

Impact of Thermo-Diffusion, Diffusion-Thermo effects, and Space Dependent Heat Source on the Micropolar Fluids within a Porous Medium in a Vertical Channel

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ABSTRACT : The current study examines the convective heat and mass transfer characteristics of micropolar fluid flow through a porous vertical channel, accounting for the combined effects of thermo-diffusion (Soret effect), diffusion-thermo (Dufour effect), space-dependent heat generation/absorption, and spin-gradient viscosity. The governing equations for momentum, rotational momentum, energy, and concentration are developed using buoyancy forces, porous-medium resistance, and micropolar fluid properties. The resulting coupled nonlinear differential equations are numerically solved by using Runge-Kutta shooting technique to investigate the effects of the governing parameters on velocity, microrotation, temperature, and concentration profiles, as well as the skin friction coefficient, Nusselt number, and Sherwood number. The results demonstrate that thermo-diffusion and diffusion-thermo effects significantly modify the thermal and concentration fields, while the space-dependent heat source alters the temperature distribution and heat-transfer rate. Spin-gradient viscosity strongly influences microrotation and velocity, highlighting the importance of micropolar effects in porous-channel transport. The results show that thermo-diffusion (Sr) and diffusion-thermo (Du) effects have a major impact on the thermal and concentration fields, whereas a space-dependent heat source (A1) changes the temperature distribution and heat transfer rate. Spin-gradient viscosity (Λ) has a considerable influence on microrotation and velocity, emphasising the relevance of micropolar effects in porous channel transport.

KEYWORDS: Micropolar fluid; Porous medium; Vertical channel; Thermo-diffusion; Diffusion-thermo; Space-dependent heat source; Spin-gradient viscosity; Microrotation.

INTRODUCTION

Micropolar fluid flow and coupled heat and mass transfer through porous media have attracted considerable attention because they provide a more realistic representation of fluids containing suspended microstructures, such as polymeric liquids, blood, colloidal suspensions, and lubricants. Unlike classical Newtonian fluids, micropolar fluids account for the independent rotation of fluid micro-elements, thereby introducing additional characteristics such as microrotation, vortex viscosity, and spin-gradient viscosity. These effects can substantially modify the momentum, thermal, and concentration fields by Srinivasacharya and RamReddy [1]. In particular, vertical-channel configurations are important for studying buoyancy-driven convection and transport processes in engineering and industrial systems. Previous investigations (Dulal Pal and Sewli Chatterjee[2], Suresh et.al.[3], Pala and Das [4]) have demonstrated that Soret (thermo-diffusion) and Dufour (diffusion-thermo) effects can strongly influence heat and mass transfer in micropolar fluids and porous media.

Laminar flows through channels have applications in the fields of gas diffusion, ablation cooling, filtration, microfluidic devices, surface sublimation, grain regression (as in the case of combustion in rocket motors) and the modelling of air circulation in the respiratory system. Laminar air –flow systems have been used by the aerospace industry to control particular contamination. Furthermore, the laminar flow cabinet have been used in the maintenance of negative pressure and in the adjustment of the fans to exhaust more air. Therefore, the Navier-Stokes equations which are the governing equations for these problems, have attracted the interest of the researchers. Sutton and Barto [5] described an exact solution of Navier-Stokes equations for motion of an incompressible viscous fluid in a channel with different pressure gradients. Their solutions are helpful in verifying and validating computational models of complex on unsteady motions, to guide the design of fuel injectors and controlled experiments. Simulation of flow through microchannels with design roughness was presented numerically by Rawool et al [6]. A numerical investigation is made by Robinson [7] for the problem of steady laminar incompressible flow in a porous channel with uniform suction at both walls. Taylor et al [8] studied three-dimensional flow buy uniform suction through parallel porous walls. Two dimensional viscous incompressible fluid flow between two porous walls with uniform suction was analysed by Cox [9]. Berman [10] proposed the two dimensional laminar steady flow through a porous channel which was driven by suction or injection .Similarity one/two dimensional laminar flow in a porous channel with wall suction or injection was examined analytically by Laurent et al [11]. Raftari and Vajravelu [12] have discussed the flow and heat transfer characteristics of a magnetohydrodynamic viscoelastic fluid in a parallel plate channel with a stretching wall. Sami Ullah Khan et al [13] have

discussed hydromagnetic flow and heat transfer over a porous oscillating stretching surface in a viscoelastic fluid with porous medium. Sarojamma et al [14] have discussed MHD Casson fluid flow, heat and mass transfer in a vertical channel with stretching walls. Vijayalakshmi et al [15] have investigated unsteady flow of a casson fluid through a vertical channel with walls of expansion and contraction. Sreenivasarao [16] has discussed the combined influence of chemical reaction and Soret effect on MHD convective heat and mass transfer in a vertical channel with stretching walls.

The motion of rotating 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. Balasubramanyam [17] have investigated convective heat and mass transfer flow in horizontal rotating fluid under different conditions. Jayasudha et al [18] have discussed the effect of chemical reaction, Non-Uniform Heat source on convective heat and mass transfer flow past a stretching sheet in a rotating fluid. Garg et al [19] have investigated rotating MHD convective flow of Oldroyd B fluid through a porous medium in a vertical porous channel with thermal radiation. Venkatarami Reddy [20] has analysed radiation absorption on convective heat and mass transfer flow past a vertical porous plate in a rotating fluid with chemical reaction and dissipation. BhuvanaVijaya et al [21] have analysed double diffusive convection of a rotating fluid over a vertical plate embedded in Darcy-Forchheimer porous medium with non-uniform heat source. Mahmud Alam et.al.[28] have analyzed the viscous dissipation and joule heating effects on steady MHD combined heat and mass transfer flow through a porous medium in a rotating system also their results compared have good agreement the present research work.

Latterly the studies(Abdalbagi [22]) on micropolar-fluid transport have increasingly focused on the coupled effects of Soret and Dufour diffusion, porous-medium resistance, heat generation, and micro structural rotation. Recent work has examined micropolar flow in permeable channels while explicitly accounting for coupling, spin-gradient viscosity, and micro-inertia, demonstrating their significant influence on velocity, microrotation, and heat-transfer characteristics. More recently, studies (Arslan et.al. [23]) have investigated Soret–Dufour effects in micropolar fluids under magnetic fields, chemical reactions, permeable media, and stretching surfaces, confirming the strong interaction between thermal and concentration fields. A particularly recent 2026 (Abul Kalam Azad et.al. [24]) study incorporated Soret and Dufour effects with heat generation in unsteady MHD free-convective micropolar flow through a porous medium and reported substantial changes in velocity, temperature, concentration, microrotation, skin friction, and Nusselt number. Other recent research (Laltesh Kumar et.al. [25], Verma et.al. [26], Anguiano and Suárez-Grau [27]) have also emphasized the role of spin-gradient viscosity and micro-inertia in controlling micropolar-flow behaviour. Despite these developments, the combined influence of thermo-diffusion, diffusion-thermo effects, space-dependent heat source, and spin-gradient viscosity on convective heat and mass transfer of micropolar fluid in a vertical porous channel remains comparatively less explored, providing the motivation and research gap for the present investigation.

In this paper, we investigate the combined effect of micropolar viscosity, Chemical reaction and thermo-diffusion, diffusion-thermo on convective and mass transfer flow of micro-polar fluid in a vertical channel bounded by stretching walls. The nonlinear governing equations have been solved by using Runge-Kutta shooting technique. The velocity, microrotation, temperature and concentration have been analysed for different variations of G , M , N , Sc , γ , Sr , Du , Ec , $A1$, $B1$, Re , Δ , λ , Λ and Pr . The Skin friction, rate of heat and mass transfer are evaluated numerically for different variations.

NEED OF THE STUDY

The study is needed to understand heat and mass transfer of micropolar fluids flowing through porous vertical channels under realistic physical conditions. The effects of thermo-diffusion (Soret), diffusion-thermo (Dufour), space-dependent heat source, and spin-gradient viscosity significantly influence fluid velocity, temperature, concentration, and microrotation. Previous investigations have considered combinations of Soret/Dufour effects, MHD forces, porous media and micropolar fluids, but the present formulation integrates these important mechanisms into a unified convective heat-and-mass-transfer model. Studying these effects helps improve the prediction and control of heat and mass transfer in engineering systems.

NOVELTY OF THE STUDY

The previous investigations have considered and present study of thermo-diffusion (Soret), diffusion-thermo (Dufour), space-dependent heat source, and spin-gradient viscosity effects on the convective heat and mass transfer of a micropolar fluid through a porous vertical channel. This integrated model provides a better understanding of the interaction between fluid motion, microrotation, temperature, and concentration fields and helps to predict the variations in skin friction, heat-transfer and mass-transfer rates under different physical conditions.

REAL-TIME APPLICATIONS

The present engineering systems / practical applications in heat exchangers, cooling and thermal-management systems, polymer and chemical processing, petroleum and geothermal systems, porous-media transport, lubrication, microfluidic devices, and biomedical engineering. The model can help in designing and optimizing systems where simultaneous fluid flow, heat transfer, mass diffusion, internal heat generation, and microstructural fluid effects are important.

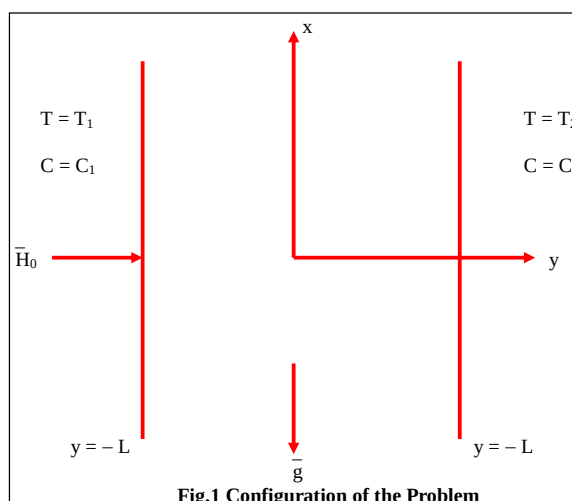


Fig.1 Configuration of the Problem

FORMULATION OF THE PROBLEM

We consider the steady two-dimensional hydromagnetic laminar convective heat and mass transfer flow of an electrically conducting micro-polar fluid in a vertical channel bounded by a stretching sheet on the left a stationary plate on the right. We choose a rectangular coordinate system O (x, y, z) with the walls at $y = \pm L$. The flow is subjected to a strong magnetic field with a constant intensity B_0 along the positive y-direction. Assuming magnetic Reynolds number R_m to be small we neglect the induced magnetic field in comparison to the applied magnetic field. It is used to compare the transport of magnetic lines of the force in a conducting fluid with the leakage of such lines from the fluid.

Taking the viscous dissipation and joule heating effects into consideration, the governing equations of the flow, heat and mass transfer for the problem are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$\left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y}\right) = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \left(\frac{\mu + k}{\rho}\right) \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{k}{\rho} \frac{\partial \omega}{\partial y} - \frac{\sigma B_0^2}{\rho} u - \rho g \quad (2)$$

$$\left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y}\right) = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \left(\frac{\mu + k}{\rho}\right) \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \left(\frac{k}{\rho}\right) \frac{\partial \omega}{\partial x} \quad (3)$$

$$\rho j \left(u \frac{\partial \omega}{\partial x} + v \frac{\partial \omega}{\partial y}\right) = (\gamma) \left(\frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2}\right) + k \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) - 2k\omega \quad (4)$$

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y}\right) = k_f \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + q''' - \frac{\partial(q_R)}{\partial y} + \frac{D_T K_T}{C_s} \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right) + \left. \begin{aligned} &+ 2\mu \left(\left(\frac{du}{dy}\right)^2\right) + \sigma \mu_e^2 H_o^2 (u^2) = 0 \end{aligned} \right\} \quad (5)$$

$$\left(u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y}\right) = D_b \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right) - k_c^i (C - C_2) + \frac{D_T K_T}{T_m} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) = 0 \quad (6)$$

$$\rho - \rho_o = -\beta(T - T_o) - \beta^*(C - C_o) \quad (7)$$

Where (u,v,0) are the velocity components along x, y directions respectively are the dimensional temperature and concentration respectively, ρ is the density, p is the pressure, σ is the electrical conductivity, μ_e is the magnetic permeability of the medium, μ is the dynamic viscosity, g is the gravity, Q_H is the strength of the heat source, D_B is the molecular diffusivity, D_T is the mass diffusivity, K_T is the thermal diffusion ratio, β is the coefficient of thermal expansion, β^* is the coefficient of volume expansion, T_m is the mean fluid temperature, j is the micro-inertia density, γ is the spin gradient viscosity, C_p is the specific heat at constant pressure, k_f is the thermal conductivity

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

$$\begin{aligned} u(x, -L) = us = bx, u(x, +L) = bx, v(x, \pm L) = 0, \omega(x, \pm L) = 0 \\ T(x, -L) = T_1, T(x, +L) = T_2 \\ C(x, -L) = C_1, C(x, +L) = C_2 \end{aligned} \quad (8)$$

Where $b > 0$ is the stretching rate of the channel wall, T_1, T_2 (with $T_1 > T_2$) are the fixed temperature of the left and right walls respectively, C_1, C_2 (with $C_1 > C_2$) are the fixed concentrations of the channel walls respectively.

The coefficient q''' is the rate of internal heat generation (>0) or absorption (<0). The internal heat generation /absorption q''' is modelled as

$$q''' = \left(\frac{k_f u_s}{xv} \right) [A_1(T_1 - T_2) f' + B_1(T - T_2)] \quad (9)$$

Where A_1 and B_1 are coefficients of space dependent and temperature dependent internal heat generation or absorption respectively. It is noted that the case $A_1 > 0$ and $B_1 > 0$, corresponds to internal heat generation and that $A_1 < 0$ and $B_1 < 0$, the case corresponds to internal heat absorption case.

Using Roseland approximation, the radiative heat flux is given by

$$q_r = -\frac{4\sigma^*}{\beta_R} \frac{\partial}{\partial y} (T^4) \quad (10)$$

And expanding T^4 about T_∞ by Taylor's expansion

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \quad (11)$$

Using (9) & (10) equation (5) reduces to

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k_f \frac{\partial^2 T}{\partial y^2} + \left(\frac{k_f u_s}{xv} \right) [A_1(T_1 - T_2) f' + B_1(T - T_2)] + \frac{16\sigma^* T_\infty^3}{3\beta_R} \frac{\partial^2 T}{\partial y^2} + \frac{D_T K_T}{C_s} \frac{\partial^2 C}{\partial y^2}$$

We introduce the following Similarity variables as:

$$\eta = \frac{y}{L}; u = bxf'(\eta); v = -bLf(\eta), \omega = -\frac{b}{L} xg(\eta) \quad (12)$$

$$\theta(\eta) = \frac{T - T_2}{T_1 - T_2}, \phi(\eta) = \frac{C - C_2}{C_1 - C_2}$$

The above proposed velocity field is compatible with equation (1) and therefore represents the possible fluid motion. Eliminating the pressure between the equations (2) and (3) and using (8) & (9) the governing equations reduces to

$$(1 + \Delta) f^{iv} - \lambda g'' + \text{Re}_x (f f'' - f' f') - M^2 f'' + G(\theta' + N\phi') = 0 \quad (13)$$

$$\Lambda g'' + \Delta \lambda (f'' - 2g) + (fg' - f'g) = 0 \quad (14)$$

$$\left(1 + \frac{4Rd}{3}\right) \theta'' + \text{Pr Re}_x (f\theta') + (A_1 f' + B_1 \theta) + \text{Pr Ec} (f'')^2 + \quad (15)$$

$$+ M^2 \text{Ec} (f')^2 + Du \phi'' = 0$$

$$\phi'' + \text{Sc Re}_x (f\phi') - \gamma \phi + \text{ScSo} \theta'' = 0 \quad (16)$$

Where $Gr = \frac{\beta g (T_1 - T_2) L}{bx}$, is the Grashof number, $N = \frac{\beta^* (C_1 - C_2)}{\beta (T_1 - T_2)}$, is the buoyancy ratio, $M^2 = \frac{\sigma \mu_e^2 H_o^2 L^2}{v x}$, magnetic

parameter, $\text{Pr} = \frac{\mu C_p}{k_f}$ is Prandtl number, $\text{Re}_x = \frac{bL^2}{\mu}$, is the local Reynolds number, $\text{Sc} = \frac{\nu}{D_m}$, is the Schmidt number,

$Sr = \frac{D_T K_T (T_1 - T_2)}{T_m (C_1 - C_2)}$ is the Soret parameter, $Du = \frac{D_T K_T (C_1 - C_2)}{C_s C_p (T_1 - T_2)}$ is the Dufour parameter, $\gamma = \frac{k_c L^2}{D_m}$ is the chemical

reaction parameter, $\text{Ec} = \frac{(us)^2}{C_p \Delta T}$ is the Eckert number, $\Delta = \frac{k}{\mu}$ is the vortex viscosity parameter, $\lambda = \frac{\mu}{\rho j b}$ is the micro-inertia

density parameter, $\Lambda = \frac{\gamma}{(\rho j L^2 / b)}$ is the spin gradient viscosity parameter.

Boundary conditions (8), in view of equation (9) in non-dimensional form reduce to

$$f(\pm 1) = 0, f'(-1) = 1, f'(1) = 1, g(\pm 1) = 0, \theta(-1) = 1, \theta(1) = 0, \phi(-1) = 1, \phi(1) = 0 \quad (17)$$

METHOD OF SOLUTION

A usual approach is to write the nonlinear ODE in form of a first order initial value problem as follows:

$$f = f_1, f' = f_2, f'' = f_3, f''' = f_4, g = f_5, g' = f_6 \quad (18)$$

$$\theta = f_7, \theta' = f_8, \phi = f_9, \phi' = f_{10} \quad (19)$$

$$f^{iv} = f_4 = [\Delta f_6' + \text{Re } x(f_4 f_1 - f_2 f_3) + M^2 f_3 + Gr(f_8 + f_{10})]/(1 + \Delta) \quad (20)$$

$$g'' = f_6 = [-f_6 f_1 - f_2] - \Delta \lambda f_2 / \Lambda \quad (21)$$

$$\theta'' = f_8 = [-\text{Pr Re } x(f_1 f_{10}) - A1 f_2 + B1 f_7 - \text{Pr Ec}(f_5^2) - M^2 \text{Ec}(f_2^2) - \text{Du} f_{10}] \quad (22)$$

$$\phi'' = f_{10} = [-\text{Sc Re } x(f_1 f_{10}) + \gamma \text{Sc} f_9 - \text{Sc So} - \text{Pr Re } x(f_1 f_8) - (A1 f_2 + B1 f_7) - M^2 \text{Ec}(f_2^2) - \text{Pr Ec}(f_3^2)]/(1 + \text{Sc So})$$

The corresponding boundary conditions are

$$f_1(\pm 1) = 0, f_2(-1) = 1, f_2(+1) = 1, f_5(-1) = 0, f_5(+1) = 0, f_7(-1) = 1, f_7(+1) = 0, f_9(-1) = 1, f_9(+1) = 0, \quad (23)$$

Here $f_3(-1), f_4(-1), f_6(-1), f_8(-1), f_{10}(-1)$ are the unknown initial condition, Therefore, a shooting methodology is incorporated to solve the above system, which may be a combination of the Runge-Kutta method(to solve first order ODE) and a five dimensional zero finding algorithm(to find the missing coordinates).It is noted that the missing initial conditions are coupled so that the solution satisfies the boundary conditions $f(+1)=0, f'(+1)=0, g(+1)=0, \theta(+1)=0, \phi(+1)=0$ of the original boundary value problem.

COMPARISON

Numerical comparison of Space dependent heat source (A1), Temperature dependent heat source (B1), and inertia parameter (λ) in the absence of thermo-diffusion ($\text{Sr}=0$), diffusion-thermo ($\text{Du}=0$) the results on skin friction ($\tau(1)$), Nusselt number($\text{Nu}(1)$) and Sherwood number ($\text{Sh}(1)$) the results are in good agreement with those of Muahmud Alam et.al.[28]

Parameters			Muahmud Alam et.al.[28]			Present results		
A1	B1	λ	$\tau(1)$	$\text{Nu}(1)$	$\text{Sh}(1)$	$\tau(1)$	$\text{Nu}(1)$	$\text{Sh}(1)$
-1	-1	0.7	-3.2974	0.4024	0.9647	-3.2986	0.4022	0.9651
-3			-3.3521	0.3206	0.9843	-3.3544	0.3203	0.9849
1			-3.4066	0.2360	1.0040	-3.4071	0.2368	1.0039
3			-3.4611	0.1483	1.0239	-3.4609	0.1485	1.0233
	-3		-3.3896	0.2552	0.9995	-3.3887	0.2559	0.9999
	1		-3.5089	0.0819	1.0401	-3.5081	0.0821	1.0412
	3		-3.6405	0.1133	1.0482	-3.6404	0.1136	1.0481
		1.5	-3.3674	0.3222	0.9860	-3.3678	0.3227	0.9858
		2.0	-3.4581	0.2306	1.0113	-3.4583	0.2302	1.0115
		2.5	-3.5554	0.1333	1.0380	-3.5565	0.1331	1.0388

DISCUSSION OF THE NUMERICAL RESULTS

The axial velocity (f') is shown in figs.2a-17a for different variations of G, M, N, Re, Sc, N, γ , Sr, Du, Rd, A1, B1, Ec, Δ , λ , Λ and Pr.

From fig.2a-2d represent the velocity, angular velocity, temperature and concentration with Grashof number (G). From the profiles we find that the axial velocity reduces in the left half (-1,0) and enhances in the right half (0,1) of the channel with increase in G. The microrotation(g) and temperature enhance in the left half and reduces in the right half of the channel. We follow the convention that the non-dimensional concentration (ϕ) is positive/negative according as the actual concentration is greater/lesser than the temperature (C2) on the right wall. From fig.2d we find that the actual concentration reduces in the left half and enhances in the right half of the channel.

Figs.3a-3d demonstrate the f', g, θ and ϕ with magnetic parameter(M). From the profiles we notice that higher the Lorentz force smaller the magnitude of the velocity in the flow regions adjacent to the walls and enhances in the central region. Application of magnetic field gives rise to a retarding force viz., Lorentz force which reduces $|f'|$ in the region (-1,1.0). The microrotation reduces in the entire flow region(fig.3b). The temperature enhances and the actual concentration reduces with increasing values of M(figs.3c&d).

Figs.4a-4d shows the variation of f', g, θ and ϕ with buoyancy ratio(N). It can be seen from the profiles that when the molecular buoyancy force dominates over the thermal buoyancy force, $|f'|$ enhances in (-1,0) and reduces in (0,1) of the flow region when the buoyancy forces are in the same direction while for the buoyancy forces acting in opposite directions, it reduces in the left half and in the right half of the channel, it enhances with $N < 0$. The microrotation (g) reduces with $N > 0$ and enhances

with $N < 0$ in the entire flow region $(-1, 1)$. The temperature reduces with $N > 0$ and enhances with $N < 0$ in $(-1, 0)$ in $(0, 1)$, it reduces with $N > 0$ and enhances with $N < 0$. From fig.4d we find that the actual concentration enhances when the buoyancy forces are in the same direction and for the forces acting in opposite directions, it reduces in the flow region

Figs.5a-5d shows the variation of f' , g , θ and ϕ with Reynolds number (Re). From fig.5a shows the variation of f' with Reynolds number Re. It can be seen from the profiles an increase in Re leads to a reduction in the velocity, microrotation and temperature in $(-1, 0)$ and enhancement in $(0, 1)$. The actual concentration reduces with increase in Re in the flow region $(-1, 1)$.

Figs.6a-6d shows the variation of f' , g , θ and ϕ with Schmidt number (Sc). Fig.6a express f' with Schmidt number Sc. Lesser the molecular diffusivity larger the velocity in the left half and smaller in the right half of channel. The microrotation and the actual concentration depreciate in $(-1, 0)$ and enhance in $(0, 1)$ with increase in Sc. (figs.6b&6c). The temperature reduces with Sc in $(-1, 0, 1, 0)$ (fig.6c).

Fig.7a -7d shows the variation of f' , g , θ and ϕ with chemical reaction parameter (γ). we notice from the profiles that the magnitude of the velocity reduces in both the degenerating/generating chemical reaction cases. The microrotation(g) enhances with increase in $\gamma (< 0 >)$ in the region $(-1, 0)$ while in the right half of the channel it reduces in the degenerating chemical reaction case and enhances in generating case. The temperature and the actual concentration reduce in the degenerating chemical reaction case and in generating case, the temperature enhances and the actual concentration reduces in $(-1, 1)$ (figs.7c&7d).

The effect of thermo-diffusion and diffusion-thermo effects (Sr/Du) on f' can be seen from the fig.8a. It can be seen from the graphs that increasing Soret parameter (Sr) (or decreasing Dufour parameter Du) larger $|f'|$, microrotation reduces in $(-1, 0)$ and enhance in $(0, 1)$ (figs.8a&8b). From figs.8c&8d we find that the temperature reduces and the actual concentration enhances in $(-1, 1)$ with increasing Sr (or decreasing Du).

Figs.9a-9d shows the variation of f' , g , θ and ϕ with thermal radiation parameter (R_d). From fig.9a we find that the velocity reduces in the region $(-1, 0)$ and enhances in the region $(0, 1, 0)$. Higher the radiative heat flux, smaller the microrotation(g) in the entire flow region. The temperature reduces and the actual concentration enhances in the entire flow region with increasing R_d .

The effect of space dependent heat source (A_1) on f' , g , θ and ϕ can be seen from figs.10a-10d. In the presence of space dependent heat source ($A_1 > 0$) the velocity enhances and reduces with heat sink ($A_1 < 0$) in $(-1, 1)$. The microrotation(g) reduces with $A_1 > 0$ and enhances with $A_1 < 0$ in $(-1, 0)$ while a reversed effect is observed in g in the right half $(0, 1)$, f' reduces enhances with $A_1 < 0$. The temperature reduces in $(-1, 0)$ and enhances in $(0, 1)$ with increase in the strength of the heat source fig.10c) while a reversed effect is noticed in θ with $A_1 < 0$. The actual concentration enhances with $A_1 > 0$ and $A_1 < 0$ in $(-1, 0)$ and in $(0, 1)$, it reduces with all values of A_1 (fig.10d).

Figs.11a-11d show the variation of f' , g , θ and ϕ with temperature dependent heat source (B_1). Fig.11a represents f' with temperature dependent heat source parameter B_1 . We find that in the presence of heat generating heat source, heat is generated which results in an enhancement in $|f'|$ while in the presence of heat absorption ($B_1 < 0$), f' reduces in the region $(-1, 0)$ and in $(0, 1)$ it enhances with $B_1 (< 0 >)$. The microrotation(g) reduces with $B_1 > 0$ and enhances with $B_1 < 0$ in the flow region $(-1, 0)$ and in $(0, 1)$ a reversed effect is noticed in g . The temperature and actual concentration enhance with $B_1 > 0$ and $B_1 < 0$ in the flow region $(-1, 1)$.

Figs.12a-12d represent f' , g , θ and ϕ with Eckert parameter (Ec). From the profiles we find that the velocity enhances, microrotation reduces in $(-1, 1)$. Also, Higher the dissipative energy, larger the temperature and actual concentration in the flow region $(-1, 1)$.

Figs.13a-13d&14a-14d demonstrate the variation of f' , g , θ and ϕ with micropolar parameters Δ/λ . We find that the velocity reduces in the region $(-1.0, -0.5)$ and enhances in the region $(-0.5, 1.0)$ with increase in Δ . The microrotation (g) enhances in $(-1, 1)$ with Δ/λ . The temperature enhances and the actual concentration reduces with increase in Δ/λ in the entire flow region (13c, 14c, 13d, 14d).

Figs.15a-15d show the variation of f' , g , θ and ϕ with micropolar parameter Λ . From figs.15a we find that an increase in Λ reduces the velocity in the region $(-1, -0.5)$ and enhances in $(-0.5, 1.0)$. The microrotation and temperature depreciate in the entire flow region with increase in Λ . The actual concentration enhances with rise in Λ (fig.15d).

The effect of Prandtl number (Pr) on f' , g , θ and ϕ can be observed from figs.16a-16d. From the profiles we find that lesser the thermal diffusivity larger the velocity and the microrotation in $(-1, 0)$ and in the region $(0, 1)$, the velocity reduces, the microrotation enhances. The temperature enhances and the actual concentration reduces with increase in Pr in the entire flow region (figs.12c&12d).

The skin friction (τ), couple stress (C_w), Nusselt and Sherwood number (Sh) at $\eta = \pm 1$ is exhibited in table.2&3 for different variations of G , M , N , Re , Sc , γ , Sr , Du , A_1 , B_1 , R_d , Ec , Δ , λ , Λ and Pr . From the tabular values we find an increase in G enhances the skin friction (τ), couple stress (C_w), Nusselt number (Nu). Higher the Lorentz force larger the stress at $\eta = -$ and reducers at $\eta = +$. The rate of heat mass transfer (Sh) enhances with G at both the walls. Higher the Lorentz force larger τ , C_w The rate of heat transfer reduces and mass transfer enhances at $\eta = -1$ while Nu enhances at $\eta = +1$. Sh reduces with increase $M \leq 1.5$, enhances with higher $M \geq 2$. With reference to buoyancy ratio (N) we find that τ , C_w and Nu at $\eta = -1$ and reduces at $\eta = +1$ when the buoyancy forces are in the same direction and for the .When the molecular buoyancy force dominates over the thermal buoyancy force the forces acting in opposite directions, τ , C_w and Nu reduces at $\eta = -1$ and enhances at $\eta = +1$. The Sherwood number enhances at $\eta = +1$ and reduce at $\eta = -1$ with $N > 0$ and reduces at $\eta = -1$ and enhances at $\eta = +1$ with $N < 0$. Lesser the molecular diffusivity (Sc) smaller τ , C_w and Nu at $\eta = -1$ and larger at $\eta = +1$. Sh enhances with increase in Sc at both the walls. An increase in Re reduces τ , enhances C_w , Nu at $\eta = \pm 1$. Sh enhances at $\eta = -1$ and reduces at $\eta = +1$. With respect to chemical reaction parameter (γ), we find that τ and C_w reduce at $\eta = -1$ and enhances at $\eta = +1$ in the degenerating chemical reaction case while in the generating case, τ , C_w enhance at $\eta = -1$ and reduces at $\eta = +1$. Nu reduces with $\gamma (< 0 >)$ at $\eta = +1$. Sh enhances at $\eta = -1$ and reduces at $\eta = +1$ while Nu reduces with $\gamma > 0$ at $\eta = -1$ and reduces at $\eta = +1$ with $\gamma > 0$ and a reversed effect is noticed with $\gamma < 0$. Increasing Soret parameter So (or decreasing Du) leads to an enhancement in τ , C_w , Nu and Sh at $\eta = -1$ and at $\eta = +1$, τ , C_w reduces, Nu & Sh enhances with increasing Sr (or decreasing Du). Higher the radiative heat flux smaller τ , C_w at $\eta = -1$ and larger

at $\eta = +1$. Nu reduces with Rd at $\eta = \pm 1$. Sh reduces at $\eta = -1$ and enhances at smaller at $\eta = +1$. Higher the dissipation ($Ec \leq 0.03$) larger τ , Cw at $\eta = \pm 1$ and for higher dissipation ($Ec \geq 0.05$) smaller at $\eta = \pm 1$. Nu and Sh enhance with $Ec \leq 0.03$ at $\eta = -1$ and for higher $Ec \geq 0.05$, they enhance at $\eta = +1$.

In the presence of space dependent heat source ($A_1 > 0$), τ , Cw, Nu and Sh enhance at $\eta = -1$ while in the case of heat sink ($A_1 < 0$) they reduce at $\eta = -1$. Sh reduces with $A_1 > 0$ and enhances with $A_1 < 0$ at $\eta = \pm 1$. With respect to temperature dependent heat source ($B_1 > 0$) we find τ , Cw reduce at $\eta = -1$ and enhance at $\eta = +1$ with increase in the strength of the heat generating/absorbing heat source. Nu and Sh enhance with $B_1 > 0$ and reduce at $B_1 < 0$ at both the walls. Nu enhances and Sh reduces with $B_1 > 0$ and Nu reduces, Sh enhances with $B_1 < 0$ at $\eta = -1$. At $\eta = +1$, Nu and Sh enhance with $B_1 > 0$ and for $B_1 < 0$, Nu enhances, Sh reduces. An increase in micropolar parameters (Δ/λ) reduces τ , enhances Cw, Nu at both the walls. Sh reduces with $\Delta \leq 2, \lambda \leq 3$ and enhances with higher $\Delta \geq 3, \lambda \geq 2.5$. An increase in Λ increases τ , enhances Cw, Nu at $\eta = \pm 1$. Sh reduces at $\eta = -1$ and enhances at $\eta = +1$ with increase in Λ . With respect to Prandtl number (Pr), we find that τ , Cw, Nu and Sh enhance at $\eta = -1$ and at $\eta = +1$, τ , Cw and Sh reduce and Nu enhances with increase Pr.

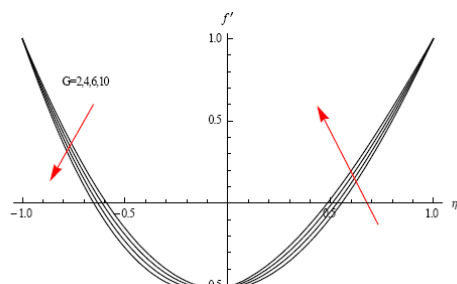


Fig.2a : Variation of Velocity (f') with G (Grashof number)

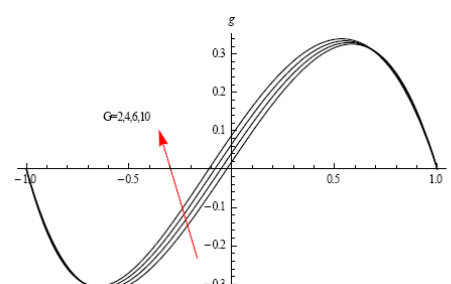


Fig.2b: Variation of Microrotatin(g) with G

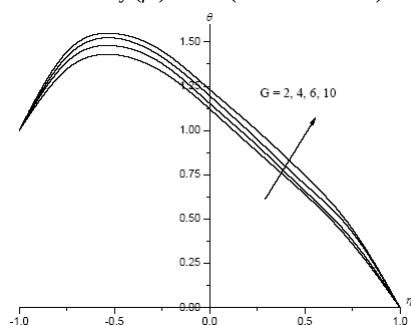


Fig.2c : Variation of Temperature(θ) with G

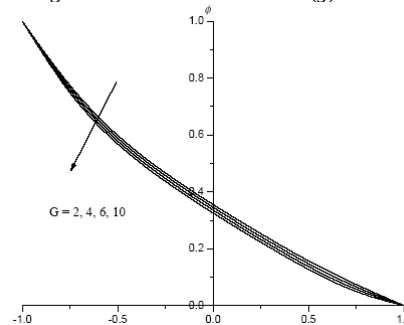


Fig.2b: Variation of Concentration(ϕ) with G

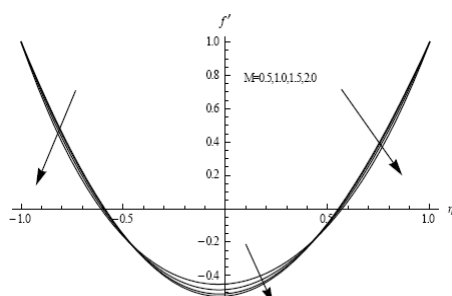


Fig.3a : Impact of f' with M (Magnetic parameter)

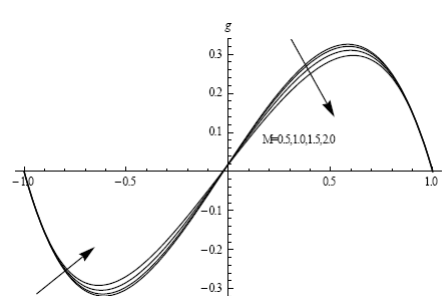


Fig.3b: Impact of g with M

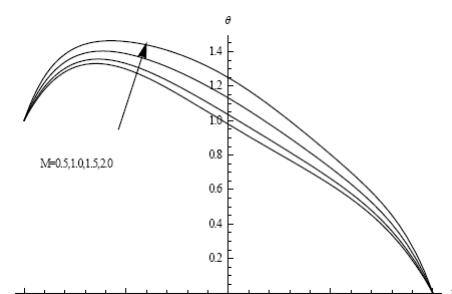


Fig.3c : Impact of θ with M

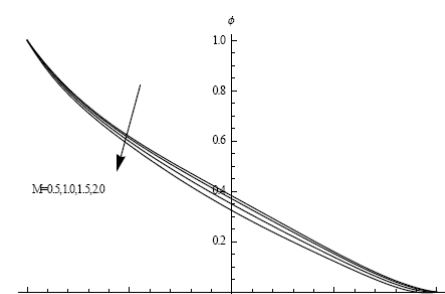


Fig.3d: Impact of ϕ with M

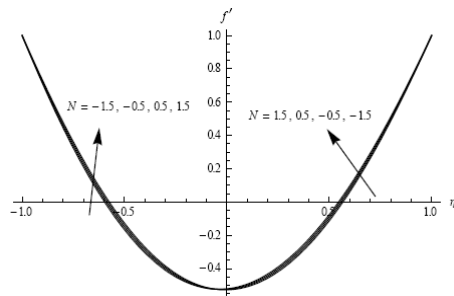


Fig.4a : Impact of f' with N (buoyancy ratio)

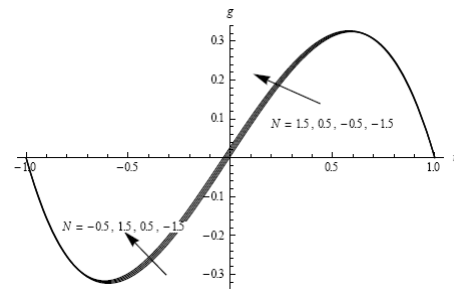


Fig.4b: Impact of g with N

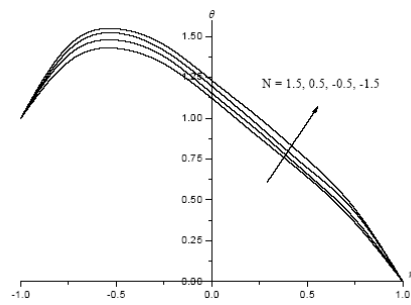


Fig.4c : Impact of θ with N

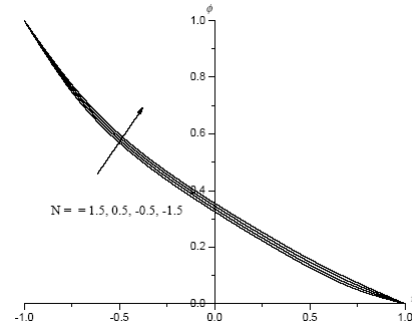


Fig.4d: Impact of ϕ with N

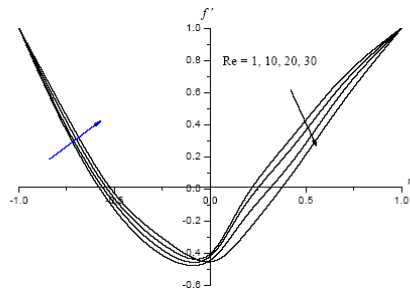


Fig.5a : Impact of f' with Re (Reynolds number)

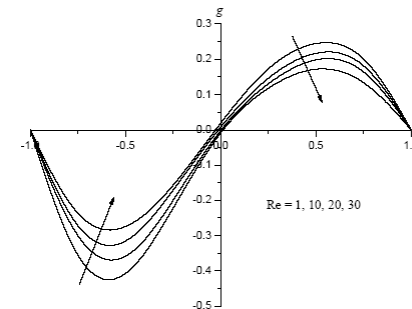


Fig.5b: Impact of g with Re

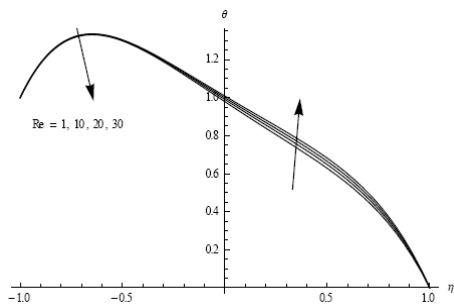


Fig.5c : Impact of θ with Re

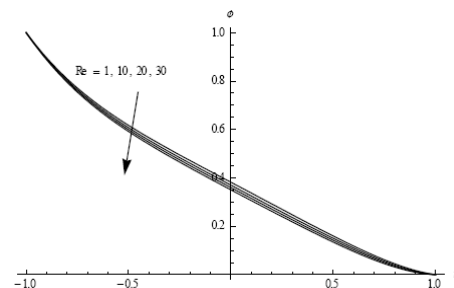


Fig.5d: Impact of ϕ with Re

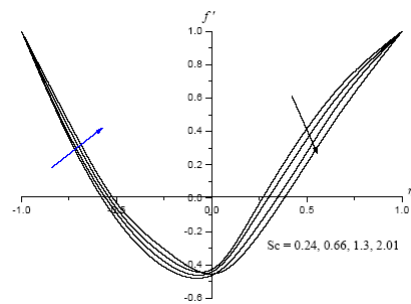


Fig.6a : Impact of f' with Sc (Schmidt number)

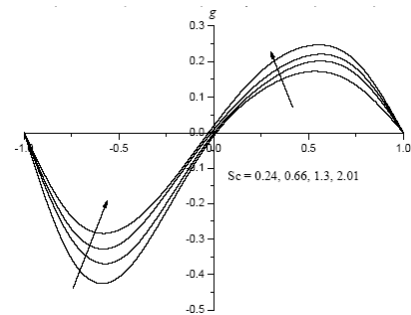


Fig.6b: Impact of g with Sc

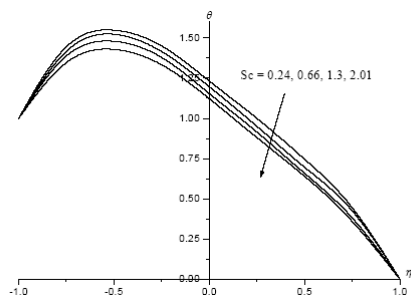


Fig.6c : Impact of θ with Sc

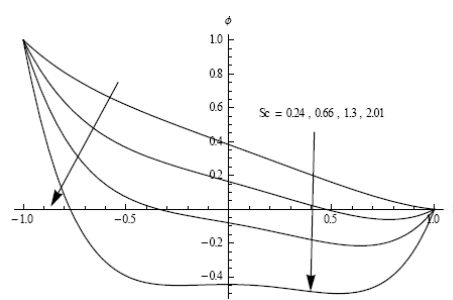


Fig.6d: Impact of ϕ with Sc

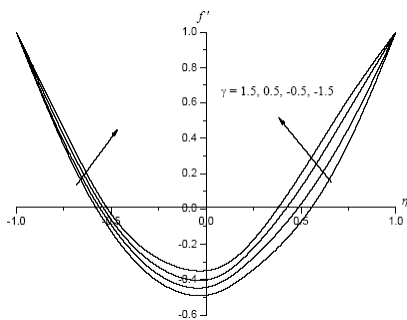


Fig.7a : Impact of f' with γ (Chemical Reaction)

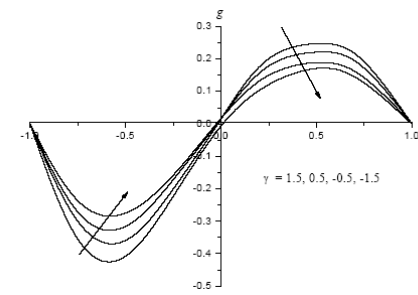


Fig.7b: Impact of g with γ

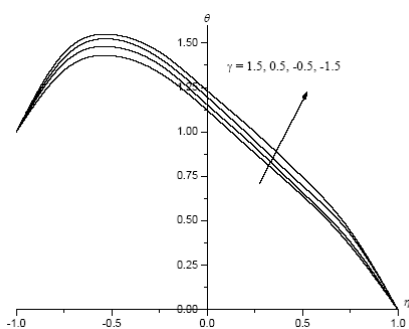


Fig.7c : Impact of θ with γ

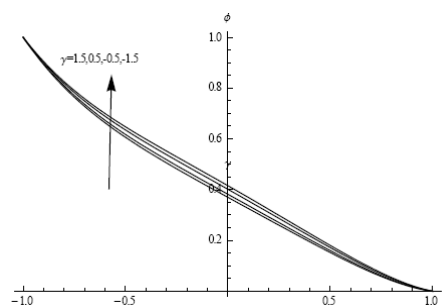


Fig.7d: Impact of ϕ with γ

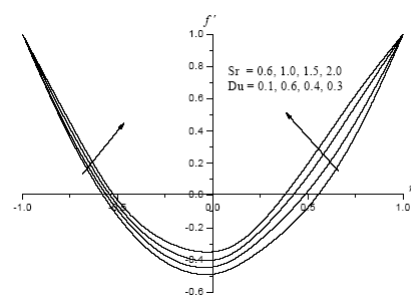


Fig.8a : Impact of f' with Soret/Dufour parameter (Sr/Du)

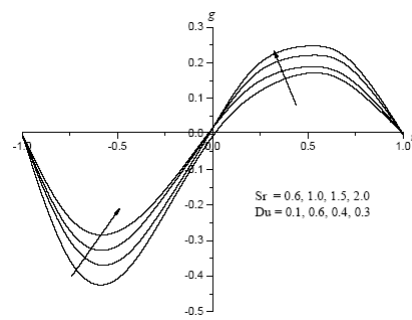


Fig.8b: Impact of g with Sr/Du

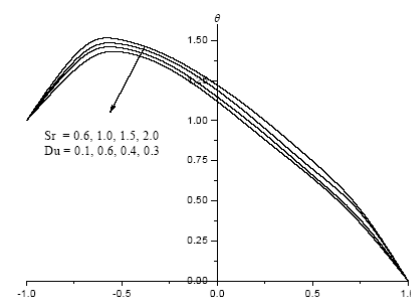


Fig.8c : Impact of θ with Sr/Du

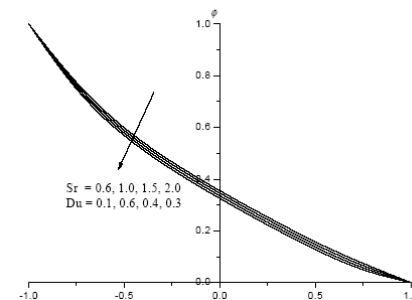


Fig.8d: Impact of ϕ with (Sr/Du)

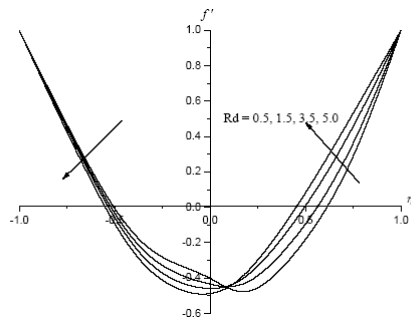


Fig.9a : Impact of f' with Rd (radiation parameter)

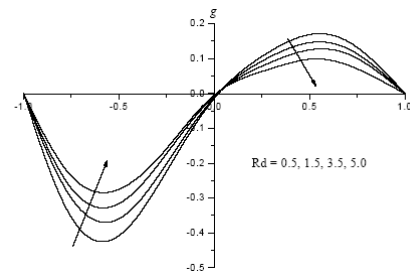


Fig.9b: Impact of g with Rd

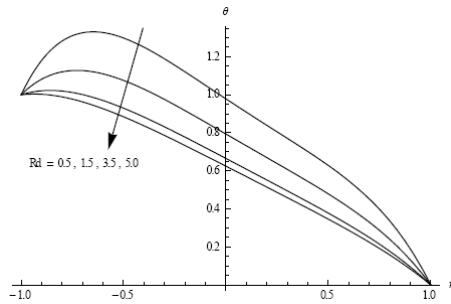


Fig.9c : Impact of θ with Rd

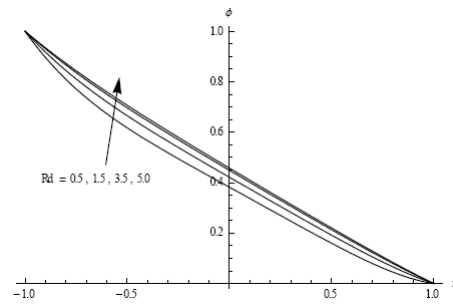


Fig.9d: Impact of ϕ with Rd

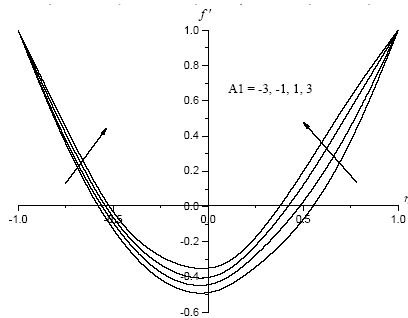


Fig.10a : Impact of f' with $A1$ (space dependent heat source)

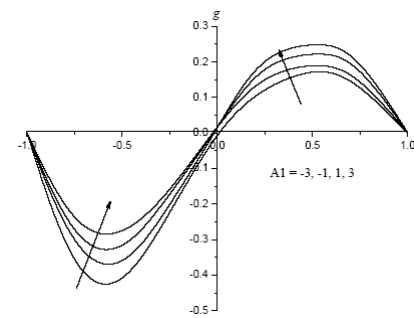


Fig.10b: Impact of g with $A1$

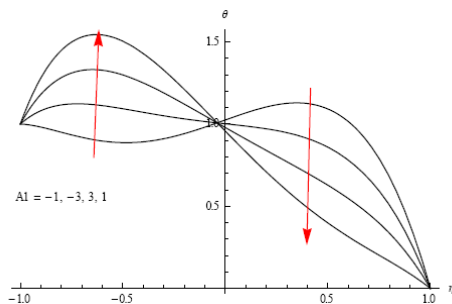


Fig.10c : Impact of θ with $A1$

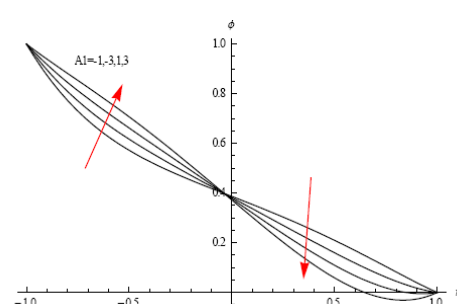


Fig.10d: Impact of ϕ with $A1$

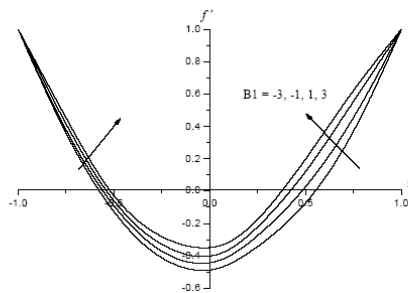


Fig.11a : Impact of f' with $B1$ (Temperature dependent heat source)

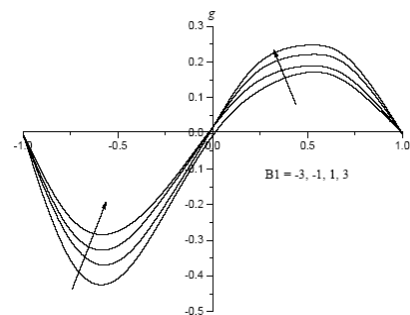


Fig.11b: Impact of g with $B1$

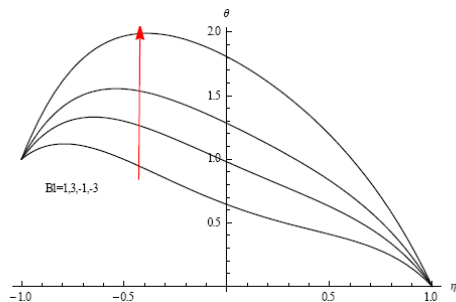


Fig.11c : Impact of θ with B1

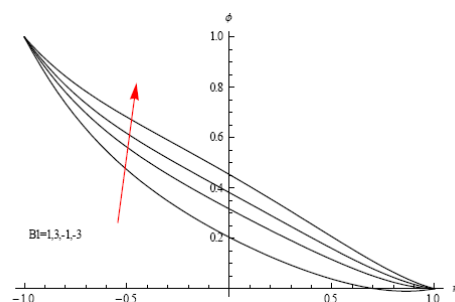


Fig.11d: Impact of ϕ with B1

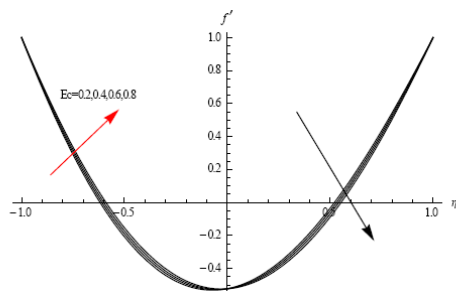


Fig.12a : Impact of f' with Ec (Eckert parameter)

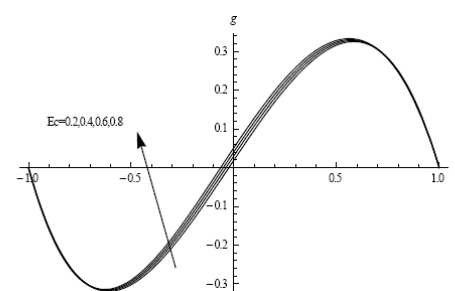


Fig.12b: Impact of g with Ec

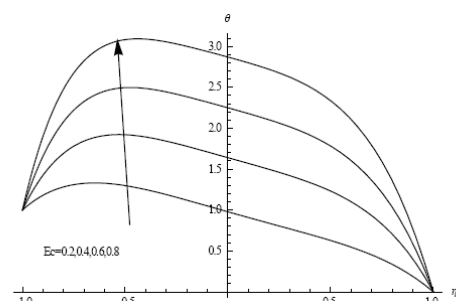


Fig.12c : Impact of θ with Ec

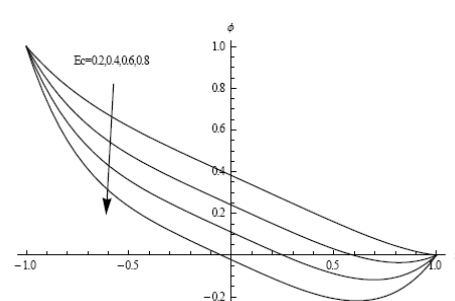


Fig.13d: Impact of ϕ with Ec

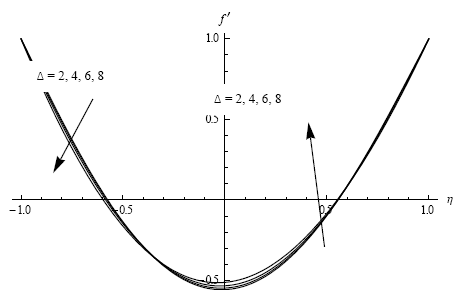


Fig.13a : Impact of f' with Δ (micropolar parameter)

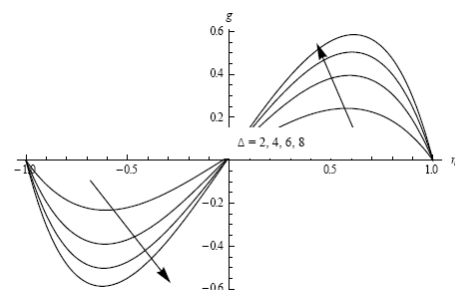


Fig.13b: Impact of g with Δ

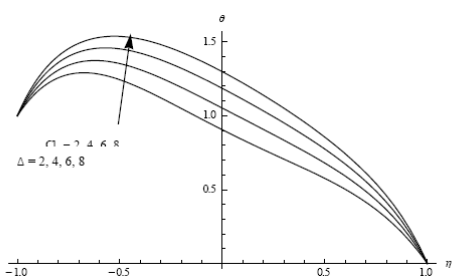


Fig.13c : Impact of θ with Δ

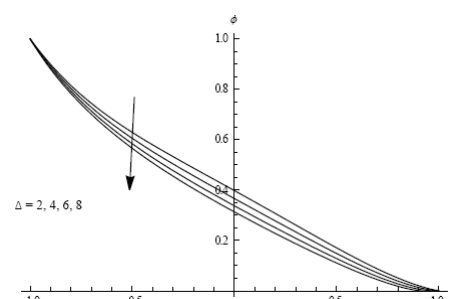


Fig.13d: Impact of ϕ with Δ

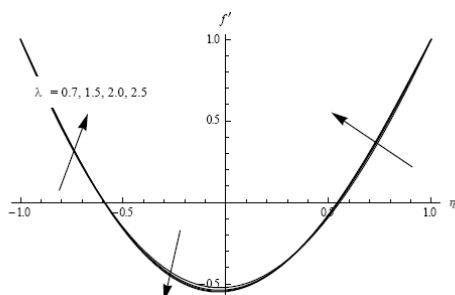


Fig.14a : Impact of f' with λ (micropolar parameter)

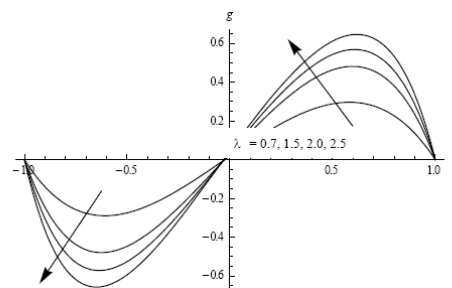


Fig.14b: Impact of g with λ

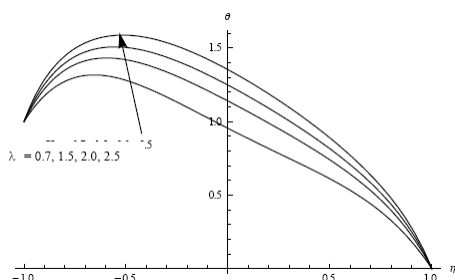


Fig.14c : Impact of θ with λ

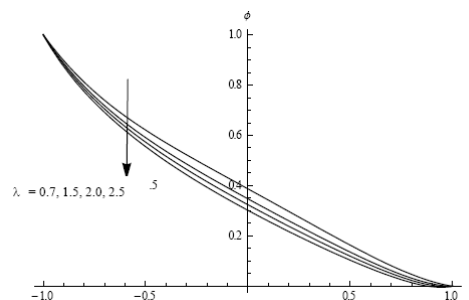


Fig.14d: Impact of ϕ with λ

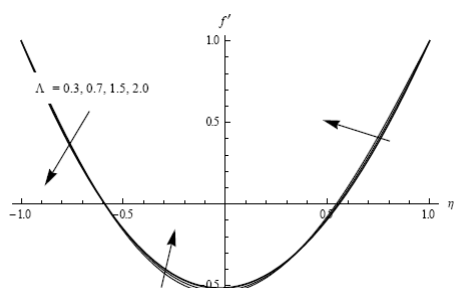


Fig.15a : Impact of f' with Λ (micropolar parameter)

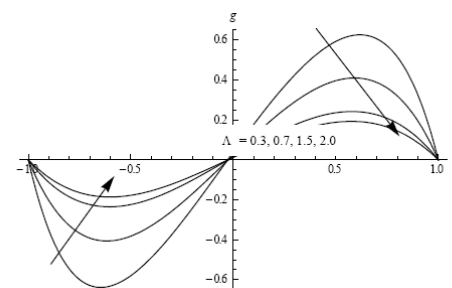


Fig.15b: Impact of g with Λ

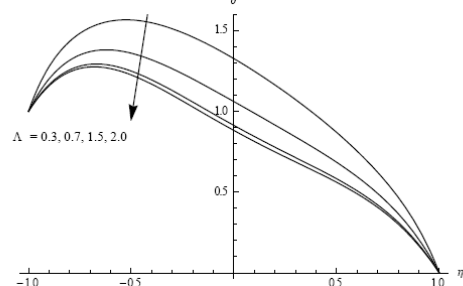


Fig.15c : Impact of θ with Λ

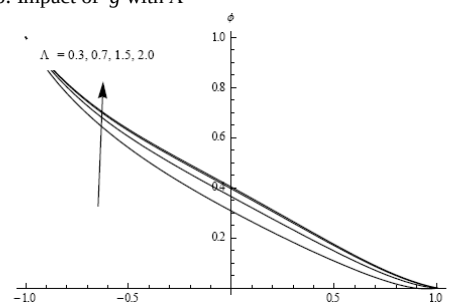


Fig.15d: Impact of ϕ with Λ

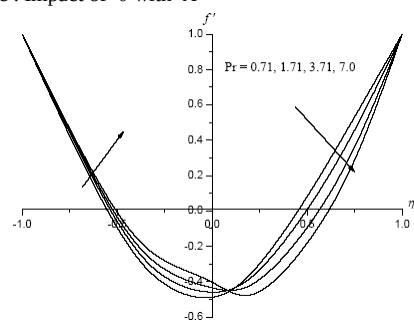


Fig.16a : Impact of f' with Pr (Prandtl number)

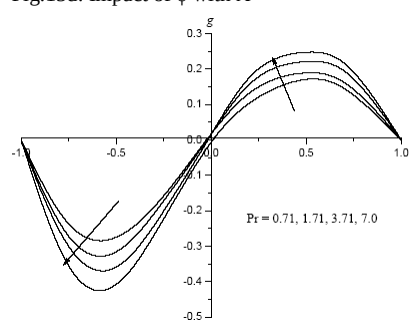


Fig.16b: Impact of g with Pr

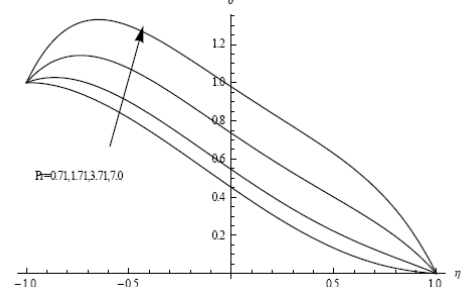


Fig.16c : Impact of θ with Pr

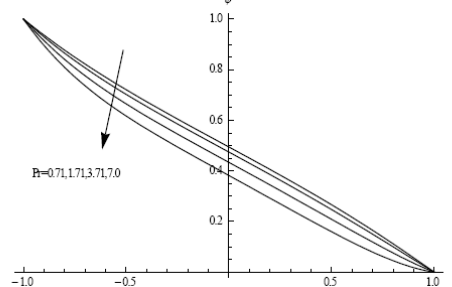


Fig.16d: Impact of ϕ with Pr

Table – 1
Skin friction (τ), Couple Stress (Cw), Nusselt Number (Nu), Shear stress (Sh) at $\eta = \pm 1$

Parameter		$\tau(-1)$	$\tau(1)$	Cw(-1)	Cw(1)	Nu(-1)	Nu(1)	Sh(-1)	Sh(1)
G	2	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	0.130037
	4	-3.17943	2.5073	-1.74217	-1.59234	-2.34786	2.02131	1.16628	0.150979
	6	-3.40033	2.34581	-1.78523	-1.55329	-2.50378	1.93864	1.20012	0.169491
	10	-3.62312	2.18332	-1.82872	-1.51405	-2.6754	1.86655	1.23737	0.185708
M	0.5	-2.95897	2.6692	-1.69922	-1.63152	-2.21436	2.12272	1.13733	0.128393
	1.0	-3.06483	2.77136	-1.70522	-1.63753	-2.42354	2.33406	1.18293	0.0822632
	1.5	-3.26642	2.96795	-1.71622	-1.64902	-2.82816	2.74309	1.27115	-0.0070415
	2.0	-3.54636	3.2461	-1.7305	-1.66513	-3.37273	3.29605	1.38996	-0.127843
N	1.0	-2.95897	2.6692	-1.69922	-1.63152	-2.21436	2.12272	1.13733	0.128393
	2.0	-3.03931	2.62015	-1.71374	-1.61887	-2.25111	2.0822	1.18165	0.121785
	-0.5	-2.87374	2.72257	-1.68364	-1.6452	-2.1598	2.15155	1.04924	0.156017
	-1.5	-2.78407	2.77979	-1.66712	-1.65981	-2.11242	2.19183	0.998942	0.16563
Sc	0.24	-2.95897	2.6692	-1.69922	-1.63152	-2.21436	2.12272	1.13733	0.128393
	0.66	-2.93962	2.68621	-1.69513	-1.63543	-2.1931	2.1246	2.44217	-0.607413
	1.3	-2.92015	2.70416	-1.69096	-1.63947	-2.17972	2.13446	3.74687	-1.53953
	2.01	-2.82883	2.79241	-1.67066	-1.65949	-2.11537	2.18467	7.49349	-4.65406
γ	0.5	-2.95897	2.6692	-1.69922	-1.63152	-2.21436	2.12272	1.13733	0.128393
	1.5	-2.95781	2.67027	-1.69896	-1.63177	-2.20543	2.11562	1.17172	0.114399
	-0.5	-2.96064	2.66772	-1.69958	-1.63117	-2.20746	2.11417	1.05951	0.164457
	-1.5	-2.96169	2.66677	-1.69981	-1.63095	-2.20821	2.11363	1.01949	0.183426
Sr/Du	0.6/0.1	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	0.130037
	1.0/0.06	-3.04746	2.58089	-1.71882	-1.61206	-5.07731	4.54051	1.76069	-0.39729
	1.5/0.04	-3.12916	2.49981	-1.73692	-1.59417	-7.81504	6.65756	2.35695	-0.857372
	2.0/0.03	-3.21218	2.41785	-1.75529	-1.57606	-10.6846	8.69648	2.98209	-1.30026
Rd	0.5	-2.95827	2.66922	-1.69931	-1.63152	-2.21437	2.12273	1.13731	0.128394
	1.5	-3.03934	2.62014	-1.71385	-1.61886	-2.25110	2.08226	1.18163	0.121787
	3.5	-2.87368	2.72256	-1.68362	-1.64513	-2.15981	2.15160	1.04928	0.156010
	5.0	-2.78414	2.77984	-1.66716	-1.65989	-2.11299	2.19181	0.998940	0.165634
Ec	0.02	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	0.130037
	0.04	-2.9668	2.68172	-1.69934	-1.63274	-3.37593	0.955687	1.3921	0.383991
	0.06	-2.95063	2.65711	-1.69898	-1.6304	-1.03613	3.2744	0.878934	-0.123859
	0.08	-2.94258	2.64465	-1.69882	-1.6292	0.133868	4.43341	0.622324	-0.377695
A1	-1	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	1.13553
	-3	-2.91602	2.70871	-1.68975	-1.6407	-1.26095	1.64875	0.930444	0.930444
	1	-3.05942	2.57259	-1.72182	-1.60935	-4.03524	3.31883	1.5314	1.5314
	3	-3.65293	1.97535	-1.85859	-1.47466	-13.0713	11.2004	3.48035	3.48035
B1	-1	-2.95897	2.6692	-1.69922	-1.63152	-2.21436	2.12272	1.13733	0.128393
	-3	-2.92326	2.70946	-1.69324	-1.63784	-2.20454	2.19846	1.22725	0.0757444
	1	-2.9001	2.7374	-1.68977	-1.64165	-2.20847	2.26783	1.00578	0.160175
	3	-2.87606	2.76611	-1.68611	-1.64563	-2.2115	2.33826	0.839386	0.231414
Re	5	-3.09247	2.72839	-1.21413	-1.16467	-2.07724	1.94151	1.10754	0.167817
	10	-2.85478	2.61068	-2.1271	-2.04545	-2.36452	2.29763	1.16998	0.0903486
	20	-2.698	2.50681	-2.85717	-2.75469	-2.70925	2.66474	1.245	0.0104722
	30	-2.58229	2.4222	-3.4676	-3.35034	-3.05061	3.01447	1.31936	-0.0656759
Δ	2	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	0.130037
	4	-2.82919	2.49651	-3.05442	-2.86394	-2.83395	2.67061	1.27221	0.0093034
	6	-2.77564	2.42075	-3.73609	-3.46114	-3.21612	2.99484	1.35552	-0.0612748
	8	-2.73395	2.36055	-4.33737	-3.97613	-3.57435	3.28946	1.43368	-0.125461
λ	0.7	-2.72412	2.34983	-4.50275	-4.11183	-3.65852	3.35346	1.45208	-0.139429
	1.5	-2.87837	2.56461	-2.49826	-2.36438	-2.54917	2.42194	1.21018	0.0633859
	2.0	-2.99717	2.71737	-1.35408	-1.30903	-2.08802	2.00745	1.10987	0.153411
	2.5	-3.03235	2.76011	-1.05523	-1.02623	-2.00345	1.9295	1.0915	0.17031
Λ	0.3	-2.95871	2.66946	-2.69916	-2.63158	-3.60607	2.81516	1.53553	0.030037
	0.7	-2.98534	2.70378	-2.48521	-2.32759	-3.44332	2.71501	1.4046	0.07158
	1.5	-3.07348	2.88532	-1.3595	-1.30381	-3.02274	2.34154	1.31305	0.0820005
	2.0	-3.09897	2.92772	-1.05884	-1.02274	-2.94439	2.26911	1.29601	0.0975966

Parameter		$\tau(-1)$	$\tau(1)$	$Cw(-1)$	$Cw(1)$	$Nu(-1)$	$Nu(1)$	$Sh(-1)$	$Sh(1)$
Pr	0.71	-2.88849	2.74079	-1.68352	-1.64721	-0.026981	0.06125	0.661246	0.57682
	1.71	-2.90096	2.7281	-1.6863	-1.64443	-0.409877	0.432733	0.744577	0.495999
	3.71	-2.92643	2.70221	-1.69197	-1.63876	-1.19753	1.18223	0.916006	0.332954
	7.0	-2.95871	2.66946	-1.69916	-1.63158	-2.20607	2.11516	1.13553	0.130037

CONCLUSIONS

The governing non-linear, coupled equations of flow heat and mass transfer of a micropolar fluid confined in a vertical channel bounded by stretching walls. Have been solved by Runge-Kutta shooting technique. The conclusions of this analysis are

- Higher the magnetic field (M) smaller the velocity, actual concentration, larger the temperature. Microrotation reduces in the flow region of the channel., The stress, couple stress, Nu reduces and Sh grows with M at both the walls.
- The velocity ,temperature and actual concentration reduce in degenerating chemical reaction case and in generating case they enhance in (-1,1).The microrotation(g) reduces with $\gamma > 0$ and enhances with $\gamma < 0$, and enhances with $\gamma < 0$. τ , Cw reduces with $\gamma > 0$ and enhances with $\gamma < 0$ at $\eta = -1$ while at $\eta = +1$, they depreciate with $\gamma < 0$ and enhance with $\gamma > 0$. Nu reduces with $\gamma < 0$ at $\eta = \pm 1$, Sh increase at $\eta = -1$, decrease at $\eta = +1$ with $\gamma > 0$. An opposite effect is observed with $\gamma < 0$.
- Increasing Soret parameter So (or decreasing Du) leads to a depreciation in velocity, temperature and reduces actual concentration in (-1,1). τ , Cw, Nu reduces at $\eta = -1$ while at $\eta = +1$, τ , Cw reduce, Nu enhances with with increasing So (or decreasing Du). Sh enhances with Sr (or decreasing Du) at both the walls.
- Higher radiative heat flux smaller the velocity, microrotation in the regions adjacent to the wall $\eta = -1$ and enhances in the region (0,1). The temperature reduces and actual concentration enhances with Rd in (-1,1). Cw, Sh reduces at $\eta = -1$ and enhances at $\eta = +1$ with Rd, Nu depreciates with Rd at both the walls.
- Higher the dissipation larger the velocity, larger microrotation in (-1,0) and in (0,1), f, g reduces with increasing Ec. The temperature enhances and actual concentration reduces with Ec. Nu and Sh enhance with Ec at $\eta = -1$ and enhances at $\eta = +1$ with increase in Ec.
- The temperature reduces in (-1,0) and enhances in (0,1) with increase in A1. The actual concentration enhances with A1 > 0 in (-1,0) and reduces with A1 < 0 in (0,1), Nu and Sh increase with A1 > 0 at $\eta = -1$ and reduces at $\eta = +1$ with A1 > 0 a reversed effect is noticed with A1 < 0
- An increase in heat generating /absorbing source parameter (B1 > 0) enhances the temperature and actual concentration with B1 (< 0 >). Nu enhances at $\eta = \pm 1$ with B1 > 0, it reduces at $\eta = -1$, enhances at $\eta = +1$ with B1 < 0. Sh reduces at $\eta = -1$, enhances at $\eta = +1$ with B1 > 0 and for B1 < 0, it enhances at $\eta = -1$ and reduces at $\eta = +1$.
- The temperature enhances and the actual concentration reduces with increases with increase in Λ . An increase in $\Delta/\lambda/\Lambda$ enhances. τ , Nu at both the walls. Sh reduces at $\eta = -1$ with λ/Λ , enhances at $\eta = +1$ with Δ . Sh reduces with smaller values and enhances with higher values of Δ/λ at $\eta = +1$. An increase in Λ enhances Sh at $\eta = +1$

The present study can be extended in a fluid motion, microrotation, temperature, and concentration fields and helps to predict the variations in parametric under different physical conditions subject to different boundary conditions can be another future study.

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H.G. Suguna : Conceptualization, Methodology, Formal analysis, Writing – original draft

B. Sreenivasa Reddy : Investigation, resources formal analysis of conceptualization support of the original draft

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article

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