. Initially the plate is at rest, after that the whole system is allowed to rotate with a constant angular velocity \( \Omega \) about the \( y \)-axis. At the plate are maintained at convective heat and mass boundary conditions. \( T_\infty \) and \( C_\infty \) are the temperature and species concentration of the uniform flow respectively. A uniform magnetic field \( B \) is taken to be along the \( y \)-axis which is assumed to be electrically non-conducting. We assumed following (Pai) that the magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field is negligible in comparison with applied one, so that \( B=(0,B_0,0) \) and the magnetic lines of force are fixed relative to the fluid. The equation of conservation of charge \( \nabla \cdot \vec{J} = 0 \) gives \( J_y = \text{constant} \), where the current density \( \vec{J} = (J_x, J_y, J_z) \). Since the plate is electrically non-conducting, this constant is zero and hence \( J_y = 0 \) at the plate and also zero everywhere. A uniform magnetic field in the presence of fluid flow induces the current \( \vec{J} = (J_x, 0, J_z) \).

When the strength of the magnetic field is very large we include the Hall current so that the generalized Ohm’s law (Cowling) is modified to

\[
\vec{J} + \omega_e \tau_e \vec{J} \times \vec{H} = \sigma ( \vec{E} + \mu_e \vec{v} \times \vec{H} )
\]  

(1)

where \( \vec{q} \) is the velocity vector, \( \vec{H} \) is the magnetic field intensity vector, \( \vec{E} \) is the electric field, \( \vec{J} \) is the current density vector, \( \omega_e \) is the cyclotron frequency, \( \tau_e \) is the electron collision time, \( \sigma \) is the fluid conductivity and \( \mu_e \) is the magnetic permeability. The effect of Hall current give rise to a force in the \( z \)-direction which in turn produces a cross flow velocity in this direction and thus the flow becomes three-dimensional. To simplify the analysis, we assume that the flow quantities do not vary along \( z \)-direction and this will be valid if the surface is of very width along the \( z \)-direction. Neglecting the electron pressure gradient, ionslip and thermo-electric effects and assuming the electric field \( E=0 \).
The physical configuration considered here is shown in **Figure 1**. It is assumed that the plate is semi-infinite in extent and hence all the physical quantities depend on y and x. Thus accordance with the above assumptions and Boussinesq’s approximation, the basic equations relevant to the problem

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(2)

\[
u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} + \beta g(T - T_\infty) + \beta^* g(C - C_\infty) + 2\Omega w + \frac{\sigma B^2}{\rho} (U_o - u - mw)
\]  

(3)

\[
u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} = \nu \frac{\partial^2 w}{\partial y^2} + 2\Omega (U_o - u) - \frac{\sigma B^2}{\rho} (mw - (u - U_o))
\]  

(4)

\[
u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k_f}{\rho C_p} \frac{\partial^2 T}{\partial y^2} + \nu \left( \left( \frac{\partial u}{\partial y} \right)^2 + \left( \frac{\partial w}{\partial y} \right)^2 \right) + \frac{\sigma B^2}{\rho} ((U_o - u)^2 + w^2)
\]  

(5)

\[
u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_m \frac{\partial^2 C}{\partial y^2} + \frac{D_m K_f T}{T_m} \frac{\partial^2 T}{\partial y^2}
\]  

(6)

The boundary conditions for the problem are

\[u = b x, v = -V_w, w = 0, -k_j \frac{\partial T}{\partial y} = h (T - T_w(x, 0)), -D_m \frac{\partial C}{\partial y} = h (C_w - C_w(x, 0)) \text{ at } \eta = 0
\]  

(7)

\[u = U_o \quad w = 0, T \rightarrow T_o, C \rightarrow C_\infty \text{ as } \eta \rightarrow \infty
\]

Where b>0. The boundary conditions on the velocity in (2.7) are the no-slip conditions at the surface at y=0, while the boundary conditions on the velocity as y → ∞ follow from the fact that there is no flow far away from the stretching surface. The temperature and species concentration are maintained at a prescribed constant values T_w and C_w at the sheet and are assumed to vanish far away from the sheet.

Following the work of Sattar [37], a transformation is now made as

\[u_i = U_o - u \quad \Rightarrow \quad u = U_o - u_i
\]  

(8)

Equations (2)-(6) and the boundary conditions (6), respectively, transform to

\[- \frac{\partial u_i}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(9)

\[\left( U_o - u_i \right) \frac{\partial u_i}{\partial x} + v \frac{\partial u_i}{\partial y} = \nu \frac{\partial^2 u_i}{\partial y^2} - \beta g(T - T_\infty) - \beta^* g(C - C_\infty) - \frac{\sigma B^2}{\rho} (u_i - mw)
\]  

(10)

\[\left( U_o - u_i \right) \frac{\partial w_i}{\partial x} + v \frac{\partial w_i}{\partial y} = \nu \frac{\partial^2 w_i}{\partial y^2} + 2\Omega u_i - \frac{\sigma B^2}{\rho} (mw - u_i)
\]  

(11)

\[\left( U_o - u_i \right) \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = k_f \frac{\partial^2 T}{\partial y^2} + \nu \left( \left( \frac{\partial u_i}{\partial y} \right)^2 + \left( \frac{\partial w_i}{\partial y} \right)^2 \right) + \frac{\sigma B^2}{\rho C_p} (u_i^2 + w_i^2)
\]  

(12)
\[(U_0 - u_1) \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_m \frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m} \frac{\partial^2 T}{\partial y^2} - K' C\]  

\[(13)\]

\[u = bx, v = -V_w, w = 0, -k_f \frac{\partial T}{\partial y} = h(T_w - T_{\infty}(x,0)), -D_m \frac{\partial C}{\partial y} = h_2(C_w - C_w(x,0)) \text{ at } \eta = 0\]

\[u = U_o, \quad w = 0, T \rightarrow T_{w}, C \rightarrow C_{\infty} \quad \text{as} \quad \eta \rightarrow \infty\]  

\[(14)\]

Where \(u, v, w\) are the velocity components in the \(x, y, z\) directions respectively, \(v\) is the kinematics viscosity, \(g\) is the acceleration due to gravity, \(\rho\) is the density, \(\beta\) is the coefficient of Volumetric thermal expansion, \(\beta^*\) is the Volumetric mass expansion. \(T, T_w, T_{\infty}\) are the temperature of the fluid inside the thermal boundary layer, the plate temperature and the fluid temperature in the free stream respectively, while \(C, C_w, C_{\infty}\) are the corresponding concentrations. Also, \(K^1\) is the permeability of the porous medium, \(k\) is the thermal conductivity of the medium, \(D_m\) is the coefficient of mass diffusivity, \(Cp\) is the specific heat constant pressure, \(T_m\) is the mean fluid temperature, \(k_{T}\) is the thermal diffusion ratio, \(Cp\) is the concentration and other symbols have their usual meaning, \(C_s\) is the concentration susceptibility and other symbols have their usual meaning.

3. MATHEMATICAL ANALYSIS

In order to solve equations (10)-(13) under the boundary conditions (14), we adopt the well-defined similarity analysis to attain similarity solutions.

For this purpose, the following similarity transformations are now introduced:

\[\eta = y \sqrt{\frac{U_o}{2\nu x}}\]  

\[(15)\]

\[g_o(\eta) = \frac{w}{U_o}\]  

\[(16)\]

\[\theta(\eta) = \frac{T - T_{w}}{T_{w} - T_{\infty}}\]  

\[(17)\]

\[\phi(\eta) = \frac{C - C_{\infty}}{C_w - C_{\infty}}\]  

\[(18)\]

\[\psi = \sqrt{2\nu x U_o f(\eta)}\]  

\[(19)\]

\[u_1 = \frac{\partial \psi}{\partial y} = U_o f' (\eta)\]  

\[(20)\]

\[\frac{u}{U_o} = 1 - f'(\eta)\]

Now for reasons of similarity, the plate of concentration is assumed to be

\[C_w(x) = C_o + \bar{x}(C_0 - C_{\infty})\]

where \(C_o\) is considered to be mean concentration and \(\bar{x} = \frac{x U_o}{\nu}\)

The continuity equation (2) then yields

\[v = \frac{\partial \psi}{\partial x} = \sqrt{\frac{\nu U_o}{2\nu}} (\eta f'(\eta) - f(\eta))\]  

\[(21)\]
Also we have \( f_w = v_w(x) \sqrt{\frac{2x}{V U_0}} \) \hspace{1cm} (22)

Where \( f_w \) is the suction parameter or transpiration parameter and clearly in (22) \( f_w < 0 \) corresponds to suction and \( f_w > 0 \) corresponds to injection at the plate. From equations (10)-(14) and (15)-(20), we have the following dimensionless ordinary coupled non-linear differential equations.

\[
f'' + (\eta - f) f'' - G(\theta + N\phi) - D^{-1} f' - \frac{M^2}{1 + m^2} (f'' - mg) + Rg = 0 \hspace{1cm} (23)
\]

\[
g'' + (\eta = f) g' - Rg' + \frac{M^2}{1 + m^2} (mg' - f) = 0 \hspace{1cm} (24)
\]

\[
\theta'' + P_r (\eta - f) \theta' + Pr Ec((f'^2) + (g'^2)) + Pr Ec \frac{M^2}{1 + m^2} (f'^2 + g'^2) = 0 \hspace{1cm} (25)
\]

\[
\phi'' + Sc(\eta - f) \phi' + 2Scf' \phi + ScSod\phi'' = 0 \hspace{1cm} (26)
\]

With the corresponding boundary conditions

\[
f = f_w, f' = 1 + Af''(0), g = 0, \frac{d\theta}{d\eta} = -Bi(1 - \theta(0)), \frac{d\phi}{d\eta} = -Bc(1 - \phi(0)), \hspace{1cm} (27)
\]

where

\[
G_r = \frac{2\beta g (T_w - T_\infty) x^3}{v^2} \hspace{1cm} \text{(Grashof Number)}, \quad N = \frac{\beta^* (C_w - C_\infty)}{(T_w - T_\infty)} \hspace{1cm} \text{(Buoyancy parameter)},
\]

\[
D^{-1} = \frac{2vx}{k U_0} \hspace{1cm} \text{(Darcy parameter)}, \quad M = \frac{2x\sigma B_o^2}{\rho U_0} \hspace{1cm} \text{(Magnetic parameter)},
\]

\[
M_i^2 = \frac{M^2}{1 + m^2}, \quad R = \frac{4\Omega x}{U_0} \hspace{1cm} \text{(Rotational parameter)}, \quad P_r = \frac{\rho v C_p}{k} \hspace{1cm} \text{(Prandtl Number)},
\]

\[
Ec = \frac{U_0^2}{C_p (T_w - T_\infty)} \hspace{1cm} \text{(Eckert Number)}, \quad Sc = \frac{v}{D_m} \hspace{1cm} \text{(Schmidt Number)}, \quad S_o = \frac{D_m k (T_w - T_\infty)}{(T_m (C_w - C_\infty))} \hspace{1cm} \text{(Soret parameter)}
\]

For the computational purpose and without loss of generality \( \infty \) has been fixed as 8. The whole domain is divided into 11 line elements of equal width, each element being three noded.

**4. METHOD OF SOLUTION**

The equations (23 to 26) have been solved by employing finite element technique with three noded approximation functions. The Local Stiffness Matrices have been assembled by using inter element continuity, equilibrium and boundary conditions. The resulting global matrices have been solved by using iteration procedure. The process in continued until the convergence is reached.
5. SKIN FRICTION COEFFICIENT, NUSSELT NUMBER AND SHERWOOD NUMBER

The quantities of chief physical interest are the skin friction coefficients, the Nusselt Number and the Sherwood number. The wall skin frictions are defined by

\[ \tau_x = \mu \left( \frac{\partial u}{\partial y} \right)_{y=0} \quad \text{and} \quad \tau_z = \mu \left( \frac{\partial v}{\partial y} \right)_{y=0} \]

which are proportional to

\[ \left( \frac{\partial^2 f}{\partial \eta^2} \right)_{\eta=0} \quad \text{and} \quad \left( \frac{\partial g_0}{\partial \eta} \right)_{\eta=0} \]

The Nusselt Number is defined by

\[ Nu = \frac{1}{\Delta T} \left( \frac{\partial T}{\partial \eta} \right)_{\eta=0} \]

which is proportional to

\[ \left( \frac{\partial \theta}{\partial \eta} \right)_{\eta=0} \]

The Sherwood Number is defined by

\[ Sh = \frac{1}{\Delta C} \left( \frac{\partial C}{\partial \eta} \right)_{\eta=0} \]

which is proportional to

\[ \left( \frac{\partial \phi}{\partial \eta} \right)_{\eta=0} \]

The numerical values of the skin friction coefficients, the Nusselt Number and the Sherwood Number are sorted in Table 2.

6. COMPARISON

In the absence of Hall currents \((m=0)\) and no slip regime \((A=0)\) and \(Bi=Bc=1\), the results are in good agreement with Sreerangavani et al[52].

Table 1 shows the comparison

| Parameters | Sreerangavani et al[52] | Present results \((m=0, A=0, Bi=Bc=1)\) |
|------------|------------------------|------------------------------------------|
| R          | So                     | Ec | \(\tau_x(0)\) | Nu(0) | Sh(0) | \(\tau_x(0)\) | Nu(0) | Sh(0) |
| 0.5        | 0.5                    | 0.01 | 3.49064 | 0.07426 | 1.2087 | 3.48997 | 0.07429 | 1.2091 |
| 1.0        | 0.5                    | 0.01 | 3.48376 | 0.07328 | 1.2079 | 3.48372 | 0.07329 | 1.2081 |
| 1.5        | 0.5                    | 0.01 | 3.47259 | 0.07164 | 1.2054 | 3.47261 | 0.07169 | 1.2052 |
| 0.5        | 1.0                    | 0.01 | 3.48853 | 0.07523 | 1.2761 | 3.48849 | 0.07521 | 1.2762 |
| 0.5        | 1.5                    | 0.01 | 3.48704 | 0.07596 | 1.3214 | 3.48709 | 0.07599 | 1.3210 |
| 0.5        | 0.5                    | 0.03 | 3.43136 | 0.08732 | 1.4987 | 3.43133 | 0.08736 | 1.4989 |
| 0.5        | 0.5                    | 0.05 | 3.57222 | 0.05684 | 0.8670 | 3.57221 | 0.05686 | 0.8669 |
| 0.5        | 0.5                    | 0.07 | 3.69426 | 0.03131 | 0.4445 | 3.69424 | 0.03128 | 0.4448 |

7. DISCUSSION OF THE NUMERICAL RESULTS

The non-linear linear equations governing the flow have been analysed by employing Galerkin finite element technique with three nodded line segments. The velocity, temperature and concentrations distributions have been analysed for different variations of the parameters \(m, R, So, Ec, Bi \) and \(Bc\).

Figs. 2-7 show the variation of the axial velocity \(f^i(\eta)\) with different values of \(m, R, So, Ec, Bi \) and \(Bc\). An increase in the Hall parameter \((m)\) decreases the axial velocity in the flow region (fig. 2a). Fig. 6a represent \(f^i(\eta)\) with rotation parameter \(R\) (fig. 3). It can observed from the profiles that \(f^i(\eta)\) reduces with increase in the rotation parameter \(R\). Increasing the Soret parameter \(S_0\) larger the axial velocity in the flow region (fig. 4a). With reference to Ec (fig. 5), it can be seen that higher the dissipative heat larger the velocity. From figs. 6a\&7a we find
that the axial velocity reduces with increase in the convective heat and mass transfer constants Bi&Bc.

The cross velocity \( g(\eta) \) which arises due to the rotation and hall current is shown in figures 2b-7b for different parametric values. It is found that the cross velocity \( g(\eta) \) enhances with increase in \( m, Ec, So \) (figs.2b,4b,5b) and reduces with inverse rotation parameter \( R \),Soret parameter \( (So) \) and Eckert number \( (Sc) \). When the molecular buoyancy force dominates over the thermal buoyancy force the magnitude of cross velocity reduces when the buoyancy forces are in the same direction and for the forces acting in opposite directions. The cross velocity reduces with Bi and enhances with increase in Bc(figs.6b&7b).

The non-dimensional temperature \( (\theta) \) is shown in figures2c-7c for different parametric values. Higher the Hall parameter \( (m) \) /rotation parameter\( (R) \) larger the temperature in the flow region (figs.2c,3c). Increasing the Soret parameter \( S_0 \) results in an enhancement in the temperature (fig.4c). An increase in Eckert number \( Ec \) leads to an enhancement in the temperature (fig.5).From figs.6c&7c we find that higher the convective heat and mass transfer constants larger the temperature in the flow region.

The concentration distribution \( (\chi) \) is shown in figures.2d-7d for different parametric values. We follow the convention that the non-dimensional concentration is positive/negative according as actual concentration is greater/lesser than the ambient concentration. It is found that an increase in \( m \) leads to a depreciation in the actual concentration (figs. 2d). Increasing Soret parameter \( S_0 \) leads to an enhancement in the concentration (fig.4d). From fig.5, we find that the concentration reduces with Eckert number \( Ec \). An increase in rotation parameter \( R \) leads to an enhancement in the concentration (fig.3d).
Table 1: Skin friction ($\tau$), Nusselt Number (Nu) at $\eta = 0$

| Parameter | $\tau_x(0)$ | $\tau_z(0)$ | Nu(0) | Sh(0) |
|-----------|-------------|-------------|-------|-------|
| m 0.5     | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
|           | -2.60166    | -0.107289   | 0.593857 | 1.12706 |
|           | -2.72838    | -0.11423    | 0.540852 | 1.16808 |
|           | -2.73211    | -0.121966   | 0.551873 | 1.16965 |
| R 0.5     | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
|           | -2.62843    | -0.120678   | 0.533361 | 1.13811 |
|           | -2.69052    | -0.185135   | 0.490127 | 1.15165 |
|           | -2.65772    | -0.282248   | 0.482666 | 1.14009 |
| So 0.5    | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
|           | -2.64864    | -0.0983021  | 0.548881 | 1.0827 |
|           | -2.75688    | -0.126451   | 0.593793 | 1.00159 |
|           | -2.77041    | -0.138365   | 0.680923 | 0.99381 |
| Ec 0.01   | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
| 0.03      | -2.64414    | -0.086250   | 0.512556 | 1.13957 |
| 0.05      | -2.82623    | -0.109015   | 0.452638 | 1.20124 |
| 0.07      | -4.12237    | -0.253574   | 0.241422 | 1.77627 |
| Bi 0.1    | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
| 0.2       | -2.03456    | -0.085643   | 0.556754 | 1.0245 |
| 0.3       | -1.67543    | -0.095643   | 0.589765 | 0.9854 |
| 0.4       | -1.45676    | -0.123454   | 0.603456 | 0.9235 |
| Bc 0.05   | -2.59033    | -0.079692   | 0.534913 | 1.1203 |
| 0.10      | -1.56785    | -0.065455   | 0.556746 | 1.2435 |
| 0.15      | -1.23457    | -0.56743    | 0.576548 | 1.3056 |
| 0.20      | -0.96754    | -0.045666   | 0.586643 | 1.4056 |

The components of skin friction $\tau_x$ & $\tau_z$ are depicted in table 2 for different values of m, R, Ec, So, Bi and Bc. It is found that $\tau_x$ & $\tau_z$ enhances with increase in m. $\tau_z$ enhances at
the wall. $\tau_x$ reduces with increase in convective heat ad mass transfer constants $Bi$&$Bc$ at the wall while $\tau_z$ enhances with $Bi$ and reduces with $Bc$ at $\eta=0$. Higher the dissipative heat larger $\tau_x$ & $\tau_z$ at the wall. It can be seen that increasing the Soret parameter $S_0$ results in an enhancement in $\tau_x$ and $\tau_z$ at the wall $\eta=0$.

The rate of heat transfer (Nusselt number) at $\eta=0$ is exhibited in table 2 for different parametric values. Higher the thermal buoyancy force larger the rate of heat transfer at the wall. $|Nu|$ reduces with increase in the rotation parameter $R$ or Eckert number $Ec$. The rate of heat transfer at the wall experiences an enhancement with increase in the convective heat and mass transfer constants $Bi$&$Bc$. For an increase in the Soret parameter $S_0$, we notice an enhancement in $Nu$ at the wall.

The rate of mass transfer (Sherwood number) at $\eta=0$ is shown in table 2 for different parametric values. It is found that the rate of mass transfer enhances with increase in $m$. $|Sh|$ reduces with increase in the rotation parameter $R$ and enhances with increase in $Ec$. Increasing the Soret parameter $S_0$ leads to a depreciation in the rate of mass transfer at the wall. The rate of mass transfer at the wall reduces with $Bi$ and enhances with $Bc$.

8. CONCLUSIONS
An attempt has been made to discuss the combined impact of rotation and Hall currents on convective heat and mass transfer flow of a viscous fluid through a porous medium past a stretching surface. Using Finite element technique the governing equations have been solved. The important conclusion of this analysis are

- The profiles the primary and secondary velocities enhance, the temperature and concentration reduces with increase in $G$. The stress components $\tau_x$, $\tau_z$, Nusselt and Sherwood number enhances with $G$.
- An increase in Hall parameter reduces the primary velocity, concentration, enhances the secondary velocity, concentration. The stress components, Nusselt and Sherwood number enhances with $m$.
- An increase in rotation parameter ($R$) enhances the primary velocity, temperature, concentration and reduces the secondary velocity in the flow region. The Nusselt number reduces and Sherwood number enhances at the wall with rotation parameter $R$.
- The effect of thermo-diffusion is to enhance the velocities, concentration, temperature. The stress components, temperature enhances while the concentration reduces with $So$.
- An increase in the slip parameter ($A$) enhances the primary velocity, reduces the secondary velocity, temperature and concentration in the flow region. The Nusselt and Sherwood number enhances on the wall.
- An increase in $Bi$ and $Bc$ reduces the primary velocity, and enhances the secondary velocity and temperature while the concentration reduces with $Bi$ and enhances with $Bc$. The rate of heat and mass transfer enhance on the wall with increase in $Bi$ and $Bc$.

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