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Influence of Soret and Dufour Effects on Unsteady Hydromagnetic Heat and Mass Transfer Flow of a Micropolar Fluid past a Stretching Sheet with Heat Sources

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Abstract: *In this paper, we investigate the combined influence of Heat source, Soret and Dufour effects on transient convective heat and mass transfer flow of a micro polar fluid through porous medium past permeable stretching sheet in slip flow regime with constant heat and mass flux. The non linear coupled equations governing the flow heat and mass transfer flow have been solved by Employing Galerkin finite element technique with quadratic approximation polynomials. The velocity, microrotation, temperature and concentration have been discussed for governing parameters. The skin friction, the rate of heat and mass transfer have evaluated numerically for different parametric variations.*

Keywords: *Unsteady Hydromagnetic, Soret and Dufour, Micropolar, stretching sheet, Heat Sources*

1. Introduction

The boundary layer flow, heat and mass transfer in a quiescent Newtonian and non-Newtonian fluid driven by a continuous stretching sheet are of significance in a number of industrial engineering processes such as drawing of a polymer sheet or filaments extruded continuously from a die , the cooling of a metallic plate in a bath, the aerodynamic extrusion of plastic sheets, the continuous casting, rolling, annealing and thinning of copper wires, the wires are fiber coating etc .The final product of desired characteristics depends on the rate of cooling in the process and the process of stretching. Mohammadi and Nourazar [30] studied on the insertion of a thin gas layer in micro cylindrical coquette flows involving power-law liquids. The analytical solution for two-phase flow between two rotating cylinders filled with power-law liquid and a micro layer of gas has been investigated by Mohammadi et al [31]. The dynamics of the boundary layer flow over a stretching surface originated from the pioneering work of carne [11]. Later on, various aspects of the problem have been investigated such as Gupta and Gopta [21], chen and char [10], Datta et al [13], extended the work of Crane [11] by including the effect of heat and mass transfer analysis under different physical situations.

Micropolar fluids are fluids with microstructure and asymmetrical stress tensor. Physically, they represent fluids consisting of randomly oriented particles suspended in a viscous medium. These types of fluids are used in analyzing liquid crystals, animal blood, fluid flowing in brain, exotic lubricants, the flow of colloidal suspensions, etc. The theory of micro polar fluids is first proposed by Eringen [18&19]. In this theory the local effects arising from the microstructure and the intrinsic motion of the fluid elements are taken into account. The comprehensive literature on micro polar fluids, thermo micropolar fluids and their applications in engineering and technology was presented by Ariman et al [4&5], Prathap kumar et al. [34]. Kelson and Desseaux [25] studied the effect of surface conditions on the micro polar flow driven by a porous stretching sheet. Srinivasacharya et al [39] analyzed the unsteady flow of micro polar fluid between two parallel porous plates. Bhargava et al [6] investigated by using a finite element method the flow of a mixed convection micropolar fluid driven by a porous stretching sheet with uniform suction.

Gorla and Nakamura [20] discussed the combined convection from a rotating cone to micro polar fluids with an arbitrary variation of surface temperature. Anwar Beg and Takhar et al. [3] examined the buoyancy effects in a forced flow in the three dimensional non-steady motion of an incompressible, micropolar fluid in the vicinity of the forward stagnation point of a blunt nosed body. Ibrahim et al. [22] discussed the case of mixed convection flow of a micro polar fluid past a semi-finite, steadily moving porous plate with varying suction velocity normal to the plate in the presence of thermal radiation and viscous dissipation. DmaeshRebhi et al. [12] have investigated natural convection heat and mass transfer adjacent to a continuously moving vertical porous infinite plate for incompressible, micropolar fluid in the presence of heat generation or absorption effects and a first-order chemical reaction. Ali and Magyari [2] have studied the unsteady fluid and heat flow by a submerged stretching surface while its steady motion is slowed down gradually. Mukhopadhyay [33] extended it by assuming the viscosity and thermal diffusivity are linear functions of temperature and studied unsteady mixed convection boundary layer flow of an incompressible viscous liquid through porous medium along a permeable surface, and the thermal radiation effect on heat transfer was also considered.

Mohamood and Nadeem et al. [29] have been analyzed the heat transfer analysis of water-based nanofluid over an exponentially stretching sheet. The nanofluid flow over an unsteady stretching surface in the presence of thermal radiation was examined by Das et al. [14]. The fluid flow past over a stretching sheet has been studied by many authors. Yacos et al [45] have been investigated melting heat transfer in boundary layer stagnation point flow towards a stretching/shrinking sheet in micropolar fluid. The mixed convection flow of a micro polar fluid from an unsteady stretching surface with viscous dissipation has been proposed by EI-Aziz [1]. Mahmood et al. [29] analyzed the non-orthogonal stagnation point flow of a micro polar second-grade fluid toward a stretching/shrinking sheet in a porous medium with suction was observed by Rosali et al. [37]. Heat and Mass transfer on MHD flow of a viscoelastic fluid through porous medium over a shrinking sheet was investigated by Bhukta et al [7]. Mahmood and Waheed [28] have been proposed the MHD flow and heat transfer of a micro polar fluid over a stretching surface with heat generation (absorption) and slip velocity. The boundary layer flow of hyperbolic tangent fluid over a vertical exponentially stretching cylinder was studied by Ishak and Nazar et al. [23].

As many industrially and environmentally relevant fluids are not pure, it is been suggested that more attention should be paid to convective phenomena which can occur in mixtures, but are not in common liquids such as air or water. Applications involving liquid mixtures include the costing of alloys, ground water pollutant migration and separation operations. In all of these situations, multi component liquids can undergo natural convection driven by buoyancy force resulting from simultaneous temperature and species gradients. In the case of binary mixtures, the species gradients can be established by the applied boundary conditions such as species rejection associated with alloys costing, or can be induced by transport mechanism such as Soret (thermo) diffusion. In the case of Soret diffusion, species gradients are established in an otherwise uniform concentration mixture in accordance with on sager reciprocal relationship. Thermal-diffusion known as the Soret effect takes place and as a result a mass fraction distribution is established in the liquid layer. The sense of migration of the molecular species is determined by the sign of Soret coefficient. Soret and Dufour effects are very significant in both Newtonian and non-Newtonian fluids when density differences exist in flow regime. The thermo-diffusion (Soret) effect is corresponds to species differentiation developing in an initial homogeneous mixture submitted to a thermal gradient and the diffusion-thermo (Dufour) effect corresponds to the heat flux produced by a concentration gradient. Usually, in heat and mass transfer problems the variation of density with temperature and concentration give rise to a combined buoyancy force under natural convection and hence the temperature and concentration will influence the diffusion and energy of the species. Many papers are found in literature on Soret and Dufour effects on different geometries. Dulal Pal et al.[15] has studied MHD non-Darcian mixed convection heat and mass transfer over a non-linear stretching sheet with Soret and Dufour effects and chemical reaction. MHD mixed convection flow with Soret and Dufour effects past a vertical plate embedded in porous medium was studied by Makinde [27]. Reddy et al. [36] has presented finite element solution to the heat and mass transfer flow past a cylindrical annulus with Soret and Dufour effects. Recently, Chamkha et al. [9] has studied the influence of Soret and Dufour effects on unsteady heat and mass transfer flow over a rotating vertical cone and they suggested that temperature and concentration fields are more influenced with the values of Soret and Dufour parameter.

Wang [44] was first studied the unsteady boundary layer flow of a liquid film over a stretching sheet. Later, Elbashbeshy and Bazid [17] have presented the heat transfer over an unsteady stretching surface. Tsai et.al [42] has discussed flow and heat transfer characteristics over an unsteady stretching surface by taking heat source into the account. Ishak et al [23] analyzed the effect of prescribed wall temperature on heat transfer flow over an unsteady stretching permeable surface. Ishak [24] has presented unsteady MHD flow and heat transfer behavior over a stretching plate. Dulal pal [15] has described the analysis of flow and heat transfer over an unsteady stretching surface with non-uniform heat source/sink and thermal radiation. Dulal pal et al. [16] have presented MHD non-Darcian mixed convection heat and mass transfer over a non-linear stretching sheet with Soret–Dufour effects, heat source/sink and chemical reaction.

2. Formulation of the Problem

We analyse two-dimensional transient unsteady viscous electrically conducting heat and mass transfer of micropolar fluid flow through porous medium over a stretching sheet in the presence of suction/injection, Soret and Dufour effects in slip flow regime. The coordinate system is such that *x*-axis is taken along the stretching surface in the direction of the motion with the slot at origin and the *y*-axis is perpendicular to the surface of the sheet as shown schematically in Fig.1. A uniform transverse magnetic field (B_0) is applied along the y-axis. The stretching surface and the fluid are maintained same temperature and concentration initially, instantaneously they raised to a temperature T_w ($>T_\infty$) and concentration C_w ($>C_\infty$) which remain unchanged. Under the above stated physical situations, the governing boundary-layer and Darcy-Boussinesq's approximations, the basic equations are given by:

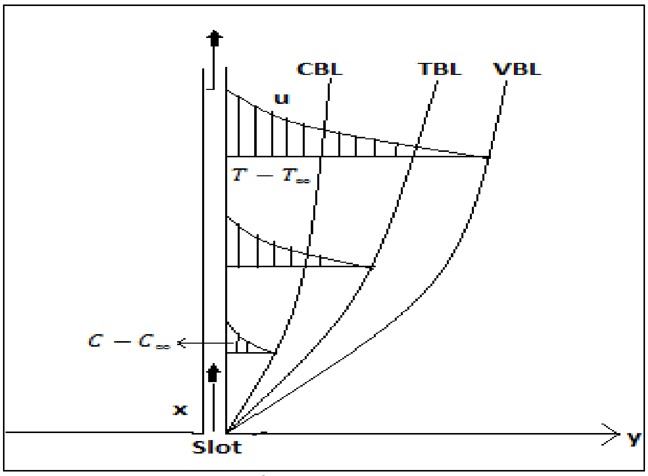

Fig. 1.Flow configuration and coordinate system.

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=(\nu+\frac{k_1}{\rho})\frac{\partial^2 u}{\partial y^2}+k\frac{\partial \omega}{\partial y}+ \\ +g(\beta(T-T_\infty)+\beta^{\infty}(C-C_\infty))-(\frac{\mu}{\rho k})u-\frac{\sigma B_o^2}{\rho}u \tag{2}$$

$$\frac{\partial \omega}{\partial t}+u\frac{\partial \omega}{\partial x}+v\frac{\partial \omega}{\partial y}=(\frac{\gamma}{\rho j})\frac{\partial^2 \omega}{\partial y^2}+(\frac{k_1}{\rho j})(2\omega+\frac{\partial u}{\partial y}) \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=(\frac{k_f}{\rho C_p})\frac{\partial^2 T}{\partial y^2}+(\frac{\mu}{\rho C_p})(\frac{\partial u}{\partial y})^2+(\frac{D_T K_T}{C_s C_p})\frac{\partial^2 C}{\partial y^2}-Q_H(T-T_\infty) \tag{4}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=(D_m)\frac{\partial^2 C}{\partial y^2}+(\frac{D_m K_T}{T_m})\frac{\partial^2 T}{\partial y^2} \tag{5}$$

The associated boundary conditions on the vertical surface are defined as follows

$$U=U_w=ax, v=-v_w, \frac{\partial T}{\partial y}=-\frac{q_w}{k_f}, \frac{\partial C}{\partial y}=-\frac{m_w}{D_m}\ , \omega'=0 \quad at \quad y=0$$

$$U \to 0, T \to T_\infty, C \to C_\infty \ , \omega' = 0 \quad at \quad y \to \infty \tag{6}$$

The boundary condition ω = 0 at y = 0 in Eq. (6), represents the case of concentrated particle flows in which the microelements close to the wall are not able to rotate, due to the no slip condition in the above equations *x* and y represents coordinate axis along the continuous surface in the direction of motion and perpendicular to it, *u* and *v* are the velocity components along *x* and y directions, respectively. The term $V_w = -\sqrt{\frac{a\nu}{2}}V_o$ represents the mass transfer at the surface with $V_w < 0$ for suction and $V_w > 0$ for injection.

The following similarity transformations are introduced to simplify the mathematical analysis of the problem

$$\eta = \sqrt{\frac{a}{\nu(1-ct)}}y, \psi = \sqrt{\frac{a\nu}{(1-ct)}}f(\eta), u = \frac{ax}{(1-ct)}f'(\eta), v = -\sqrt{\frac{a\nu}{(1-ct)}}f(\eta), \omega = \sqrt{\frac{a^3}{\nu(1-ct)^3}}xg(\eta)$$
$$T = T_\infty + \frac{bx}{(1-ct)^2}, C = C_\infty + \frac{dx}{(1-ct)^2}, \theta = \frac{T - \dot{T}_\infty}{(\frac{q_w}{k_f})}\sqrt{\frac{a}{\nu(1-ct)}}, \phi = \frac{C - C_\infty}{(\frac{m_m}{D_m})}\sqrt{\frac{a}{\nu(1-ct)}} \tag{7}$$

Using equation (7), the governing equations (2) – (5) are transformed into the following form

$$(1 + A1)f''' + ff'' - (f')^2 - A(f' + \frac{1}{2}\eta f'') + A1g' + G(\theta + N\phi) - (M^2 + D^{-1})f' = 0 \tag{8}$$

$$\lambda g'' + fg' - gf' - \frac{A}{2}(3g + \eta g') + A1B(2g + f'') = 0 \tag{9}$$

$$\theta'' + \Pr(f\theta' - f'\theta) - \Pr\frac{A}{2}(4\theta + \eta\theta') - Ec(f'')^2 + Du\phi'' - \theta = 0 \tag{10}$$

$$\phi'' - Sc(f\phi\theta - f'\phi) - Sc\frac{A}{2}(4\phi + \eta\phi') + ScSr\theta'' = 0 \tag{11}$$

The corresponding transformed boundary conditions are

$$f' = 1, f = fw, g = 0, \frac{\partial\theta}{\partial\eta} = -1, \frac{\partial\phi}{\partial\eta} = -1, \omega = 0 \ \ at\, \eta = 0$$
$$f' = 0, \ \ g = 0, \theta = 0, \phi = 0 \ \ as \ \eta \to \infty \tag{12}$$

Where

$$A1 = \frac{k_1}{\mu} coupling\ parameter, G = \frac{\beta g q_w \nu^{1/2}(1-ct)^{5/2}}{k_f x a^{5/2}}(Grashof\ number)$$

$$N = (\frac{\beta^* k_f m_w}{\beta D_m q_w})(Buoyancy\ parameter), A = \frac{c}{a}(unsteadiness\ parameter)$$

$$D^{-1} = \frac{\nu(1-ct)}{ka}(Inverse\ Darcy\ parameter), \Pr = \frac{\mu C_p}{k_f}(\Pr andtl\ paraameter)$$

$$Sc = \frac{\nu}{D_m}(Schmidt\ parameter), Sr = \frac{D_m K_T}{\nu T_m}(Soret\ parameter)$$

$$Du = \frac{D_m K_T l}{C_s C_p b \nu}(Dufour\ parameter), Ec = \frac{a^2 x}{C_p b}(Ec\ker tNumber)$$

$$M = \frac{\sigma B_o^2(1-ct)}{\rho a}(Magnetic\ parameter), \ \lambda_0 = \frac{\gamma}{\nu j}, B = \frac{\nu(1-ct)}{aj}$$

The major physical quantities of interest in this problem are the local skin friction coefficient (C_{fx}), couple stress coefficient (C_{sx}), local Nusselt number (Nu_x) and the local Sherwood number (Sh_x) are defined, respectively, by

$$C_{fx}=\frac{2(1+A1)f''(0)}{\mathrm{R}_{ex}^{1/2}},C_{sx}=\frac{\nu aU_w h'(0)}{\mathrm{R}_{ex}^{1/2}},Nu_x=-\frac{1}{\mathrm{R}_{ex}^{1/2}}(\frac{1}{\theta(0)}),Sh_x=-\frac{1}{\mathrm{R}_{ex}^{1/2}}(\frac{1}{\phi(0)})$$

3. METHOD OF SOLUTION

The set of ordinary differential equations (8) – (11) are highly non-linear, and therefore cannot be solved analytically. The Finite-element method [29, 30, 31, and 32] has been employed to solve these non-linear equations. The procedure of Finite element method is as follows.

- Finite-element discretization
- Generation of the element equations
- Assembly of element equations
- Imposition of boundary conditions
- Solution of assembled equations

The very important aspect in this numerical procedure is to select an approximate finite value of ψ_0. So, in order to estimate the relevant value, the solution process has been started with an initial value and then the equations (8) – (11) are solved together with boundary conditions (12). We have updated the value and the solution process is continued until the results are not affected with further values. The choice of velocity, micro-rotation, temperature and concentration has confirmed that all the numerical solutions approach to the asymptotic values at the free stream conditions.

For the solution of system of non-linear ordinary differential equation (8) – (11) together with boundary conditions (12), first we assume that

$$\frac{\partial f}{\partial \eta}=j \tag{12}$$

The equations (8) to (11) then reduces to

$$(1+A1)j''+fj'-(j)^2-A(j+\frac{1}{2}\eta j')+A1g'+G(\theta+N\phi)-(M^2+D^{-1})j=0 \tag{13}$$

$$\lambda g''+fg'-gf'-\frac{A}{2}(3g+\eta g')+A1B(2g+j')=0 \tag{14}$$

$$\theta''+\Pr(f\theta'-j\theta)-\Pr\frac{A}{2}(4\theta+\eta\theta')-Ec(j')^2+Du\phi''-Q\theta=0 \tag{15}$$

$$\phi''-Sc(f\phi\theta-j\phi)-Sc\frac{A}{2}(4\phi+\eta\phi')+ScSr\theta''=0 \tag{16}$$

The boundary conditions take the form

$$\begin{aligned}&j=1,f=fw,g=0,\frac{d\theta}{d\eta}=-1,\frac{d\phi}{d\eta}=-1\ at\ \eta=0\\&j=0,g=0,\theta=0,\phi=0\qquad as\ \eta\to\infty\end{aligned} \tag{17}$$

- **Variational formulation**

The variational form associated with Eqs. (20) to (24) over a typical linear element (η_e,η_{e+1}) is given by

$$\int_{\eta_e}^{\eta_{e+1}} w_1(\frac{\partial f}{\partial \eta}-j)d\eta=0 \tag{18}$$

$$\int_{\eta_e}^{\eta_{e+1}} w_2((1+A1)j''+j'-(j)^2-A(j)+\frac{1}{2}\eta j')+A1g'+G(\theta+N\phi)-(M^2+D^{-1})j)d\eta=0 \tag{19}$$

$$\int_{\eta_e}^{\eta_{e+1}} w_3(\lambda g''+fg'-gf'-\frac{A}{2}(3g+\eta g')+A1B(2g+j'))d\eta=0 \tag{20}$$

$$\int_{\eta_e}^{\eta_{e+1}} w_4(\theta'' + \Pr(f\theta' - j\theta) - \Pr\frac{A}{2}(4\theta + \eta\theta') - Ec(j')^2 + Du\phi'' - Q\theta)d\eta = 0 \tag{21}$$

$$\int_{\eta_e}^{\eta_{e+1}} w_5(\phi'' - Sc(f\phi' - j\phi) - Sc\frac{A}{2}(4\phi + \eta\phi') + ScSr\theta'')d\eta = 0 \tag{22}$$

Where w_1, w_2, w_3, w_4, w_5 are arbitrary test functions and may be viewed as the variations in f, j, g, θ and ϕ respectively.

- **Finite- element formulation**

The finite-element model may be obtained from above equations by substituting finite-element approximations of the form

$$f = \sum_{j=1}^{3} f_j\psi_j,\ j = \sum_{j=1}^{3} j_j\psi_j, g = \sum_{j=1}^{3} g_j\psi_j, \theta = \sum_{j=1}^{3} \theta_j\psi_{,j}, \phi = \sum_{j=1}^{3} \phi_j\psi_{,j}$$

With $w_1=w_2=w_3=w_4=w_5=\psi_j$ (i=1, 2, 3)

Where ψ_j are the shape functions for a typical element (η_e, η_{e+1}) and are defined as

$$\psi_1^e = \frac{(\eta_{e+1} + \eta_e - 2\eta)(\eta_{e+1} - \eta)}{(\eta_{e+1} - \eta_e)^2}, \psi_3^e = \frac{(\eta_{e+1} + \eta_e - 2\eta)(\eta - \eta_{e+1})}{(\eta_{e+1} - \eta_e)^2}$$

$$\psi_2^e = \frac{4(\eta - \eta_e)(\eta_{e+1} - \eta)}{(\eta_{e+1} - \eta_e)^2} \quad (\eta_e \le \eta \le \eta_{e+1})$$

The finite element model of the equations thus formed is given by

$$\begin{bmatrix} [K^{11}][K^{12}][K^{13}][K^{14}][K^{15}] \\ [K^{21}][K^{22}][K^{23}][K^{24}][K^{25}] \\ [K^{31}][K^{32}][K^{33}][K^{34}][K^{35}] \\ [K^{41}][K^{42}][K^{43}][K^{44}][K^{45}] \\ [K^{51}][K^{52}][K^{53}][K^{54}][K^{55}] \end{bmatrix} \begin{bmatrix} f \\ j \\ g \\ \theta \\ \phi \end{bmatrix} = \begin{bmatrix} \tau^1 \\ \tau^2 \\ \tau^3 \\ \tau^4 \\ \tau^5 \end{bmatrix}$$

where, $[K^{mn}]$ and $[\tau^m]$ (m, n=1,2,3,4,5) are defined as

$$K_{ij}^{11} = \int_{\eta_e}^{\eta_{e+1}} \psi_i \frac{\partial\psi_j}{\partial\eta} d\eta, K_{ij}^{12} = -\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_j d\eta, K_{ij}^{13} = K_{ij}^{14} = K_{ij}^{15} = 0$$

$$K_{ij}^{21} = 0, K_{ij}^{24} = G\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_j d\eta, K_{ij}^{25} = N\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_j d\eta,$$

$$K_{ij}^{22} = -(1 + A1)\int_{\eta_e}^{\eta_{e+1}} \frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta} d\eta - (M^2 + D^{-1})\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_j d\eta +$$
$$0.5A\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_1 \frac{\partial\psi_j}{\partial\eta} d\eta + 0.5A\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_2 \frac{\partial\psi_j}{\partial\eta} d\eta - \bar{f}_1\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_1 \frac{\partial\psi_j}{\partial\eta} d\eta -$$
$$\bar{f}_2\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_2 \frac{\partial\psi_j}{\partial\eta} d\eta$$

$$K_{ij}^{23} = A1\bar{g}_1\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_1\psi_j d\eta - A1\bar{g}_2\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_2\psi_j d\eta$$
$$K_{ij}^{31} = 0, K_{ij}^{32} = 0$$
$$K_{ij}^{33} = -\lambda\int_{\eta_e}^{\eta_{e+1}} \frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta} d\eta - (2A1B + 1.5A\bar{j})\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_1\psi_j d\eta +$$
$$1.5A\eta\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_1 \frac{\partial\psi_j}{\partial\eta} d\eta + 1.5A\eta\int_{\eta_e}^{\eta_{e+1}} \psi_i\psi_2 \frac{\partial\psi_j}{\partial\eta} d\eta, K_{ij}^{34} = K_{ij}^{35} = 0$$

$$K_{ij}^{41}=0, K_{ij}^{42}=Ec\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1(\frac{\partial\psi_j}{\partial\eta})^2 d\eta, K_{ij}^{43}=0,$$

$$K_{ij}^{44}=-\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta+\Pr(1+1.5A\eta)\,\bar{f}_1\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1(\frac{\partial\psi_j}{\partial\eta})d\eta+$$

$$\Pr(1+1.5A\eta)\,\bar{f}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2(\frac{\partial\psi_j}{\partial\eta})d\eta+\Pr(1+Q+1.5A\eta)\,\bar{j}_1\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1\psi_j d\eta+$$

$$\Pr(1+Q+1.5A\eta)\,\bar{j}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2\psi_j d\eta$$

$$K_{ij}^{45}=-\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta, K_{ij}^{51}=0, K_{ij}^{52}=0, K_{ij}^{53}=0$$

$$K_{ij}^{54}=-ScSr\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta, K_{ij}^{55}=-\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{f}_1$$

$$\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{f}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{j}_1$$

$$\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1\psi_j d\eta+Sc(1+1.5A\eta)\,\bar{j}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2\psi_j d\eta, \tau_i^1=0, \tau_i^2=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^2=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}},$$

$$\tau_i^3=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^4=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^5=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}$$

$$K_{ij}^{54}=-ScSr\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta, K_{ij}^{55}=-\int_{\eta_e}^{\eta_{e+1}}\frac{\partial\psi_i}{\partial\eta}\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{f}_1$$

$$\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{f}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2\frac{\partial\psi_j}{\partial\eta}d\eta+Sc(1+1.5A\eta)\,\bar{j}_1$$

$$\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_1\psi_j d\eta+Sc(1+1.5A\eta)\,\bar{j}_2\int_{\eta_e}^{\eta_{e+1}}\psi_i\psi_2\psi_j d\eta, \tau_i^1=0, \tau_i^2=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^2=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}},$$

$$\tau_i^3=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^4=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}, \tau_i^5=-(\psi_i\frac{\partial\psi_i}{\partial\eta})_{\eta_e}^{\eta_{e+1}}$$

Where $\bar{f}=\sum_{j=0}^{3} f_i\psi_i,\ \bar{j}=\sum_{j=0}^{3} j_1\psi_i$

4. Results and Discussion

Comprehensive numerical computations were conducted for different values of the parameters and results are illustrated graphically as well as in tabular form. Selected computations are presented in Figs (2a–6d). The correctness of the current numerical method is checked with the results obtained by Mohanty et al. [32] and is shown in Table 1. Thus, it is seen from Table 1 that the numerical results are in close agreement with those published previously.

Figures (2a-2d) depicts the effect of Eckert number (*Ec*) on velocity, micro-rotation, temperature and concentration profiles in the boundary layer regime. It is seen from fig 2a that the thickness of momentum boundary layer is rised as the values of (*Ec*) increases. Furthermore, the micro-rotation profiles are elevated with the higher values of (*Ec*). The thickness of thermal and solutal boundary layer is boosted in the flow region as the values of Eckert number (*Ec*) rises. Higher the dissipative energy smaller the skin friction, Couple stress, Nusselt number and larger the Sherwood number, at the wall η=0.

Figs.3a-3d shows the effect of heat sources on the velocity, micro-rotation, temperature and concentration. It is found that an increase in the strength of the heat generating/absorbing source enhances the velocity and temperature in the flow region.The micro-rotation and concentration enhances with increase in Q>0 and reduces with Q<0. This is due to the fact that heat energy is generated in the momentum boundary layer ,thermal boundary layer, the solutal boundary layer while for Q<0, heat energy is absorbed in the solutal boundary layer. The skin friction , the couple stress and Nusselt number enhances with increae in the strength of the heat generating/absorbing sources.The Sherwood number reduces on the wall with increasing the strength of the heat generating source and enhances with heat absorbing source.

The impact of Soret and Dufour effect (*Sr&Du*) on velocity, microrotation, temperature and concentration profiles is portrayed in Figs. (4a-4d). It is noticed that the velocity profiles ,the concentratrion distributions elevates, the micro-rotation and temperature deteriorates with the rising values of (*Sr*)(or decreasing values of Du) in the boundary layer regime. This is because of the fact that the diffusive species with higher values of Soret parameter (*Sr*) (or lower the values of Du) has the tendency of increasing concentration profiles. Thus, it is concluded from Figs. (4a-4d) that the temperature and concentration distributions are more influenced with the values of Soret and Dufour parameters. Increasing Sr (or decreasing Du) leads to a decay in skin friction, couple stress and Sherwood number and depreciation in Nusselt number at the wall η=0.

Figs.5a-5d represent the effect of micropolar parameter (λ) on the velocity, micro-rotation, temperature and concentration. It is found that the velocity enhances, the micro-rotation, temperature and concentration reduces with increase in λ in the flow region. An increase in λ enhances the skin friction, Nusselt and Sherwood number, reduces the couple stress, Nusselt Number on the wall η=0.

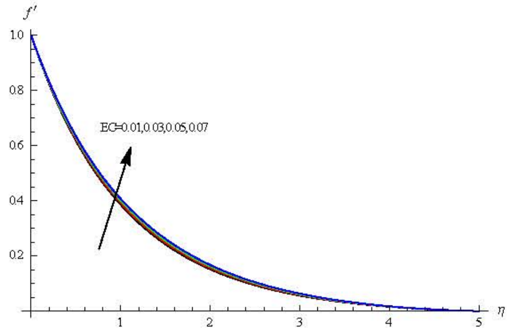

Fig2a. *variation of f' with Ec*

Sr=2, Du=0.03,Q=2, λ=0.5,B=0.5

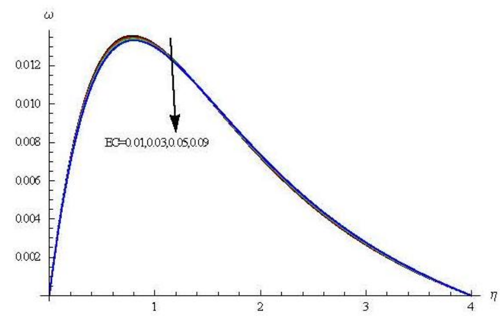

Fig2b. *Variation of ω with Ec*

Sr=2,Du=0.03,Q=2, λ=0.5,B=0.5

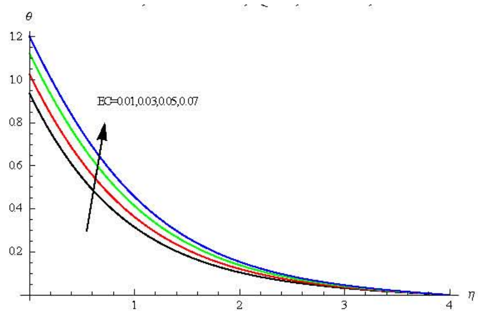

Fig2c. *Variation of θ with Ec*

Sr=2,Du=0.03,Q=2, λ=0.5,B=0.5

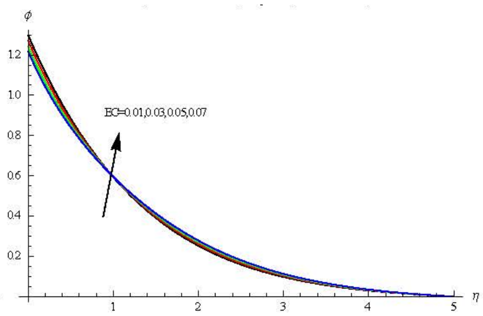

Fig2d. *Variation of ϕ with Ec*

Sr=2,Du=0.03,Q=2, λ=0.5,B=0.5

Fig.6a-6d exhibits the effect of micropolar parameter B on the velocity, micro-rotation, temperature and concentration. It is found that an increase in B reduces the velocity and enhances the micro-rotation, temperature and concentration in the flow region. This is due to the fact that an increase in B reduces the thickness of momentum boundary layer while the thickness of the micro-rotation, thermal and solutal boundary layers increases with B. An increase in B enhances the skin friction, couple stress and Nusselt number. The Sherwood number reduces with B≤1 and enhances with higher B≥1.5 at the wall η=0.

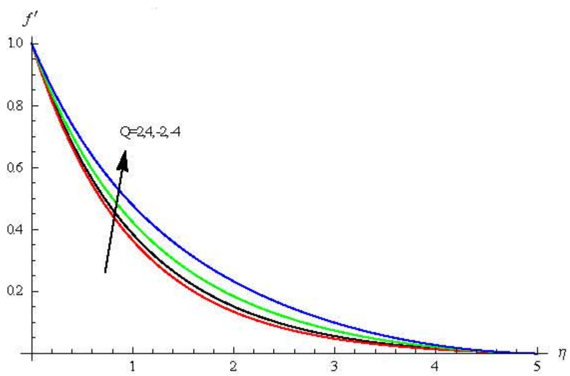

Fig3a. *variation of f' with Q*

Ec=0.01,Sr=2,Du=0.03, λ=0.5,B=0.5

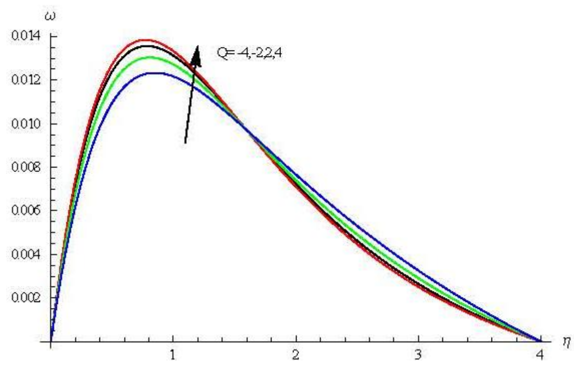

Fig3b. *Variation of ω with Q*

Ec=0.01,Sr=2,Du=0.03, λ=0.5,B=0.5

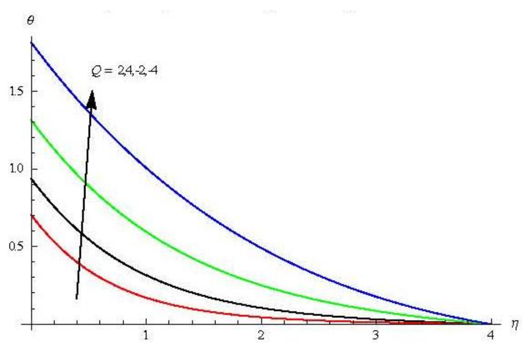

Fig3c. *Variation of θ with Q*

Ec=0.01,Sr=2,Du=0.03, λ=0.5,B=0.5

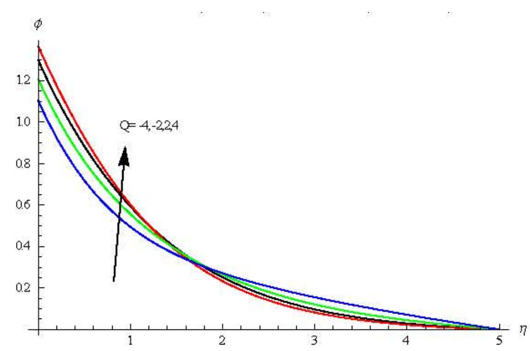

Fig3d. *Variation of ϕ with Q*

Ec=0.01,Sr=2,Du=0.03, λ=0.5,B=0.5

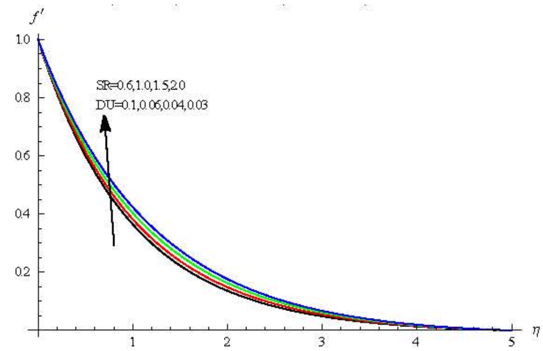

Fig4a. *variation of f' with Sr&Du*

Ec=0.01,Q=2,λ=0.5,B=0.5

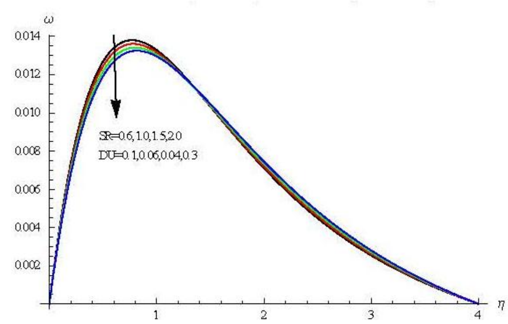

Fig4b. *Variation of ω with Sr & Du*

Ec=0.01,Q=2,λ=0.5,B=0.5

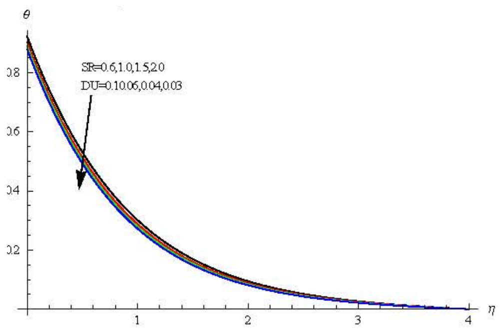

Fig4c. *Variation of θ with Sr & Du*

Ec=0.01,Q=2,λ=0.5,B=0.5

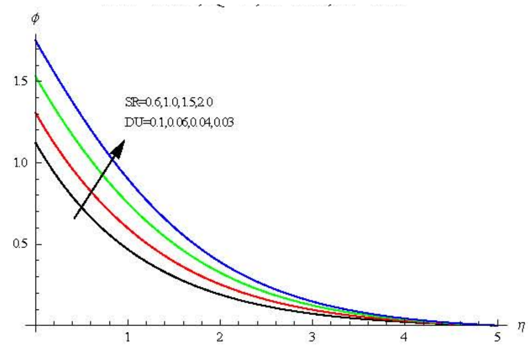

Fig4d. *Variation of ϕ with Sr & Du*

Ec=0.01,Q=2,λ=0.5,B=0.5

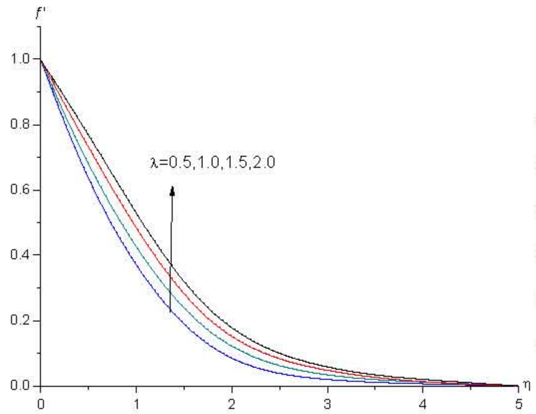

Fig5a. *variation of f' with λ*

Ec=0.01,Sr=2,Q=2,B=0.5,Du=0.03

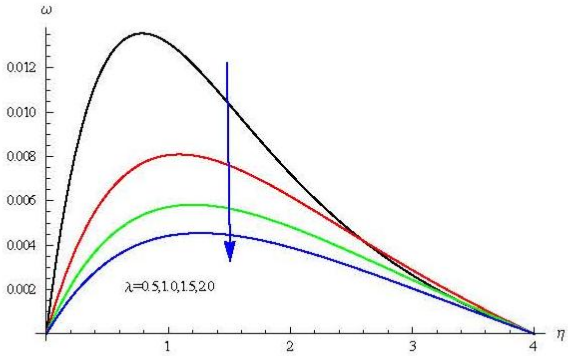

Fig5b. *Variation of ω with λ*

Ec=0.01,Sr=2,Q=2,B=0.5,Du=0.03

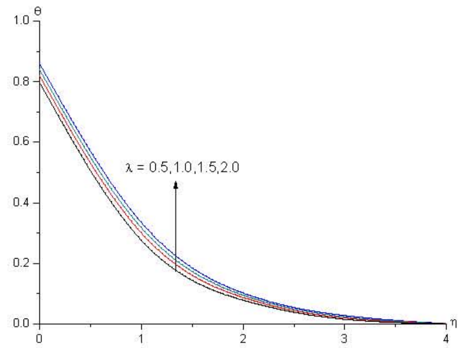

Fig5c. *Variation of* θ *with* λ

Ec=0.01,Sr=2,Q=2,B=0.5,Du=0.03

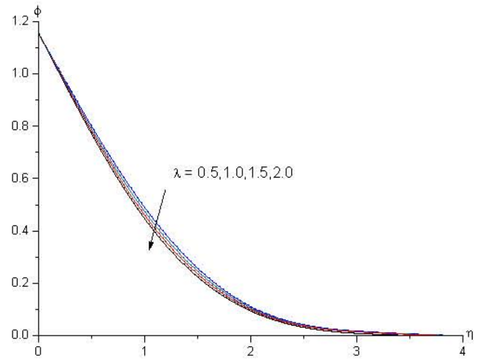

Fig5d. *Variation of* ϕ *with* λ

Ec=0.01,Sr=2,Q=2,B=0.5,Du=0.03

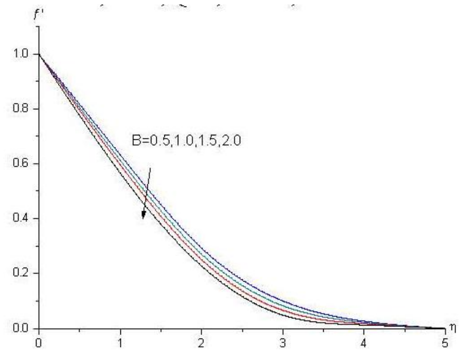

Fig6a. *variation of* $f\,'$ *with B*

Ec=0.01,Sr=2,Q=2,λ*=0.5,Du=0.03*

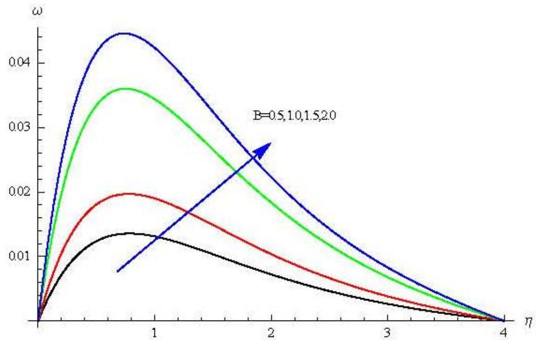

Fig6b. *Variation of* ω *with B*

Ec=0.01,Sr=2,Q=2,λ*=0.5,Du=0.03*

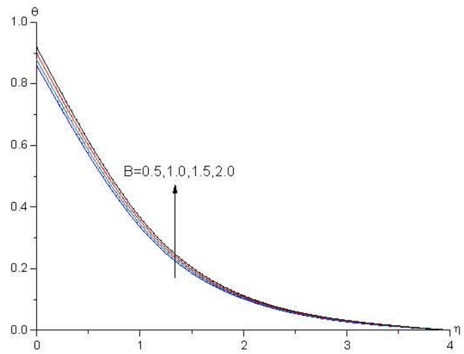

Fig6c. *Variation of* θ *with B*

Ec=0.01,Sr=2,Q=2,λ*=0.5,Du=0.03*

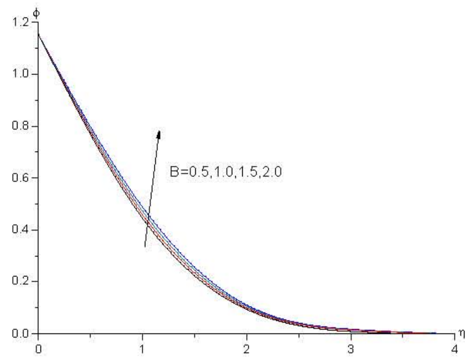

Fig6d. *Variation of* ϕ *with B*

Ec=0.01,Sr=2,Q=2,λ*=0.5,Du=0.03*

Table1. *Comparison of local Skin-friction, Nusselt number and Sherwood number with the existing results, in the absence of heat sources (Q=0), Soret and Dufour effects (Sr=Du=0)*

Parameter							C_f		Nu_x		Sh_x	
G	N	Pr	Sc	M	D-1	Ec	Mohanty et al.[32]	Present Study	Mohanty et al.[32]	Present Study	Mohanty et al.[32]	Present Study
0.0	0.0	0.72	0.00	0	100	0.00	-0.81861	-0.81873	0.85604	0.85619	0.16666	0.16671
0.1	0.0	0.72	0.00	0	100	0.00	-0.78025	-0.78019	0.86514	0.86526	0.42252	0.42263
0.1	0.0	0.72	0.22	0	100	0.00	-0.78025	-0.78019	0.86514	0.86526	0.42252	0.42263
0.1	0.0	0.72	0.22	1	100	0.00	-1.11781	-1.11776	0.78477	0.78482	0.37866	0.37872
0.1	0.0	0.72	0.22	1	0.5	0.01	-1.59782	-1.59773	0.68391	0.68386	0.33393	0.33385
0.1	0.0	0.72	0.22	1	100	0.01	-1.11775	-1.11766	0.77999	0.77981	0.37867	0.37874
0.1	1.0	0.72	0.22	1	0.5	0.01	-1.59777	-1.59782	0.67651	0.67646	0.33394	0.33398
0.1	1.0	7.00	0.22	1	100	0.01	-1.09307	-1.09311	3.02046	3.02052	0.38361	0.38370
0.5	1.0	0.72	0.22	1	100	0.01	-0.93986	-0.93991	0.82922	0.82931	0.40495	0.40486
0.1	1.0	0.72	0.22	1	100	0.01	-1.06792	-1.06798	0.79858	0.79863	0.38891	0.38896
0.5	1.0	0.72	0.22	1	0.5	0.01	-1.44651	-1.44667	0.72576	0.72569	0.35583	0.35591

Table2. *Comparison of local Skin-friction, Nusselt number and Sherwood number with the existing results, in the absence of heat sources (Q=0), Soret and Dufour effects (Sr=Du=0)*

Parameter		τ(0)	Cw(0)	Nu(0)	Sh(0)
Q	**2**	-0.979147	0.0455463	1.06666	0.770065
	4	-1.02755	0.047124	1.42043	0.732582
	-2	-0.775547	0.0387242	0.551197	0.906626
	-4	-0.880622	0.0457494	0.566214	1.03191
Ec	**0.01**	-0.979147	0.0455463	1.06666	0.770065
	0.03	-0.967	0.0451747	0.999868	0.78168
	0.05	-0.956602	0.0448576	0.949123	0.791804
	0.07	-0.946348	0.0445456	0.903996	0.801953
Sr/Du	**0.6/0.1**	-1.03106	0.0471214	1.08367	0.890039
	1.0/0.06	-0.97463	0.0454298	1.0356	0.776299
	1.5/0.04	-0.911263	0.0435312	0.999865	0.674061
	2/0.03	-0.851198	0.0417389	0.966268	0.600614
λ	**0.5**	-1.12766	0.049303	0.912272	0.956378
	1.0	-1.12713	0.036299	0.912279	0.956386
	1.5	-1.12722	0.029086	0.912283	0.956334
	2.0	-1.12734	0.020854	0.912296	0.956394
B	**0.5**	-0.951471	0.0461968	1.07486	0.737849
	1.0	-0.994247	0.0700635	1.37362	0.70184
	1.5	-1.19418	0.203025	1.46634	0.89907
	2.0	-0.215192	0.108431	2.04338	1.57911

5. CONCLUSIONS

The combined influence of Thermo–diffusion and Diffusion–thermo effect on unsteady MHD boundary layer flow, heat and mass transfer characteristics of viscous micropolar fluid over a stretching sheet by taking suction/injection into the account is studied numerically in this paper. The important findings of this study are summarized as follows:

- Increase in Soret effect (or deceasing Dufour effect) enhances the velocity, concentration profiles, whereas, depreciates the micro-rotation, temperature profiles.
- The temperature of the fluid rises with increasing values of Eckert number (*Ec*) and is because of the reality that presence of viscous dissipation produces more heat due to drag between fluid particles.
- The micro-rotation and concentration enhances with increase in $Q>0$ and reduces with $Q<0$.This is due to the fact that heat energy is generated in the momentum boundary layer ,thermal boundary layer, the solutal boundary layer while for $Q<0$, heat energy is absorbed in the solutal boundary layer. The skin friction, the couple stress and Nusselt number enhances with increase in the strength of the heat generating/absorbing sources. The Sherwood number reduces on the wall with increasing the strength of the heat generating source and enhances with heat absorbing source.
- The velocity enhances, the micro-rotation, temperature and concentration reduces with increase in λ in the flow region. An increase in λ enhances the skin friction, Nusselt and Sherwood number, reduces the couple stress, Nusselt Number on the wall $\eta=0$.
- An increase in B reduces the velocity and enhances the micro-rotation, temperature and concentration in the flow region. An increase in B enhances the skin friction, couple stress and Nusselt number .The Sherwood number reduces with $B\leq1$ and enhances with higher $B\geq1.5$ at the wall $\eta=0$.

REFERENCES

[1] Abd EI-Aziz, M : Mixed convection flow of a micropolar fluid from an unsteady stretching surface with viscous dissipation, J. Egypt. Math. Soc., Vol. 21, pp. 385–394 (2013).

[2] Ali, M.E., E. Magyari : unsteady fluid and heat flow induced by a submerged stretching surface while its steady motion is slowed down gradually , Int. J.Heat mass transf.50, pp.188-195 (2007).

[3] Anwar Bég.C, O., Takhar, HS., Bhargava, R., Rawat, S., Prasad, V.R: Numerical study of heat transfer of a third grade viscoelastic fluid in non-Darcian porous media with thermo physical effects, Phys. Scr., 77, pp.1–11 (2008).

[4] Ariman, T., Turk, M.A and Sylvester, N.D: Micro continuum fluid mechanics- review, Int. J. Eng. Sci., Vol.11, pp. 905-930 (1973).

[5] Ariman, T., Turk, M.A and Sylvester, N.D: Application of micro continuum fluid mechanics, Int. J. Eng. Sci., Vol.12, pp. 273-293 (1974).

[6] Bhargava, R., Kumar, L and Takhar, H.S: Finite element solution of mixed Convection micropoloar fluid driven by a porous stretching sheet, Int. J. Eng. Sci., Vol. 41, pp. 2161–2178 (2003).

[7] Bhukta.D, G.C.Dash, S.R. Mishra : Heat and mass transfer on MHD flow of a visco elastic fluid through porous media over a shrinking sheet, Int. Scholarly Res. Notices 14 ,vol 11. , Article ID 572162 (2014).

[8] Chamkha, A.J., Mohammad, R.A and Ahmad, E: Unsteady MHD natural convection from a heated vertical porous plate in a micropolar fluid with Joule heating, chemical reaction and radiation effects, Meccanica, 2010, DOI 10.1007/s11012-010-9321-0 (2010).

[9] Chamkha, A.J. and Rashad A.M: Unsteady heat and mass transfer by MHD mixed convection flow from a rotating vertical cone with chemical reaction and Soret and Dufour effects, The Canadian Journal of Chemical Engineering, DOI 10.1002/cjce.21894 (2014).

[10] Chen,C.K., Char.M.I : Heat transfer of a continuous stretching surface with suction or blowing,J.Math.Anual.Appl,135, pp. 568-580 (1988).

[11] Crane, L.J., Z. Angew: Flow past a stretching plate, Math. Phys, 21, pp. 645–647 (1970).

[12] DamsehRebhi, A., Al-Odat, M.Q., Chamkha, A.J. and ShannakBenbella, A : Combined effect of heat generation or absorption and first-order chemical reaction on micropolar fluid flows over a uniformly stretched permeable surface, Int. J. Therm. Sci., Vol. 48, pp. 1658–1663 (2009).

[13] Datta.B.K., Roy,A.S. and Gupta.A.S: Temperature field in the flow over a stretching sheet with uniform heat flux,Int.commun. Heat Mass Transf, 12, pp. 90-94 (1985).

[14] Das.K, P.R.Durai, P.K.Kundoo, Nano fluid flow over an unsteady stretching surface in presence of thermal radiation, Alexandria Eng. J.53(3), pp. 737-795 (2014).

[15] Dulal Pal and Mondal.H : MHD non-Darcian mixed convection heat and mass transfer over a non-linear stretching sheet with Soret and Dufour effects and chemical reaction, International communications in heat and mass transfer, pp. 463-467 (2011).

[16] Dulal pal: Combined effects of non-uniform heat source/sink and thermal radiation on heat transfer over an unsteady stretching permeable surface, Commun Nonlinear SciNumer Simulat,16, pp.1890–1904 (2011).

[17] Elbashbeshy, EMA and Bazid, MAA: Heat transfer over an unsteady stretching surface, Heat Mass Transfer, 41, pp. 1–4 (2004).

[18] Eringen, A.C : Theory of micropolar fluids, J. Math. Mech, Vol.16, (1996).

[19] Eringen, A.C: Micro continuum field theories II, fluent media. Springer, New York (2001).

[20] Gorla, R.S.R., S. Nakamura, Mixed convection from a rotating cone to micropolar fluids, Int. J.Heat fluid flow 16, pp. 69-73 (1975).

[21] Gupta, P.S., Gopta, A.S: Heat and Mass Transfer on a stretching sheet with suction or blowing, can.J.Chem.Eng, 55, pp. 744-746 (1977).

[22] Ibrahim, F.S., Elaiw, A.M. and Bakr, A.A: Influence of viscous dissipation and radiation on unsteady MHD mixed convection flow of micropolar fluids, Appl. Math. Inf.Sci., Vol. 2, pp. 143–162 (2008).

[23] Ishak, A., Nazar, R. and Pop, I: Heat transfer over an unsteady stretching permeable surface with prescribed wall temperature, Nonlinear Anal: Real World Appl, 10, pp. 2909–13 (2009).

[24] Ishak, A: UnsteadyMHD flow and heat transfer over a stretching plate,J. Applied Sci,10(18), pp. 2127-2131 (2010).

[25] Kelson, N.A, A. Desseaux: Effect of surface condition on flow of micropolar fluid driven by a porous stretching sheet, Int. J. Eng. Sci. 39, pp. 1881-1897 (2001).

[26] Lukaszewicz, G: Micropolar fluids: theory and application, Birkhäuser Basel (1999).

[27] Makinde, O.D: On MHD Mixed Convection with Soret and Dufour Effects Past a Vertical Plate Embedded in a Porous Medium, Latin American Applied Research 41, pp. 63-68 (2011).

[28] Mahmood, M.A.A., Waheed, S.E: MHD flow and heat transfer of a micropolar fluid over a stretching surface with heat generation (absorption) and slip velocity, J. Egypt. Math. Soc. 20(1), pp. 20-27 (2012).

[29] Mahmood, R., Nadeem, S and Akber., N.S: Non-orthogonal stagnation point flow of a micropolar second grade fluid towards a stretching surface with heat transfer, J. Taiwan Inst.Chem. Eng., Vol. 44, pp. 586–595 (2013).

[30] Mohammadi, M.R., Nourazar,S.S : on the insertion of a thin gas layer in micro cylindrical coquette flows involving power law liquids, Int.J.Heat Mass Transf,75, pp. 97-108 (2014).

[31] Mohammadi, M.R., Nourazar, S.S., campo, A: Analytical solution for two- phase flow between two rotating cylinders filled with power-law liquid and a micro layer of gas,J. Mech.sci.Technol, 28(5), pp. (2014).

[32] Mohanty, B., Mishra, S.R. and Pattanayak, H.B: Numerical investigation on heat and mass transfer effect of micropolar fluid over a stretching sheet through porous media, Alexandria Engineering Journal, Vol. 54, pp. 223–232 (2015).

[33] Mukhopadhyay, S: Effect of thermal radiation on unsteady mixed convection flow and heat transfer over a porous stretching surface in porous medium, Int. J. Heat Mass Tranf. 52, pp. 3261-3265 (2009).

[34] Prathap Kumar, J., Umavathi, J.C., Chamkha, A.J. and Pop, I: Fully developed free convective flow of micropolar and viscous fluids in a vertical channel, Appl. Math. Model, Vol. 34, pp. 1175–1186 (2010).

[35] Rana, P., Bhargava, R: Flow and heat transfer of a nanofluid over a nonlinearly stretching sheet: a numerical study, Comm. Nonlinear Sci. Numer Simulat., 17 pp. 212–226 (2012).

[36] Reddy, P.S and Rao, V.P: Thermo-Diffusion and Diffusion –Thermo Effects on Convective Heat and Mass Transfer through a Porous Medium in a Circular Cylindrical Annulus with Quadratic Density Temperature Variation – Finite Element Study, Journal of Applied Fluid Mechanics,5(4), pp. 139-144 (2012).

[37] Rosali, H., Ishak, A. and Pop, I: Micropolar fluid flow towards a stretching/shrinking sheet in a porous medium with suction, Int. Commun. Heat Mass Transf. Vol. 39, pp. 826–829 (2012).

[38] Sakiadis, B.C : Boundary layer behavior on continuous solid surfaces, AICE J.7, pp. 26-28 (1961).

[39] Srinivasacharya, D., Ramana murthy, J.V., Venugopalam,D., Unsteady stokes flow of micropolar fluid between two parallel porous plates, Int. J. Eng. sci. 39, pp. 1557-1563 (2001).

[40] Sudarsan Reddy, P., Chamkha, AJ: Soret and Dufour effects on MHD heat and mass transfer flow of a micropolar fluid with thermophoresis particle deposition, Journal of Naval Architecture and Marine Engineering 13 (1), pp. 39-50 (2016).

[41] Sudarsana Reddy, P and Chamkha, AJ: Soret and Dufour Effects on Unsteady MHD Heat and Mass Transfer over a Stretching Sheet with Thermophoresis and Non-Uniform Heat Generation/Absorption, Journal of Applied Fluid Mechanics, 9, pp. 2443-2455 (2016).

[42] Tsai, R., Huang, K.H. and Huang, J.S: Flow and heat transfer over an unsteady stretching surface with non-uniform heat source, Int. Commun. Heat Mass Transfer, 35, pp. 1340-1343 (2008).

[43] Tsou, F.K., Sparrow, E.M. and Goldstein, R.J: Flow and heat transfer in the boundary layer on a continuous moving surface, Int. J. Heat Mass Transfer 10, pp. 219–235 (1967).

[44] Wang, CY: Liquid film on an unsteady stretching surface, Q Appl Math, 48, pp. 601–10 (1990).

[45] Yacos, N.A., Ishak, A. and Pop, I: Melting heat transfer in boundary layer Stagnation point flow towards a stretching/shrinking sheet in a micropolar fluid, Comput.Fluids, Vol. 47, pp. 16–21 (2011).

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