Combined Influence of Hall Current ,Thermo-Diffusion, Diffusion-Thermo effects on Convective Heat and Mass Transfer Flow past a Vertical Porous Plate in a Rotating Fluid with Dissipation with Constant Heat and Mass Flux

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Abstract

In this paper we analyse the effect of thermo-diffusion, diffusion-thermo effect on convective heat and mass transfer flow of viscous electrically conducting dissipating fluid in a vertical rotating plate in the presence of transverse magnetic field with constant heat and mass flux and non-linear thermal radiation. 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. It is found that an increase in temperature(A) enhances the rate of heat and mass transfer on the stretching surface.

Keywords: Thermo Diffusion, Heat and Mass Transfer, Dissipation, Vertical Porous plate, Rotating Fluid.

1.INTRODUCTION:

The MHD fluid flow in a rotating channel is an interesting area in the study of fluid mechanics because of its relevance to various engineering applications. It is challenging approach to atmospheric science that exerts its influence of rotation to help in understanding the behavior of oceanic circulation and formation of galaxies. The effect of Coriolice force in the atmosphere is exposed to oceanic circulation and the formation of galaxies in taking into account the flow of electron is continuously liberated from the sun what is called “solar wind”. The MHD flow in the rotating environment leads to a startup process implying thereby a viscous layer at the boundary is suddenly set into motion and the rate of rotation becomes important in the application of various branches of geophysics, astrophysics and fluid engineering. Keeping these applications in view several authors [Mahendra Mohan [21], Mahendra Mohan and Srivastava [22], Rao et.al. [25], Sarojamma and Krishna [26], Krishna et.al. [18], Seth and Ghosh [29], Agarwal and Dhanpal [5], Ghosh [12], El-Mistikawy et.al. [11], Hazim Ali Attia [13], Circar and Mukherjee [9], Balasubramanyam [6] and Reddy [20], Singh and Mathew [30]] have investigated effect of rotation on convective heat / mass transfer flow in different configuration under varied conditions.

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. The combined influence of Soret and Dufour effect on convection flow have been invested by several researchers Adrian Postelnicu [1], Sreevani et. al. [33], Barletta [7] and Zanchini [37],

Soundalgekar and Pop [32], Barletta [7], Sreevani [33], Sivaiah et. al. [31], Indudhar et. al. [141], Madhusudhan Reddy et. al. [20], Kamalakhar et. al. [17], Rajasekhar et. al. [24], Muthucumaraswamy et. al. [23], Jafarunnisa [15], Srirangavani [34], Alam et. al. [3], Jayasudha et al[16], Madhavalatha et al[19]] with varied conditions.

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. Yamanishi [36], Sherman and Sutton [28] have discussed the Hall effects on the steady hydromagnetic flow between two parallel plates. Debnath [10] 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.*, [18] have investigated Hall effects on the unsteady hydromagnetic boundary layer flow. Rao *et. al.*, [25] have analyzed Hall effects on unsteady Hydromagnetic flow. Seth *et. al.*, [29] have investigated the effects of Hall currents on heat transfer in a rotating MHD channel flow in arbitrary conducting walls. Cirkar *et. al.*, [9] 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 [4] have discussed unsteady magneto hydrodynamics Hartmann-Couette flow and heat transfer in a Darcian channel with Hall current, ion-slip, Viscous and Joule heating effects. Ahmed [2] has discussed the Hall effects on transient flow pas an impulsively started infinite horizontal porous plate in a rotating system. Sukanya et al [35] have investigated the combined effect of Hall current, dissipation, Soret effect, Slip effect on convective heat and mass transfer flow of and electrically conducting fluid past a stretching surface with constant heat and mass flux.

2. FORMULATION OF THE PROBLEM:

We consider a steady hydro-magnetic heat and mass transfer flow of a viscous electrically conducting along an infinite vertical plate $y=0$ in a rotating system. The flow is also assumed to be moving with a uniform velocity U_∞ , 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 Ω about the y -axis. The temperature and the species concentration at the plate are constantly raised from T_∞ and C_∞ to T_w and C_w respectively, where T_∞ and C_∞ are the temperature and species concentration of the uniform flow respectively. A uniform magnetic field in the presence of fluid flow induces the current $(J_x, 0, J_z)$.

Fig. 1 : Physical configuration and coordinate system

$$\begin{aligned}
u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} - 2\Omega w &= \nu \frac{\partial^2 u}{\partial y^2} - \frac{\sigma \mu_e H_0^2}{1+m^2} (u + mw) + \left(-\left(\frac{\nu}{k}\right) u + \beta g(T - T_\infty) + \beta^* g(C - C_\infty) \right) \\
u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + 2\Omega u &= \nu \frac{\partial^2 w}{\partial y^2} + \frac{\sigma \mu_e^2 H_0^2}{1+m^2} (m_0 u - w) - \left(\frac{\nu}{k}\right) w
\end{aligned} \quad (1)$$

The energy equation is

$$\begin{aligned}
u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} &= \frac{k_f}{\rho C_p} \frac{\partial^2 T}{\partial y^2} + \frac{\nu}{C_p} \left(\left(\frac{\partial u_1}{\partial y} \right)^2 + \left(\frac{\partial w}{\partial y} \right)^2 \right) + \\
&+ \frac{\sigma B_o^2}{C_p (1+m^2)} (u_1^2 + w^2) + \frac{D_m K_T}{C_p C_s} \frac{\partial^2 C}{\partial y^2} - \frac{1}{\rho C_p} \frac{\partial(q_R)}{\partial y}
\end{aligned} \quad (2)$$

The diffusion equation is

$$u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_m \frac{\partial^2 C}{\partial y^2} + \frac{D_m K_T}{T_m} \frac{\partial^2 T}{\partial y^2} \quad (3)$$

The boundary conditions for the problem are

$$u = ax + L \frac{\partial u}{\partial y}, v = v_o, w = 0, \frac{\partial T}{\partial y} = -\frac{q_w}{k_f}, \frac{\partial C}{\partial y} = -\frac{m_w}{D_m} \quad \text{at } y = 0 \quad (4)$$

$$u = U_o, w = 0, T \rightarrow T_\infty, C \rightarrow C_\infty \quad \text{as } y \rightarrow \infty$$

The radiation heat term(Brewster[8]) by using The Rosseland approximation is given by

$$q_r = -\frac{4\sigma^*}{3\beta_R} \frac{\partial T'^4}{\partial y} \quad (5)$$

$$T'^4 \cong 4TT_\infty^3 - 3T_\infty^4 \quad (6)$$

$$\frac{\partial q_R}{\partial z} = -\frac{16\sigma^* T_\infty^3}{3\beta_R} \frac{\partial^2 T}{\partial y^2} \quad (7)$$

The non-dimensional temperature $\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}$ can be simplified as $T = T_\infty (1 + (\theta_w - 1)\theta)$

Where $\theta_w = \frac{T_w}{T_\infty}$ is the temperature parameter a transformation is now made as

$$u_1 = U_o - u \Rightarrow u = U_o - u_1 \quad (8)$$

Equations (1)-(5) and the boundary conditions (6), respectively, transform to

$$-\frac{\partial u_1}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (9)$$

$$(U_o - u_1) \frac{\partial u_1}{\partial x} + v \frac{\partial u_1}{\partial y} = \nu \frac{\partial^2 u_1}{\partial y^2} - \beta g(T - T_\infty) - \beta^* g(C - C_\infty) - \frac{\sigma B_o^2}{\rho} (u_1 - mw) \quad (10)$$

$$(U_o - u_1) \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} = \nu \frac{\partial^2 w}{\partial y^2} + 2\Omega u_1 - \frac{\sigma B_o^2}{\rho} (mw - u_1) \quad (11)$$

$$(U_0 - u_1) \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k_f}{\rho C_p} \frac{\partial^2 T}{\partial y^2} + \frac{\nu}{C_p} \left(\left(\frac{\partial u_1}{\partial y} \right)^2 + \left(\frac{\partial w}{\partial y} \right)^2 \right) + \frac{\sigma B_o^2}{C_p (1 + m^2)} (u_1^2 + w^2) + \frac{D_m K_T}{C_p C_s} \frac{\partial^2 C}{\partial y^2} - \frac{1}{\rho C_p} \frac{\partial (q_R)}{\partial y} \quad (12)$$

$$(U_0 - u_1) \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_m \frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m} \frac{\partial^2 T}{\partial y^2} \quad (13)$$

$$u = ax + L \frac{\partial u}{\partial y}, v = v_o, w = 0, \frac{\partial T}{\partial y} = -\frac{q_w}{k_f}, \frac{\partial C}{\partial y} = -\frac{m_w}{D_m} \quad \text{at } y = 0 \quad (14)$$

$$u = U_o, w = 0, T \rightarrow T_\infty, C \rightarrow C_\infty \quad \text{as } y \rightarrow \infty$$

Where u, v, w are the velocity components in the x, y, z directions respectively, ν is the kinematics viscosity, g is the acceleration due to gravity, ρ is the density, β is the coefficient of Volumetric thermal expansion, β^* is the Volumetric mass expansion. T, T_w, T_∞ 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_∞ are the corresponding concentrations. Also, k_1 is the permeability of the porous medium. k_f is the thermal conductivity of the medium, D_m is the coefficient of mass diffusivity, C_p is the specific heat constant pressure, T_m is the mean fluid temperature, K_T is the thermal diffusion ratio, C_p is the concentration and other symbols have their usual meaning, C_s is the concentration susceptibility and other symbols have their usual meaning.

In order to solve equations (9)-(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:

$$\eta = y \sqrt{\frac{U_o}{2\nu x}} \quad (15) \quad g_o(\eta) = \frac{w}{U_o} \quad (16)$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty} \quad (17) \quad \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \quad (18)$$

$$\psi = \sqrt{2\nu x U_o} f(\eta) \quad (19) \quad u_1 = \frac{\partial \psi}{\partial y} = U_o f'(\eta) \quad (20)$$

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

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_0 is considered to be mean concentration and $\bar{x} = \frac{x U_o}{\nu}$

The continuity equation (14) then yields

$$v = \frac{\partial \psi}{\partial x} = -\sqrt{\frac{\nu U_o}{2x}} (\eta f'(\eta) - f(\eta)) \quad (21)$$

$$\text{Also we have } f_w = v_o(x) \sqrt{\frac{2x}{\nu U_o}} \quad (22)$$

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 (9)-(13) and (15)-(20), we have the following dimensionless ordinary coupled non-linear differential equations.

$$f'' + (\eta - f)f' - G(\theta + N\phi) - \left(\frac{1}{K}\right)f' - \frac{M^2}{1+m^2}(f' + mg_o) + 2Rg_o = 0 \quad (23)$$

$$g_o'' + (\eta - f)g_o + Rf' - \left(\frac{1}{K}\right)g_o - \frac{M^2}{1+m^2}(g_o - mf') = 0 \quad (24)$$

$$Rd(1 + (\theta_w - 1)\theta)^3 \theta'' + P_r(\eta - f)\theta' + P_r Ec((f'')^2 + (g_o')^2) + \frac{Pr Ec M^2}{1+m^2}((f')^2 + (g_o)^2) + Pr Du \phi'' = 0 \quad (25)$$

$$\phi'' - Sc(\eta - f)\phi' + 2Sc(f' - 1)\phi + ScS_0\theta'' = 0 \quad (26)$$

With the corresponding boundary conditions

$$f = f_w, f' = 1 + A_1 f'', g_o = 0, \frac{d\theta}{d\eta} = -1, \frac{d\phi}{d\eta} = -1, \text{ at } \eta = 0 \quad (27)$$

$$f' = 0, \quad g_o = 0, \theta = 0, \phi = 1 \quad \text{as } \eta \rightarrow \infty$$

where

$$G_r = \frac{2\beta g(T_w - T_\infty)x^3}{\nu^2} \text{ (Grashof Number)}, N = \frac{\beta_c(C_w - C_\infty)}{\beta_T(T_w - T_\infty)} \text{ (Buoyancy ratio)}$$

$$K = \frac{2\nu x}{k U_0} \text{ (Permeability parameter)}, M = \frac{2x\sigma B_0^2}{\rho U_0} \text{ (Magnetic parameter)},$$

$$R = \frac{4\Omega x}{U_0} \text{ (Rotational parameter)}, N_r = \frac{4\sigma T_\infty^3}{\beta_R k_f} \text{ (Radiation parameter)}$$

$$P_r = \frac{\rho \nu C_p}{k} \text{ (Prandtl Number)}, Sc = \frac{\nu}{D_m} \text{ (Schmidt Number)},$$

$$S_0 = \frac{D_m k_T (T_w - T_\infty)}{C_s C_p (C_w - C_\infty)} \text{ (Soret parameter)}, Du = \frac{D_m k_T (C_w - C_\infty)}{T_m (T_w - T_\infty)} \text{ (Dufour parameter)}$$

$$A_1 = L \sqrt{\frac{U_0}{2\nu x}} \text{ (Slip parameter)}, A = \theta_w \text{ (Temperature ratio)}, M_1^2 = \frac{M^2}{1+m^2}$$

For the computational purpose and without loss of generality ∞ has been fixed as $\eta_{\max} = 8$. The whole domain is divided into 11 line elements of equal width, each element being three noded.

3. 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 is continued until the convergence is reached.

4. 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

$$\tau_x = \mu \left(\frac{\partial u}{\partial y} \right)_{y=0} \quad \text{and} \quad \tau_z = \mu \left(\frac{\partial w}{\partial y} \right)_{y=0} \quad \text{which are proportional to}$$

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

The Nusselt Number is defined by $Nu = \frac{1}{\Delta T} \left(\frac{\partial T}{\partial y} \right)_{y=0}$ which is proportional to $\left(\frac{1}{\theta(0)} \right)$

The Sherwood Number is defined by $Sh = \frac{1}{\Delta C} \left(\frac{\partial C}{\partial y} \right)_{y=0}$ which is proportional to $\left(\frac{1}{\phi(0)} \right)$

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

5.COMPARSION

In the absence of Dufour effect(Du=0), radiation (Nr=0,A=0) the results are in good agreement with those of Sukanya et al [35]

Parameter		Sukanya et al [35]				Present Results(Du=0,Nr=0,A=00)			
		$\tau_x(0)$	$\tau_x(0)$	Nu(0)	Sh(0)	$\tau_x(0)$	$\tau_x(0)$	Nu(0)	Sh(0)
m	0.5	-2.5903	-0.07969	0.53491	1.1203	-2.5902	-0.07966	0.53489	1.1202
	1.0	-2.6011	-0.10278	0.53985	1.1271	-2.6009	-0.10269	0.53968	1.1273
	1.5	-2.7283	-0.11142	0.50085	1.1688	-2.7279	-0.11138	0.50069	1.168
R	0.5	-2.5903	-0.07969	0.5349	1.1203	-2.5902	-0.0796	0.5348	1.1202
	1.0	-2.5841	-0.1206	0.5333	1.1181	-2.5841	-0.1206	0.5333	1.118
	2.0	-2.6905	-0.1851	0.4901	1.1516	-2.6905	-0.1851	0.4901	1.1515
s0	0.5	-2.5903	-0.0796	0.5349	1.1203	-2.5902	-0.0796	0.5348	1.1202
	1.5	-2.6486	-0.0983	0.5488	1.0827	-2.6486	-0.0983	0.5488	1.0825
	2.0	-2.7568	-0.1264	0.4937	1.4015	-2.7568	-0.1264	0.4937	1.4014
Ec	0.01	-2.5903	-0.079692	0.5349	1.1203	-2.5902	-0.0796	0.5348	1.1202
	0.03	-2.6441	-0.08625	0.5125	1.1395	-2.6439	-0.0861	0.5124	1.1394
	0.05	-2.8262	-0.1091	0.4526	1.2012	-2.8259	-0.109	0.4525	1.2011
A1	0.2	-2.5903	-0.0796	0.5349	1.1203	-2.5902	-0.0799	0.5348	1.1202
	0.4	-2.0901	-0.1238	0.5802	1.2299	-2.09	-0.124	0.5801	1.2295
	0.6	-1.8688	-0.1716	0.5592	1.3448	-1.8684	-0.1714	0.5591	1.3444
Pr	0.71	-2.5903	-0.0796	0.5349	1.1203	-2.5902	-0.0795	0.5348	1.1202
	1.71	-2.3855	-0.0407	0.5863	1.0781	-2.3847	-0.0406	0.5862	1.0779
	3.71	-2.4124	-0.0377	0.5453	1.1077	-2.4119	-0.0379	0.5456	1.1071

6. DISCUSSION OF THE NUMERICAL RESULTS:

The non-linear, coupled equations governing the flow, heat and mass transfer have solved by using Galerkin finite element method. The velocity, temperature, concentration, skin friction components, Nusselt number and Sherwood number at the wall have evaluated numerically for different variations of m , Ec , R , Nr , S_0 , Du , $A1$, A

Fig.2a represent $f'(\eta)$ with rotation parameter R . It can be observed from the profiles that $f'(\eta)$ reduces with increase in the rotation parameter R . Fig.3a shows the variation of axial velocity with radiation parameter (Nr). Higher the radiative heat flux smaller the axial velocity. With reference to Ec , it can be seen that higher the dissipative heat smaller the velocity. Thus the presence of the dissipative term leads to a depreciation in the axial velocity (fig.4).). Increasing the Soret parameter S_0 (or decreasing the Dufour parameter Du) smaller the axial velocity in the flow region (fig.5a). The variation of axial velocity with temperature ratio (A) shows that the axial velocity increases with increase in $A \leq 2.0$ and reduces with higher $A \geq 2.5$ in the flow region (0,1.5), while in the remaining region, it enhances with A (fig.6a). Fig.7a illustrates $f'(\eta)$ with slip parameter $A1$. It can be found from the profiles that the axial velocity enhances in the flow region (0,1.5) and reduces in the remaining flow region.

The cross velocity ($g(\eta)$) which arises due to the rotation is shown in figures.2b-7b for different parametric values. Higher the Lorentz force/higher the Coriolice force/higher the dissipative energy, larger the cross velocity (figs.2b,4b). Higher the radiative heat flux smaller the magnitude of the cross velocity (fig.3b). Increase in S_0 (or decrease in Du) results in an enhancement in the cross velocity (fig.5b). From fig.6b we find that the cross velocity reduces in the flow region with increasing temperature ratio (A). An increase in slip parameter ($A1$) enhances cross velocity in the flow region (0,1.0) and reduces in the region (1.1,4.0) with increasing $A1$ (fig.7b).

The non-dimensional temperature (θ) is shown in figures.2c-7c for different parametric values. The temperature enhances with increase in R (figs.2c). An increase in the radiation Nr leads to a depreciation in the temperature (figs.3c). Higher the dissipative energy larger the temperature in the flow region (fig.4c). Increasing the Soret parameter S_0 (or decreasing Dufour parameter Du) results in a depreciation in the temperature (fig.5c). From fig.6c, the temperature enhances in the entire flow region with increasing temperature ratio (A). An increase in slip parameter ($A1$) results in a depreciation in the flow region (fig.7c).

The concentration distribution (C) is shown in figures 2d-7d for different parametric values. From fig.2d & 3d we find that the concentration enhances with increasing rotation parameter (R) and radiation parameter (Nr). From fig. 5d we find that increasing Soret parameter S_0 (or decreasing Dufour parameter Du) leads to an enhancement in the concentration. An increase in temperature ratio ($A \leq 1.5$) enhances and reduces with higher $A \geq 2.0$ in the flow region (0,1.5) and in the remaining flow region, it reduces with increasing A (fig.6d). From fig.7d we notice a depreciation in the concentration with increasing the slip parameter ($A1$).

The components of skin friction τ_x & τ_z are depicted in tables 2 for different values of R , Nr , Ec , S_0 , Du , A and $A1$. The variation of τ_x & τ_z with rotation parameter R shows that an increase in R reduces τ_x and enhances τ_z at the wall. Lesser the molecular diffusivity smaller τ_x and τ_z at the wall. Higher the thermal radiation parameter ($Nr \leq 1.5$) reduces τ_x and τ_z while for higher $Nr \geq 3.5$, they experience an enhancement at the wall $\eta=0$. Higher the dissipative heat ($Ec \leq 0.05$) smaller τ_x & τ_z at the wall and for still higher $Ec \geq 0.07$, they enhance at the

wall. From table.1 it can be seen that increasing the Soret parameter S_0 (or decreasing Du) results in a depreciation in τ_x and τ_z at the wall $\eta=0$. An increase in temperature parameter(A) or slip parameter(A1) lead to a reduction in τ_x and increment in τ_z at the wall.

The rate of heat transfer (Nusselt number) at $\eta=0$ is exhibited in table.1 for different parametric values. $|Nu|$ enhances with increase in the radiation parameter $Nr \leq 1.5$ and for still higher $Nr \geq 3.5$, it reduces at the wall. The variation of Nu with Sc shows that lesser the molecular diffusivity, smaller $|Nu|$ at the wall. An increase in Eckert number $Ec \leq 0.03$ results in an enhancement in $|Nu|$ and for higher $Ec \geq 0.05$, $|Nu|$ reduces at the wall. Increasing the Soret parameter S_0 (or decreasing Du) results in an enhancement in the rate of heat transfer at the wall $\eta=0$. An increase in temperature parameter(A) or slip parameter(A1) lead to an enhancement in $|Nu|$ at the wall.

The rate of mass transfer (Sherwood number) at $\eta=0$ is shown in table.1 for different parametric values. It is found that the rate of mass transfer enhances with increase in Ec . $|Sh|$ reduces with increase in the rotation parameter(R). An increase in radiation parameter ($Nr \leq 1.5$) results in a reduction in $|Sh|$ and for higher $Nr \geq 3.5$, $|Sh|$ enhances at the wall. Higher the dissipative heat larger the rate of mass transfer at the wall. Increasing the Soret parameter S_0 (or decreasing Dufour parameter Du) leads to a depreciation in the rate of mass transfer at the wall. The rate of mass transfer at the wall reduces with increase in temperature parameter(A) and enhances with slip parameter(A1).

Fig.2a Effect of R on $\frac{u}{v_0}(\eta)$
 $Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.2b Effect of R on $g(\eta)$
 $Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.2c Effect of R on $\theta(\eta)$
 $Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.2d Effect of R on $\phi(\eta)$
 $Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.3a Effect of Nr on $\frac{u}{v_0}(\eta)$
 $R=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.3b Effect of Nr on $g(\eta)$
 $R=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.3c Effect of Nr on $\theta(\eta)$
 $R=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.3d Effect of Nr on $\phi(\eta)$
 $R=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.01, A1=0.1$

Fig.4a Effect of Ec on $\frac{u}{v_0}(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.4b Effect of Ec on $g(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.4c Effect of Ec on $\theta(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.4d Effect of Ec on $\phi(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.5a Effect of So & Du on $\frac{u}{v_0}(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.5b Effect of So & Du on $g(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.5c Variation of θ with So & Du
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.5d Effect of So & Du on $\phi(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.6a Effect of A on $\frac{u}{v_0}(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.6b Effect of A on $g(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, A=1.05, A1=0.2$

Fig.6c Effect of A on $\theta(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A1=0.2$

Fig.6d Effect of A on $\phi(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A1=0.2$

Fig.7a Effect of $A1$ on $\frac{u}{v_0}(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.05$

Fig.7b Effect of $A1$ on $g(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.05$

Fig.7c Effect of $A1$ on $\theta(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.05$

Fig.7d Effect of $A1$ on $\phi(\eta)$
 $R=0.5, Nr=0.5, Ec=0.01, So=0.3, Du=0.1, A=1.05$

Table.1 : Stress components(τ_x, τ_z), Nusset number(Nu) ans Sherwood number(Sh)at $\eta=0$

Parameter		$\tau_x(0)$	$\tau_z(0)$	Nu(0)	Sh(0)
R	0.5	-3.09644	-0.165061	0.516332	0.791995
	1.0	-3.01412	-0.504297	0.502481	0.774967
	1.5	-2.89859	-0.671227	0.480995	0.748635
	2.0	-2.80093	-0.693703	0.460585	0.723643
So/Du	0.6/0.1	-3.09644	-0.165061	0.516332	0.791995
	1.0/0.06	-2.89655	-0.13539	0.630398	0.707459
	1.5/0.04	-2.93765	-0.147522	0.686339	0.66107
	2.0/0.03	-2.97931	-0.157973	0.708418	0.65422
Nr	0.5	-1.72342	-0.312872	0.61395	0.927061
	1.5	-1.65197	-0.286615	0.669518	0.895061
	3.5	-1.69343	-0.301831	0.636062	0.913491
	5.0	-1.69549	-0.302753	0.634326	0.916162
Ec	0.01	-3.09644	-0.165061	0.516332	0.791995
	0.03	-2.94803	-0.134326	0.529296	0.81069
	0.05	-2.94018	-0.128126	0.495478	0.869714
	0.07	-3.14631	-0.147321	0.379515	1.16943
A1	0.2	-3.09644	-0.165061	0.516332	0.791995
	0.4	-2.28648	-0.168198	0.68294	0.781303
	0.6	-1.88822	-0.18275	0.791184	0.776691
	0.8	-1.62156	-0.197653	0.873288	0.76516
A	1.01	-1.72342	-0.312872	0.61395	0.61395
	1.5	-1.32712	-0.328646	0.636441	0.636441
	2.0	-1.283	-0.462606	0.488108	0.688108
	2.5	-0.929445	-0.481823	0.709509	0.709509

7. 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 with non-linear thermal radiation. Using Finite element technique the governing equations have been solved .The important conclusion of this analysis are

- 1) An increase in rotation parameter (R) reduces the primary velocity and enhances the secondary velocity, temperature and concentration in the flow region. The stress τ_x ,Nu and Sh reduce while τ_z enhances on the wall with increase in m.
- 2) The effect of thermo-diffusion is to enhance the velocities, concentration and reduces the temperature. The stress components, temperature enhances while the concentration reduces with So.

- 3) Higher the dissipation smaller the axial and larger the cross flow, velocity, temperature and concentration. τ_x , τ_z reduce, Nu enhances with smaller values of Ec and they enhance higher Ec. The Sherwood number enhances on the wall $\eta=0$ with increase in Ec.
- 4) An increase in Slip parameter (A1)/temperature parameter(A) enhances velocities in the region adjacent to the wall and reduces far away from the wall. The temperature and concentration enhances with A while they reduce with A1.
- 5) Increasing Sr(or decreasing Du) reduces f' , θ , stress components and enhances g , ϕ , Nu.

8. REFERENCES

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