Unsteady Hydro magnetic heat and mass transfer flow of a micropolar fluid past a stretching sheet with Thermo-Diffusion and Diffusion-Thermo effects.

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Abstract:

The present paper we investigate the combined influence of Soret and Dufour effects on unsteady convective heat and mass transfer flow of a micro polar fluid through porous medium past a permeable stretching sheet. The non linear coupled equations, governing the heat and mass transfer flow have been solved by employing Galerkin finite element technique. The velocity, micro rotation, temperature and concentration have been discussed for different values. The skin friction, couple stress and the rate of heat and mass transfer have been evaluated numerically for different parametric variations.

Key Words: micropolar fluid, heat transfer, mass transfer, Soret effects, Dufour effects, stretching sheet.

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 [24] studied on the insertion of a thin gas layer in micro cylindrical couette 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 [25]. The dynamics of the boundary layer flow over a stretching surface originated from the pioneering work of carne [9]. Later on, various aspects of the problem have been investigated such as Gupta and Gupta [17], chen and char [6], Datta et al [13], extended the work of crane [9] 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 [15&16]. 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 [3&4], Prathapkumar et al. [26]. Bhargava et al [5] investigated by using a finite element method the flow of a mixed convection micropolar fluid driven by a porous stretching sheet with uniform suction.

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. Thermo-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.[18] 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 [22]. Reddy et al. [29] 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. [6,7] 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 [36] was first studied the unsteady boundary layer flow of a liquid film over a stretching sheet. Later, Elbashbeshy and Bazid [14] have presented the heat transfer over an unsteady stretching surface. Tsai et.al [34] has discussed flow and heat transfer over an unsteady stretching surface with non-uniform heat source. Ishak et al [19] analyzed the effect of prescribed wall temperature on heat transfer flow over an unsteady stretching permeable surface with prescribed wall temperature. Ishak [20] has presented unsteady MHD flow and heat transfer behavior over a stretching plate. Dulal pal [13] 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. [12] 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. Mathematical Analysis

We consider two-dimensional, 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. 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:

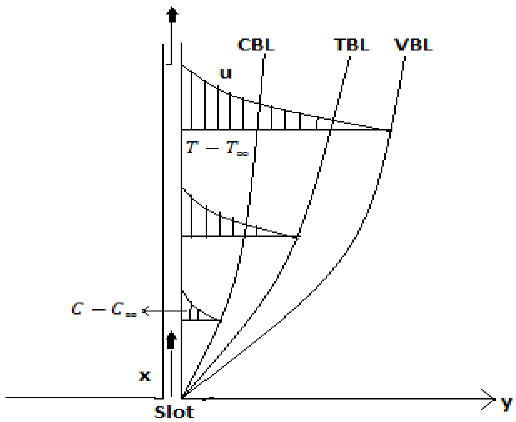

Fig. 1.Flow configuration and coordinate system.

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

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \left(\frac{\mu+\kappa}{\rho}\right)\frac{\partial^2 u}{\partial y^2} + \left(\frac{\kappa}{\rho}\right)\frac{\partial W}{\partial y} \;\; + g_a[\beta(T - T_\infty) + \beta'(C - C_\infty)] - \frac{\mu}{\rho\kappa}u - \frac{\sigma B_0^2}{\rho}u \qquad (2)$$

$$\frac{\partial \omega}{\partial t} + u\frac{\partial \omega}{\partial x} + v\frac{\partial \omega}{\partial y} = -\frac{\kappa}{\rho J}\left(2\omega + \frac{\partial u}{\partial y}\right) + \frac{\gamma}{\rho J}\frac{\partial^2 \omega}{\partial y^2} \qquad (3)$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} \qquad (4)$$

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

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

$$u = U_w(x) = ax, \qquad v = V_1(x), \qquad T = T_w, \qquad C = C_w, \qquad \omega = 0, \qquad at\;\; y = 0.$$

$$u \to 0, \qquad \omega \to 0, \qquad T \to T_\infty, \qquad C \to C_\infty, \qquad at\;\; y \to \infty. \qquad (6)$$

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 $V_1 = -\sqrt{\frac{\nu a}{2}}V_0$ represents the mass transfer at the surface with $V_1 < 0$ for suction and $V_1 > 0$ for injection.

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

$$\eta = \sqrt{\frac{a}{\nu(1-ct)}}\, y,\ \ \psi = \sqrt{\frac{\nu a}{1-ct}}\, f,\ \ u = \frac{ax}{1-ct} f',\ \ v = -\sqrt{\frac{\nu a}{1-ct}}\, f,\ W = \sqrt{\frac{a^3}{\nu(1-ct)^3}}\, x\, g\ ,$$

$$T = T_\infty + \frac{bx}{(1-ct)^2}\theta\ ,\ \ C = C_\infty + \frac{dx}{(1-ct)^2}\,\phi. \qquad (7)$$

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

$$(1 + A1)f''' + ff'' - f'^2 - A\left(f' + \frac{1}{2}\eta f''\right) + A1g' + g_r\theta + g_m\phi - (M + K)\, f' = 0 \qquad (8)$$

$$\lambda g'' + fg' - gf' - \frac{A}{2}(3g + \eta\, g') + A1\, B(2g + f'') = 0 \qquad (9)$$

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

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

The corresponding transformed boundary conditions are

$$f' = 1,\ f = V_0,\ g = 0,\ \theta = 1,\ \varphi = 1, \qquad \text{at } y = 0$$

$$f' = 0, \qquad g = 0, \quad \theta = 0, \quad \varphi = 0 \quad \text{at} \quad y \to \infty \qquad (12)$$

Where, $A1 = \frac{\kappa}{\mu},\ g_r = \frac{g_a\beta b}{a^2}, g_m = \frac{g_a\beta' l}{a^2}\ , A = \frac{c}{a}, K = \frac{\nu(1-ct)}{k\ a}, Pr = \frac{\nu}{\alpha}\ , \lambda_0 = \frac{\nu}{\mu\ j}\ ,$

$Sc = \frac{\nu}{D_m}, B = \frac{\nu\,(1-ct)}{j\ a}\ ,\ Du = \frac{D_m k_T\ l}{c_s c_p b\ \nu}, Sr = \frac{D_m k_T}{\nu T_m}, Ec = \frac{a^2 x}{c_p\ b}, M = \frac{\sigma B_0^2(1-ct)}{\rho\ a}.$

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

$$C_{fx} = \frac{2(1+A1)f''(0)}{Re_x^{\frac{1}{2}}}\ ,\ C_{s\,x} = \frac{\nu\ a\ U_w h'(0)}{Re_x^{\frac{1}{2}}}\ ,\ Nu_x = -\frac{\theta'(0)}{Re_x^{\frac{1}{2}}}\ ,\ Sh_x = -\frac{\varphi'(0)}{Re_x^{\frac{1}{2}}}.$$

3. Numerical 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, 32] has been employed to solve these non-linear equations. The procedure of Finite element method is as follows.

(i) Finite-element discretization

(ii) Generation of the element equations

(iii) Assembly of element equations

(iv) Imposition of boundary conditions

(v) Solution of assembled equations

The very important aspect in this numerical procedure is to select an approximate finite value of η_∞. So, in order to estimate the relevant value of η_∞, the solution process has been started with an initial value of $\eta_\infty = 3$, and then the equations (8) – (11) are solved together with boundary conditions (12). We have updated the value of η_∞ and the solution process is continued until the results are not affected with further values of η_∞.The choice of $\eta_{max} = 5$ for velocity, $\eta_{max} = 4$ for micro-rotation, $\eta_{max} = 4$ for temperature and $\eta_{max} = 5$ for concentration have confirmed that all the numerical solutions approach to the asymptotic values at the free stream conditions.

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.2-19. The correctness of the current numerical method is checked with the results obtained by Mohanty et al. [26] .The numerical results are in close agreement with those published previously.

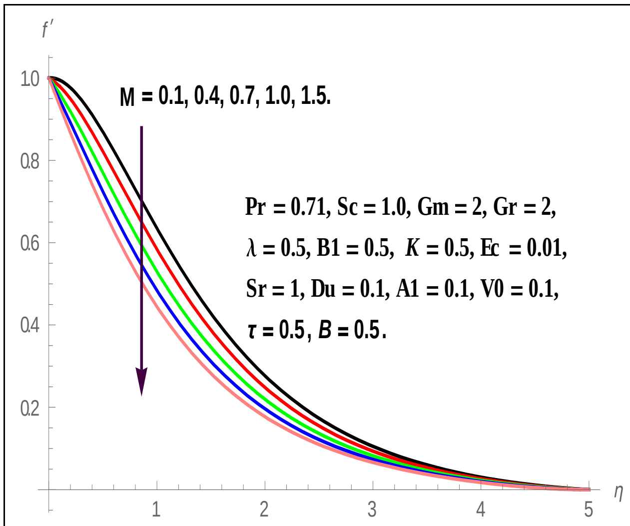

Fig. 2. Effect of (M) on Velocity profiles.

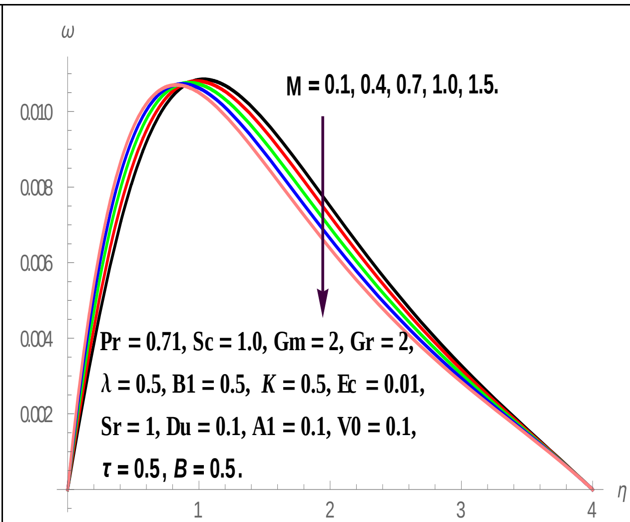

Fig. 3. Effect of (*M*) on angular velocity profiles.

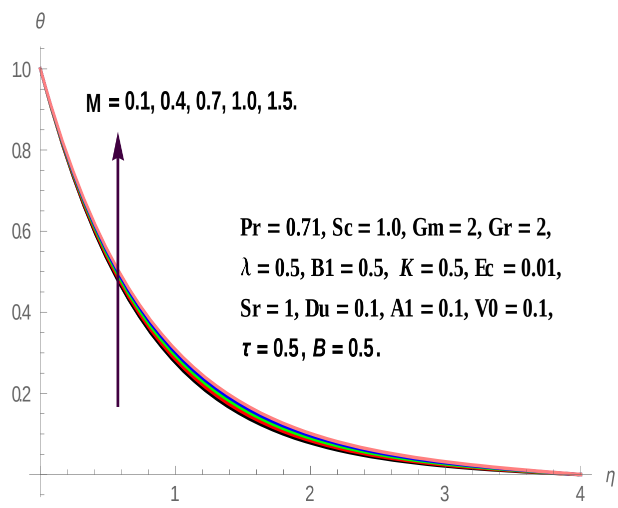

Fig. 4. Effect of (*M*) on Temperature profiles.

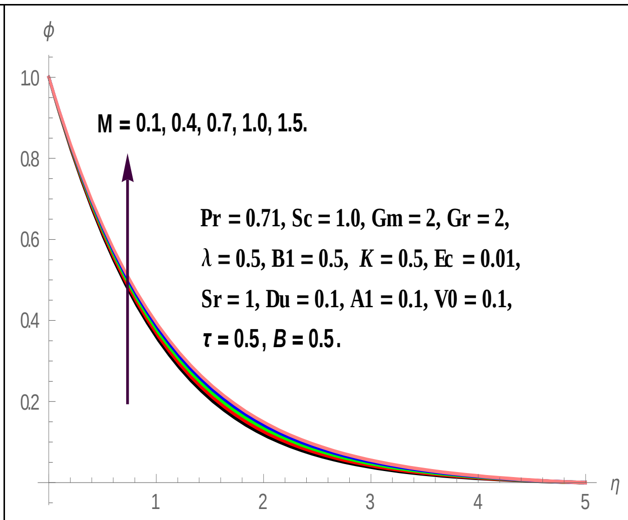

Fig. 5. Effect of (*M*) on Concentration profiles.

The influence of magnetic field parameter (M) on velocity, micro-rotation, temperature and concentration profiles in the boundary layer regime is depicted in Figs. 2- 5. It is noticed from these figures that the hydrodynamic and micro-rotation boundary layer thickness depreciates, whereas, thermal boundary layer thickness as well as the solutal boundary layer thickness enhances with the higher values of M. This is because of the reality that, the presence of magnetic field in an electrically conducting fluid produces a force called Lorentz force, this force acts against the flow direction causes the depreciation in velocity profiles (fig. 2, 3), and at the same time, to overcome the drag force imposed by the Lorentzian retardation the fluid has to perform extra work; this supplementary work can be converted into thermal energy which increases the thickness of thermal and solutal boundary layers in the fluid region (figs. 4 & 5).

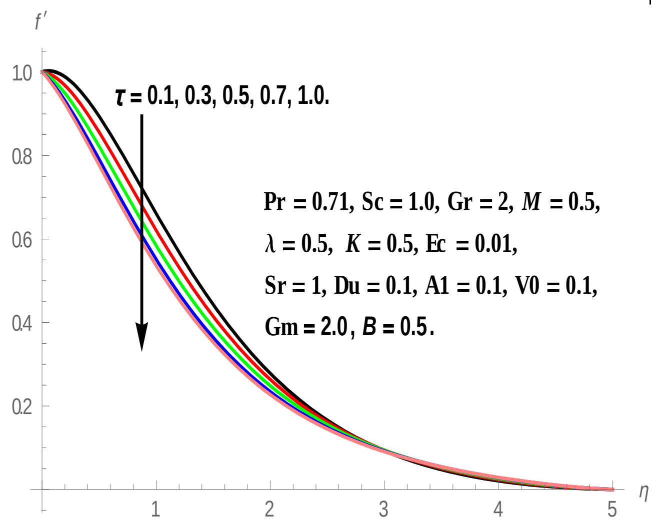

Fig. 6. Effect of (A) on Velocity profiles.

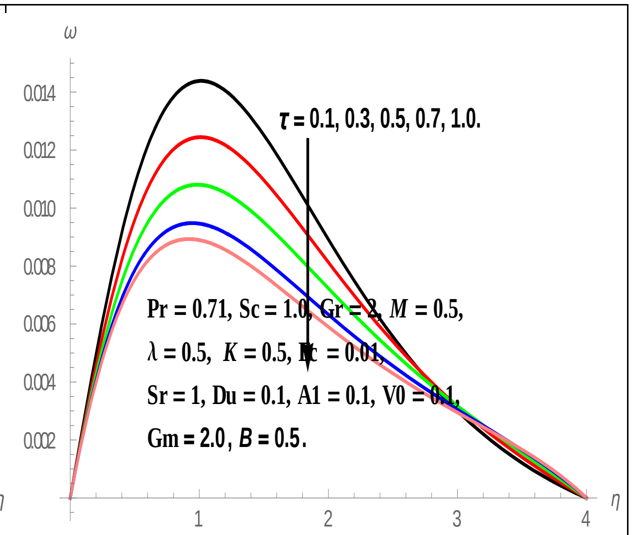

Fig. 7. Effect of (A) on angular velocity profiles.

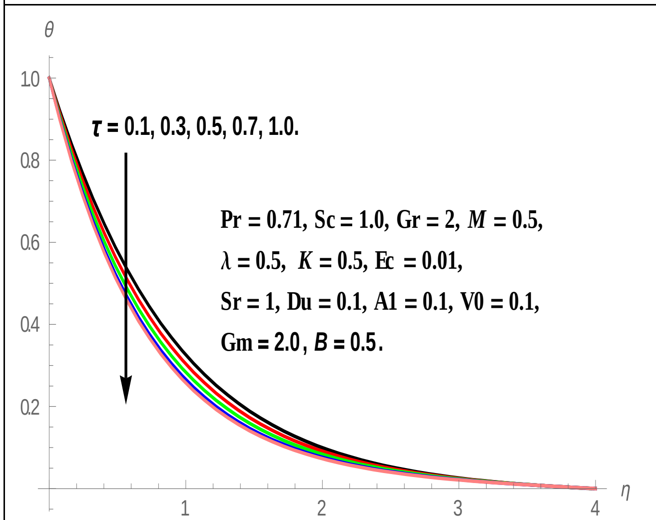

Fig. 8. Effect of (A) on Temperature profiles.

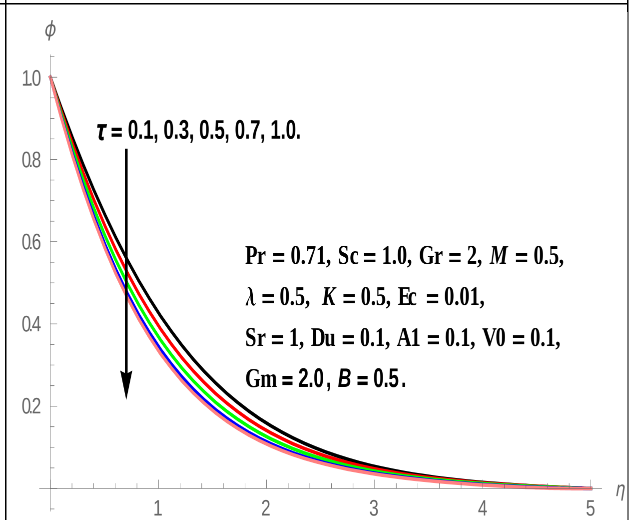

Fig. 9. Effect of (A) on Concentration profiles.

The influence of unsteadiness parameter (A) on velocity, micro-rotation, temperature and concentration profiles is depicted in figures 6- 9.The profiles of both velocity and micro-rotation are the decreasing functions of unsteadiness parameter (A) in the boundary layer regime. It can be seen that temperature profiles decelerates with increase in the values of unsteadiness parameter (α). This is because of the usual fact that, the motion is generated by the stretching of the sheet and the stretching sheet velocity and temperature is greater than the free stream velocity and temperature, so, the thermal boundary layer thickness decreases with increase in the values of α as shown in Fig.8. The concentration profiles also decreases in the flow region and is shown in Fig.9. It is also observed that temperature profiles decreases smoothly in the absence of unsteadiness parameter (α=0) whereas temperature profiles continuously decreases with the increasing values of unsteadiness parameter. This shows that the rate of cooling is much faster for the higher values of unsteadiness parameter and it takes longer time for cooling in the steady flows.

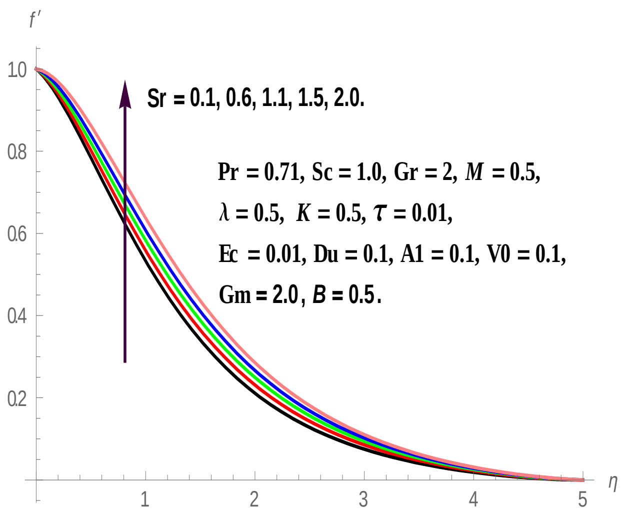

Fig. 10. Effect of (*Sr*) on Velocity profiles.

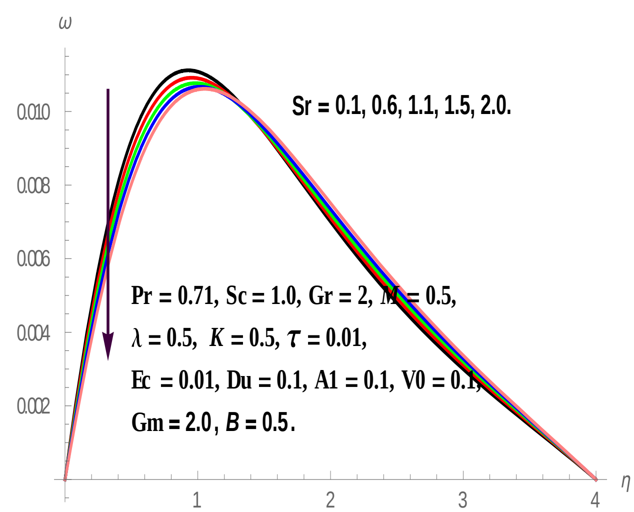

Fig. 11. Effect of (*Sr*) on angular velocity profiles.

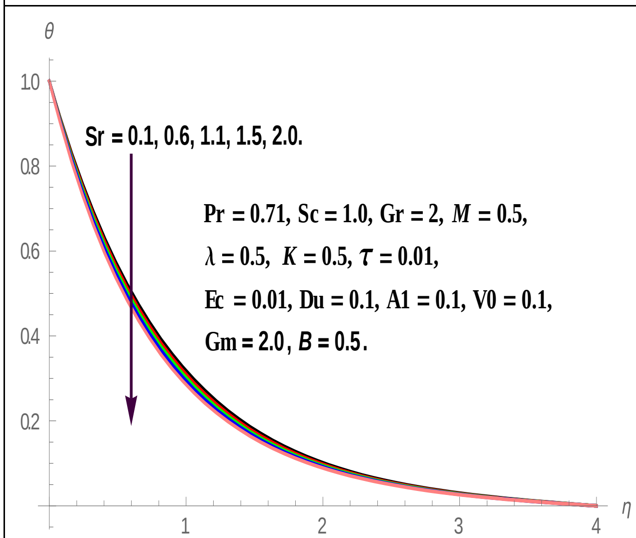

Fig. 12. Effect of (*Sr*) on Temperature profiles.

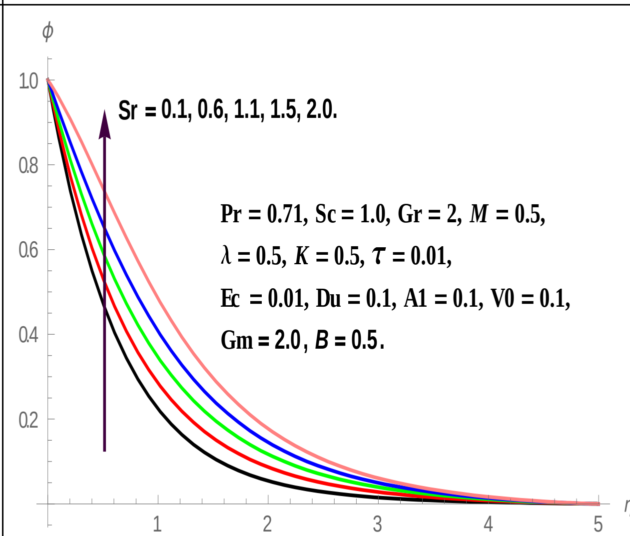

Fig. 13. Effect of (*Sr*) on Concentration profiles.

The impact of Soret effect (*Sr*) on velocity, micro-rotation, temperature and concentration profiles is portrayed in Figs. 10 – 13. It is noticed that the velocity profiles elevates, whereas, the micro – rotation distributions deteriorates with the rising values of (*Sr*) in the boundary layer regime. It is clearly observed that the temperature distributions decrease, however, concentration profiles increases at all points in the flow field with the increasing values of Soret number (*Sr*). This is because of the fact that the diffusive species with higher values of Soret parameter (*Sr*) has the tendency of increasing concentration profiles. Thus, it is concluded from Figs. 10 -13 that the temperature and concentration distributions are more influenced with the values of Soret parameter.

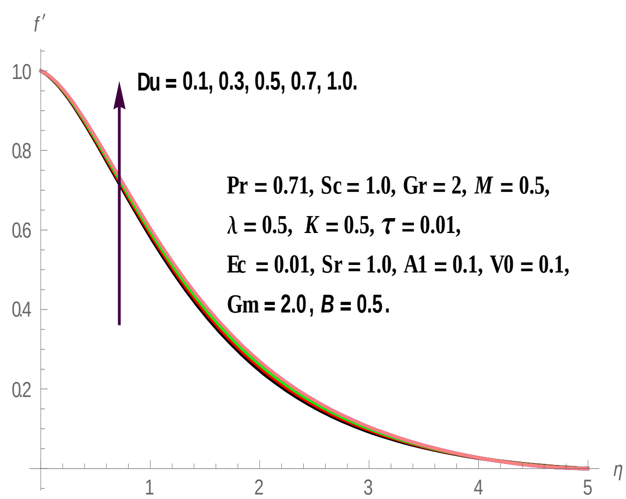

Fig. 14. Effect of (*Du*) on Velocity profiles.

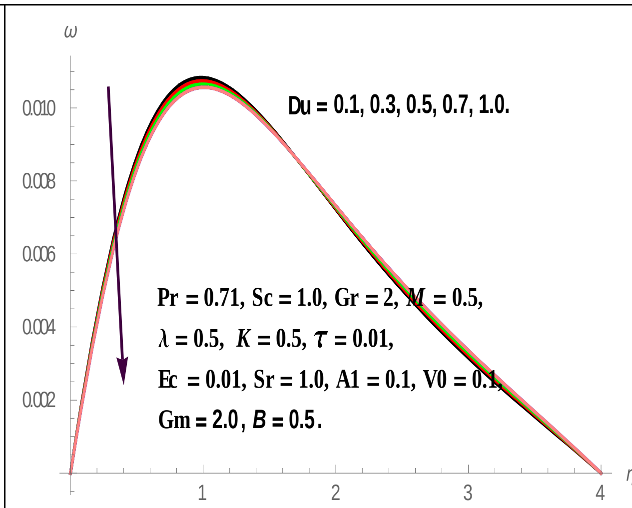

Fig. 15. Effect of (*Du*) on angular velocity profiles.

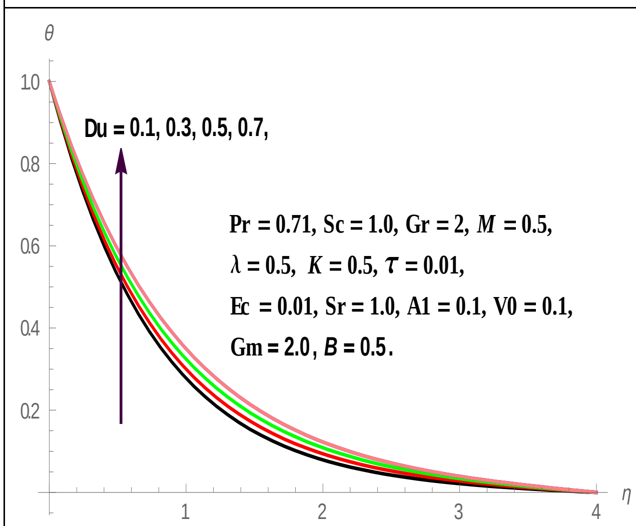

Fig. 16. Effect of (*Du*) on Temperature profiles.

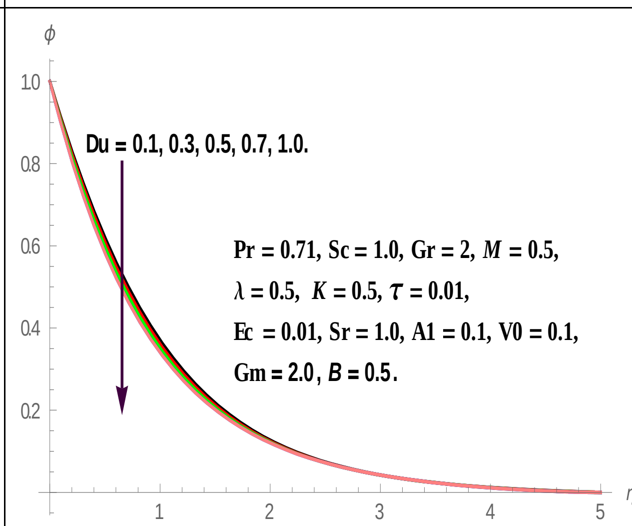

Fig. 17. Effect of (*Du*) on Concentration profiles.

The impact of Dufour parameter (Du) on velocity, micro-rotation, temperature and concentration profiles is portrayed in Figs. 14 – 17. It is perceived that the thickness of momentum boundary layer is boosted, whereas, the thickness of micro - rotation depreciates with the higher values of Dufour parameter (Du). The temperature of the fluid raises, however, the concentration of the fluid decelerates in the boundary layer regime as the (Du) increases. This is because of the reality that higher the value of (Du) has the tendency of increases the thickness of the thermal boundary layer.

Table 1: Influence of Magnetic parameter (M) and Suction/injection parameter ($V_0 > 0$) on Skin-friction co-efficient$\left(f''(0)\right)$, Couple stress coefficient $\left(h'(0)\right)$, local Nusselt number $\left(-\theta'(0)\right)$ and local Sherwood number $(-\phi'(0))$with fixed values of other parameters.

M	V_0	C_{fx}	C_{sx}	Nu_x	Sh_x
0.1	0.5	−0.029503	0.020189	1.263071	0.930092
0.4	0.5	−0.140078	0.023735	1.247951	0.916867
0.7	0.5	−0.334706	0.027632	1.230871	0.902205
1.0	0.5	−0.513352	0.031039	1.215510	0.889266
1.5	0.5	−0.678789	0.034055	1.201602	0.877778
0.5	0.1	−0.140078	0.023735	1.247951	0.916867
0.5	0.4	−0.250201	0.031057	1.352539	0.955381
0.5	0.7	−0.380552	0.038807	1.464718	0.994421
0.5	1.0	−0.587237	0.049129	1.626014	1.048395
0.5	1.5	−0.831464	0.058702	1.800411	1.106039

The variation in the values of local skin-friction co-efficient$\left(f''(0)\right)$, couple stress coefficient $\left(h'(0)\right)$, local Nusselt number $\left(-\theta'(0)\right)$ and local Sherwood number $\left(-\phi'(0)\right)$ for different values of magnetic parameter (M) and suction parameter ($V_0 > 0$) is presented in table 2. It is seen from table that the values of local skin-friction co-efficient, Nusselt number and Sherwood numbers are depreciates, whereas, the values of couple stress coefficient elevates with increase in the values of (M). It is clear from this table that the values of skin-friction coefficient worsens, however, the couple stress coefficient, dimensionless heat and mass transfer rates are boosted with the higher values of suction parameter ($V_0 > 0$).

Table 2: Influence of unsteady parameter (A) and Eckert number (Ec) on Skin-friction co-efficient$\left(f''(0)\right)$, Couple stress coefficient $\left(h'(0)\right)$, local Nusselt number $\left(-\theta'(0)\right)$ and local Sherwood number $(-\phi'(0))$ with fixed values of other parameters.

T	Ec	C_{fx}	C_{sx}	Nu_x	Sh_x
0.1	0.01	0.095679	0.025293	1.054316	0.758771
0.3	0.01	0.126948	0.024305	1.154059	0.841319
0.5	0.01	0.140078	0.023735	1.247951	0.916867
0.7	0.01	0.244878	0.023491	1.336645	0.987009
1.0	0.01	0.294497	0.023461	1.379229	1.020413
0.5	0.1	0.138366	0.023655	1.239348	0.922314
0.5	0.8	0.125396	0.023044	1.175610	0.962253
0.5	1.5	0.112999	0.022459	1.117097	0.998225
0.5	2.2	0.101126	0.021898	1.063296	1.030641
0.5	3.0	0.088146	0.021283	1.007013	1.063792

The influence of unsteady parameter (A) and Eckert number (Ec) on Skin-friction co-efficient$\left(f''(0)\right)$, Couple stress coefficient $\left(h'(0)\right)$, local Nusselt number $\left(-\theta'(0)\right)$ and local Sherwood number $(-\phi'(0))$is summarized in table 4.It is clear from this table that the values of skin-friction coefficient, Nusselt and Sherwood number are increased, whereas, the values of micro-rotation diminishes with the higher values of (A). With increase in the values of Eckert number, the non – dimensional velocity, micro-rotation and temperature are boosted, however, the values of non-dimensional concentration worsens in the fluid regime.

Table 3: Influence of Soret number (*Sr*) and Dufour number (*Du*) on Skin-friction co-efficient$\left(f''(0)\right)$, Couple stress coefficient $\left(h'(0)\right)$, local Nusselt number $\left(-\theta'(0)\right)$ and local Sherwood number $(-\phi'(0))$ with fixed values of other parameters.

Sr	Du	C_{fx}	C_{sx}	Nu_x	Sh_x
0.1	0.1	0.232941	0.026897	1.131447	1.473229
0.6	0.1	0.189636	0.025347	1.164016	1.250944
1.1	0.1	0.145116	0.023823	1.198808	1.008882
1.5	0.1	0.099296	0.022319	1.236250	0.743977
2.0	0.1	0.039967	0.020474	1.287598	0.374770
1.0	0.1	0.142382	0.023843	1.265463	0.903797
1.0	0.3	0.133788	0.023442	1.207902	0.944932
1.0	0.5	0.124237	0.023009	1.135199	0.998566
1.0	0.7	0.114095	0.022566	1.043630	1.068728
1.0	1.0	0.110503	0.022566	1.043630	1.068728

The influence of Soret number (*Sr*) and Dufour number(*Du*) on skin-friction coefficient, couple stress coefficient, Nusselt number and Sherwood number is reported in table 3. It is noticed that the values of $f''(0)$, $h'(0)$ and$-\phi'(0)$decreases, whereas, $-\theta'(0)$ values hightens as the values of (*Sr*) rises. The dimensionless velocity, micro-rotation and heat transfer rates are decreased, whereas, the dimensionless mass transfer rates increases with the increasing values of *Du*.

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:

i) The velocity of the fluid diminishes, whereas, temperature of the fluid heightens with rising values of (*M*) and is because of the fact that the presence of magnetic field into the flow produces Lorentz force, which resist the motion of the fluid causes enhancement in the temperature.

ii) Soret effect enhances the concentration profiles, whereas, depreciates the temperature profiles. However, exact reverse trend is noticed in the profiles with higher values of (*Du*).

iii) The profiles of both velocity and temperature of the fluid diminishes with higher values of unsteadiness parameter (A).

iv) 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.

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