Unsteady MHD Micropolar Flow and Mass Transfer Past a Vertical Permeable Plate with Variable Suction

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ABSTRACT
This paper deals with the behavior of unsteady MHD Micropolar flow and Mass transfer past a vertical plate with variable suction. The resultant equations are solved analytically using Perturbation method. The analytical expressions for the velocity profiles, temperature profiles and concentration profiles of the fluid have been obtained with the help of the material parameters such as Grashof number G, Modified Grashof number Gm, Prandtl number Pr and Schmidt number Sc. Numerical computations involved in the solution have been shown on graphs using MAtlab soft ware. Results show that the velocity increases with an increase in Grashof and modified Grashof numbers, chemical reaction parameter and viscosity ratio respectively and decreases as a result of an increasing Magnetic number and time. The concentration profile decreases with an increasing chemical reaction parameter and Schmidt number. The temperature field increases with increasing time and decreases with an increasing Prandtl number, while the angular velocity decreases with an increase in Grashof and Modified Grashof numbers, time and epsilon respectively.

Keywords: Micropolar fluid, MHD, Mass transfer, Variable suction, Vertical permeable plate.

1. INTRODUCTION
The problems of fluid flow and mass transfer continue to attract the attention of engineering science and applied mathematics researches owing to extensive importance and application in geophysics, metallurgy and aerodynamic extrusion of plastic sheets and other engineering, composite or ceramic engineering and heat exchanges. Soundalgekar and Takher (1977) have studied the effect of MHD forced and free convective flow past a semi-infinite plate. Raptis and Kafousias (1982) studied the influence of a magnetic field upon the steady free convection flow through a porous medium bounded by an infinite vertical plate with a constant suction velocity and when the plate temperature is also constant. Kim (2001) investigated unsteady MHD micropolar flow and heat transfer over a vertical porous moving plate with variable suction. Azzam (2002) presented radiation effect on the MHD mixed free-fixed convective flow past a semi-infinite moving vertical plate for high temperature differences. Cookey *et al*. (2003) investigated the influenceof viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous media with time dependent suction. Singh (2003) studied MHD free convection and mass transfer flow with Hall current, viscous dissipation, joule heating and thermal diffusion. Makinde and Mhone (2005) have studied heat transfer to MHD oscillatory flow in a channel filled with porous medium. Siddheshwar and Mahabaleshwar (2005) studied MHD flow and heat transfer in a visco elastic liquid over a stretching sheet in the presence of radiation. Mostafa (2009) studied thermal radiation effect on unsteady MHD free convection flow past a vertical plate with temperature dependent viscosity. Okedeye and Lamidi (2009) investigated analytical solution of unsteady free convection and mass transfer flow past an accelerated infinite vertical porous plate with suction, heat generation and chemical species when the plate accelerated in it is own plate. Beg and Gosh (2010) investigated the analytical study of MHD radiation-convection with surface temperature oscillation and secondary flow effects.

2. GOVERNING EQUATIONS
Consider the region of unsteady MHD flow of a viscous, incompressible, electrically-conducting fluid occupying a semi-infinite region of space bounded by an infinite vertical plate moving with constant velocity, U, in the presence of a transverse magnetic field. The surface temperature of the plate oscillates with small amplitude about a non-uniform mean temperature. The x-axis is taken along the plate and the y-axis is normal to the plate. Anwar et al (2009). The governing equations are: Continuity, Linear momentum, Energy and Diffusion equations respectively are:

$$\frac{\partial V^*}{\partial y^*} = 0 \tag{2.1}$$

$$\frac{\partial U^*}{\partial t^*} - V_0\left(1+\varepsilon A e^{nt}\right)\frac{\partial U^*}{\partial y^*} = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \left(V+V_r\right)\frac{\partial^2 U^*}{\partial y^{*2}} + g\beta_f\left(T-T_0\right) - V\frac{U^*}{K^*} - \sigma\frac{B_0^2 U}{\rho} + 2V_r\frac{\partial w^*}{\partial y^*} + g\beta_c\left(C-C_0\right) \tag{2.2}$$

$$\rho j^*\left(\frac{\partial w^*}{\partial t^*} - V_0\left(1+\varepsilon A e^{nt}\right)\frac{\partial w^*}{\partial y^*}\right) = \gamma\frac{\partial^2 w^*}{\partial y^{*2}} \tag{2.3}$$

$$\frac{\partial T}{\partial t^*} - V_0\left(1+\varepsilon A e^{nt}\right)\frac{\partial T}{\partial y^*} = \alpha\frac{\partial^2 T}{\partial y^{*2}} \tag{2.4}$$

$$\frac{\partial C^*}{\partial t^*} - V_0\left(1+\varepsilon A e^{nt}\right)\frac{\partial C^*}{\partial y^*} = D^*\frac{\partial^2 C^*}{\partial y^{*2}} - KC^* \qquad (2.5)$$

And the boundary conditions

$$\left.\begin{aligned} & U^* = U_p^*, T = T_w + \varepsilon\left(T_w - T_0\right)e^{nt}, \\ & \frac{\partial w^*}{\partial y^*} = -\frac{\partial^2 U^*}{\partial y^{*2}}, C^* = C_w \quad at\ y^* = 0 \\ & U^* \to U_\infty^* = U_0\left(1+\varepsilon e^{nt}\right), \\ & T \to T_\infty, w^* \to 0, \\ & C^* \to C_\infty \quad as\ y^* \to \infty \end{aligned}\right\} \qquad (2.6)$$

where x^* and y^* are the dimensional distances along and perpendicular to the plate respectively, U^*, V^* are the components of dimensional velocities along x^* and y^* respectively, ρ is the fluid density, V is the fluid kinematic viscosity, V_r is the fluid kinematic rotational viscosity, g is the acceleration due to gravity, β_f and β_c are the coefficients of volume expansions for temperature and concentration, K^* is the chemical reaction parameter, j^* is the micro-inertia density, σ is the electrical conductivity of the fluid, B_0 is the magnetic induction, w^* is the component of the angular velocity, γ is the spin-gradient viscosity, T is the temperature, C^* is the component of dimensional concentration, α is the fluid thermal diffusivity, D is the coefficient of mass diffusivity, n is the dimensionless exponential index, U_p is a scale of plate moving velocity, U_0 is a scale of free stream velocity, A is a real positive constant of suction velocity parameter, ε is the material parameter epsilon, V_0 is a scale of suction velocity which has non-zero positive constant. The first term on the RHS of equation (2.2) is the pressure term, the second term is the viscous term, the third term is the buoyancy term which is as a result of temperature difference, the fourth term is the Darcy or porous term, the fifth term is the micropolar term while the last is the mass term.

We now introduce the following dimensionless variables as

Follows:

$$\left.\begin{aligned} & U = \frac{U^*}{U_0}, V = \frac{v^*}{V_0}, y = \frac{V_0 y^*}{\nu}, U_\infty = \frac{U_\infty^*}{U_0}, \\ & w = \frac{\nu}{U_0 V_0} w^*, U_p = \frac{u_p^*}{U_0}, \ t = \frac{t^* V_0^2}{\nu}, \\ & \theta = \frac{T - T_\infty}{T_w - T_\infty}, n = \frac{n^* \nu}{V_0{}^2}, K = \frac{k^* V_0^2}{\nu^2}, \\ & j = \frac{V_0^2}{\nu^2} j^*, \ S_c = \frac{\nu}{D^*}, \Pr = \frac{\nu}{\alpha}, \\ & G = \frac{\nu\beta_f\, g\left(T_w - T_\infty\right)}{U_0 V_0^2}, C = \frac{C^* - C_\infty}{C_w - C_\infty} \\ & Gm = \frac{\nu\beta_f\, g\left(C_w - C_\infty\right)}{U_0 V_0{}^2}, M = \frac{\sigma B_0{}^2 \nu}{\rho V_0{}^2}, \\ & \gamma = uj^*\left(1+\frac{1}{2}\beta\right), \beta = \frac{\Lambda}{\mu}, N = \left(M + \frac{1}{K}\right), \end{aligned}\right\} \qquad (2.7)$$

Where γ is the spin-gradient viscosity, β is the dimensionless viscosity ratio, Hartman Magnetic number and Λ is the coefficient of gyro-viscosity or Vortex viscosity.

In view of equation (2.7), the governing equations (2.2) – (2.6) reduced to the following non-dimensional form:

$$\frac{\partial U}{\partial t} - \left(1+\varepsilon A e^{nt}\right)\frac{\partial U}{\partial y} = \frac{dU_\infty}{dt} + \left(1+\beta\right)\frac{\partial^2 U}{\partial y^2} + G\theta + N\left(U_\infty - U\right) + 2\beta\frac{\partial w}{\partial y} + GmC \qquad (2.8)$$

$$\frac{\partial w}{\partial t} - \left(1+\varepsilon A e^{nt}\right)\frac{\partial w}{\partial y} = \frac{1}{\eta}\frac{\partial^2 w}{\partial y^2} \qquad (2.9)$$

$$\frac{\partial \theta}{\partial t} - \left(1+\varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} \qquad (2.10)$$

$$\frac{\partial C}{\partial t} - \left(1+\varepsilon A e^{nt}\right)\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K^2 C \qquad (2.11)$$

where $\beta = \frac{V_r}{V}$, $\eta = \frac{\mu j^*}{\gamma}$, Pr is the Prandtl number, G is the Grashof number due to temperature, Gm is the modified Grashof number due to concentration and Sc is the Schmidt's number.

The boundary conditions (2.6) are then given by the following dimensionless form:

$$\left.\begin{array}{l} U = U_p, \theta = 1+\varepsilon e^{nt}, \dfrac{\partial w}{\partial y} = -\dfrac{\partial^2 U}{\partial y^2}, C = 1 \ \ on \ \ y = 0 \\ U \to U_\infty, \theta \to 0, w \to 0, C \to 0 \ \ as \ \ y \to \infty \end{array}\right\} \quad (2.12)$$

3. METHOD OF SOLUTION

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we may represent the linear, angular velocities, temperature and mass as:

$$U(y,t) = U_0(y) + \varepsilon e^{nt} U_1(y) + O(\varepsilon^2) \quad (2.13)$$

$$w(y,t) = w_0(y) + \varepsilon e^{nt} w_1(y) + O(\varepsilon^2) \quad (2.14)$$

$$\theta(y,t) = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + O(\varepsilon^2) \quad (2.15)$$

$$C(y,t) = C_0(y) + \varepsilon e^{nt} C_1(y) + O(\varepsilon^2) \quad (2.16)$$

Substituting equations (2.13) - (2.16) into equations (2.8) - (2.12) and neglecting the coefficient of higher order terms reduce to the zeroth and first orders respectively:

$$\begin{array}{l}(1+\beta)U_0'' + U_0' - NU_0 \\ = -N - 2\beta w_0' - G\theta_0 - GmC_0 \end{array} \quad (2.17)$$

$$w_0'' + \eta w_0' = 0 \quad (2.18)$$

$$\theta_0'' + \Pr\theta_0' = 0 \quad (2.19)$$

$$C_0'' + S_c C_0' - S_c k^2 C_0 = 0 \quad (2.20)$$

Subject to the following boundary conditions:

$$\left.\begin{array}{l} U_0 = U_p, w_0 = -U_0', \theta_0 = 1, C_0 = 1 \ \ at \ \ y = 0 \\ U_0 = 1, w_0 \to 0, \theta_0 \to 0, C_0 \to 0 \ \ as \ \ y \to \infty \end{array}\right\} \quad (2.21)$$

and

$$\begin{array}{l}(1+\beta)U_1'' + U_1' - (N+n)U_1 \\ = -(N+n) - AU_0' - 2\beta w_1' - G\theta_1 - GmC_1 \end{array} \quad (2.22)$$

$$w_1'' + \eta w_1' - n\eta w_1 = -A\eta w_0' \quad (2.23)$$

$$\theta_1'' + \Pr\theta_1' - n\Pr\theta_1 = -A\Pr\theta_0' \quad (2.24)$$

$$C_1'' + S_c C_1' - (K^2+n) S_c C_1 = -AS_c C_0' \quad (2.25)$$

Subject to the following boundary conditions

$$\left.\begin{array}{l} U_1 = 0, w_1 = -U_1', \theta_1 = 1, C_1 = 0 \ \ at \ \ y = 0 \\ U_1 = 1, w_1 \to 0, \theta_1 \to 0, C_1 \to 0 \ \ as \ \ y \to \infty \end{array}\right\} \quad (2.26)$$

The solutions of equations (2.17) - (2.20), (2.22) – (2.25) subject to the boundary conditions (2.21) and (2.26) are respectively:

$$u_0(y) = 1 + a_1 e^{-J_1 y} + a_2 e^{-\Pr y} + a_3 e^{-ry} + a_4 e^{-\eta y} \quad (2.27)$$

$$\begin{array}{l} u_1(y) = 1 + b_1 e^{-J_2 y} + b_2 e^{-J_1 y} + b_3 e^{-J_5 y} + \\ b_4 e^{-J_3 y} + b_5 e^{-J_4 y} + b_6 e^{-\Pr y} + b_7 e^{-ry} + b_8 e^{-\eta y} \end{array} \quad (2.28)$$

$$w_0(y) = c_1 e^{-\eta y} \quad (2.29)$$

$$w_1(y) = c_2 e^{-J_3 y} - \frac{A}{n}\eta c_1 e^{-\eta y} \quad (2.30)$$

$$\theta_0(y) = e^{-\Pr y} \quad (2.31)$$

$$\theta_1(y) = \left(1 + \frac{A}{n}\Pr\right) e^{-J_4 y} - \frac{A}{n}\Pr e^{-\Pr y} \quad (2.32)$$

$$C_0(y) = e^{-ry} \quad (2.33)$$

$$C_1(y) = B^*\left(e^{-ry} - e^{-J_5 y}\right) \quad (2.34)$$

Where:

$$j_1 = \frac{1}{2(1+\beta)}\left[1 + \sqrt{1 + \frac{4}{k}(1+\beta)}\right],$$

$$J_2 = \frac{1}{2(1+\beta)}\left[1 + \sqrt{1 + 4(1+\beta)(N+n)}\right],$$

$$k_1 = (1+\beta)\, j_3^2 - j_3 - (N+n) \quad (2.18)$$

(2.19)

(2.20)

$$J_5 = \frac{1}{2}\left[S_c + \sqrt{S_c^2 + 4\left(k^2+n\right)S_c}\right], \ J_3 = \frac{\eta}{2}\left[1 + \sqrt{1 + \frac{4n}{\eta}}\right],$$

$$J_4 = \frac{\Pr}{2}\left[1 + \sqrt{1 + \frac{4n}{\Pr}}\right], \ r = \frac{1}{2}\left[S_c + \sqrt{S_c^2 + 4k^2 S_c}\right],$$

$$B^* = \frac{rAS_c}{r^2 - rS_c - \left(k^2+n\right)S_c}, \ a_1 = -1 - a_2 - a_3 - a_4,$$

$$a_2 = -\frac{G}{(1+\beta)\Pr^2 - \Pr - N}, \ a_3 = -\frac{Gm}{(1+\beta)r^2 - r - N},$$

$$k_3 = (1+\beta)\eta^2 - \eta - N, \ k_4 = a_1 j_1 + a_2\Pr + a_3 r, \quad (2.23)$$

$$k_5 = b_1 j_2 + b_2 j_1 + b_3 j_5 + b_5 j_4 + b_6\Pr + b_7 r + b_8\eta \quad (2.24)$$

$$b_1 = -1 - b_2 - b_3 - b_4 - b_5 - b_6 - b_7 - b_8,$$

$$b_2 = \frac{Aa_1 j_1}{(1+\beta)\, j_1^2 - j_1 - (N+n)}, \ b_3 = \frac{GmB^*}{(1+\beta)\, j_5^2 - j_5 - (N+n)}, \quad (2.25)$$

$$b_4 = \frac{2\beta j_3 c_2}{(1+\beta)\, j_3^2 - j_3 - (N+n)}, \ b_5 = \frac{-G\left(1 + \frac{A}{n}\Pr\right)}{(1+\beta)\, j_4^2 - j_4 - (N+n)},$$

$$b_6 = \frac{A\Pr\left(\frac{G}{n}+a_2\right)}{(1+\beta)\Pr^2-\Pr-(N+n)}, a_4 = \frac{2\beta\eta c_1}{(1+\beta)\eta^2-\eta-N},,$$

$$b_7 = \frac{rAa_3 - GmB*}{(1+\beta)r^2-r-(N+n)},$$

$$b_8 = \frac{A\eta\left(a_4 - 2\frac{\beta\eta}{n}c_1\right)}{(1+\beta)\eta^2-\eta-(N+n)}, c_1 = \frac{k_3k_4}{2\left(k_3-\eta^2\beta\right)},$$

$$c_2 = \frac{k_1\left(A\frac{\eta}{n}c_1+\frac{1}{2}j_4\right)}{k_1 - j_3^2\beta}$$

By virtue of equations (2.13) - (2.16), we obtain the stream wise, angular velocities, temperature and mass transfer as follows:

$$u(y,t) = 1 + a_1e^{-J_1y} + a_2e^{-\Pr y} + a_3e^{-ry} + a_4e^{-\eta y} + \varepsilon e^{nt}\left[1 + b_1e^{-J_2y} + b_2e^{-J_1y} + b_3e^{-J_5y} + b_4e^{-J_3y} + b_5e^{-J_4y} + b_6e^{-\Pr y} + b_7e^{-ry} + b_8e^{-\eta y}\right] \quad (2.35)$$

$$w(y,t) = c_1e^{-\eta y} + \varepsilon e^{nt}\left[c_2e^{-J_3y} - \frac{A}{n}\eta c_1e^{-\eta y}\right] \quad (2.36)$$

$$\theta(y,t) = e^{-\Pr y} + \varepsilon e^{nt}\left[e^{-J_4y} + \frac{A}{n}\Pr\left(e^{-J_4y} - e^{-\Pr y}\right)\right] \quad (2.37)$$

$$C(y,t) = e^{-ry} + \varepsilon e^{nt}\left[B*\left(e^{-ry} - e^{-J_5y}\right)\right] \quad (2.38)$$

4. RESULTS AND DISCUSSIONS

The variation of velocity profile along y-axis are shown in figures 1, 2, 3, 4, 5,and 6 respectively for different varying values of Hartman Magnetic number (M=1, 2, 3, 4), chemical reaction parameter (K= 0.5, 0.7, 0.9, 1.0), Grashof number (Gr = 1, 2, 3, 4), modify Grashof number (Gm = 1, 2, 3, 4), time (t = 1, 2, 3,4), Viscosity ratio (β = 0.03, 0.06, 0.09, 0.1). Results shows that an increase in the Magnetic parameter M and time t results to a decrease in the velocity main flow in figures 1and 5 respectively. In figures 2, 3, 4 & 6 increasing the chemical reaction parameter K, Grashof number Gr, modify Grashof number Gm, and Viscosity ratio β increases the velocity.

The variation of the mass concentration along y-axis is presented in figures 7 & 8 respectively for different varying values of chemical reaction parameter (K = 1, 2, 3, 4) and Schmidt's number (Sc = 0.1, 0.2, 0.3, 0.4).It is found that for the increase of chemical reaction and Schmidt's number, the concentration decreases in figures 7 and 8 respectively.

The variation of temperature field along the y – axis shown in figures 9 and 10 indicate the effects of Prandtl number (Pr = 0.71, 1.21, 1.71, 2.21) and time (t = 0, 15, 25, 35). It is observed that an increase in the Prandtl number decreases the temperature in figure 9 while an increase in time has a significant influence in increasing the temperature as seen in figure 10.

The variation of the angular velocity profile along the y-axis are shown on figures 11, 12, 13 and 14 with different varying values of material parameters Grashof number (G = 1, 2, 3, 4), modify Grashof number (Gm = 1, 2, 3, 4), time (t = 5, 10, 15, 20) and material parameter epsilon (ε = 0.01, 0.05, 0.07, 0.09) respectively. Results shows that an increase in the material parameters Gr, Gm, t and ε results to a decrease in the angular velocity.

The graphs are shown below:

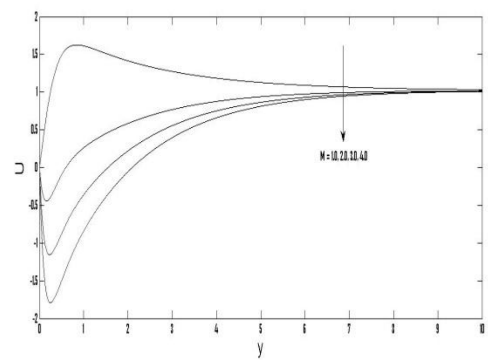

Fig. 1 Variation of Velocity against y for different values of Magnetic parameter, with, Gr = 2, Gm = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, t = 1, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

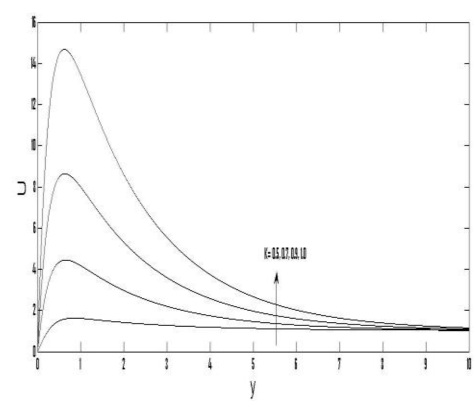

Fig. 2 Variation of Velocity against y for different values of chemical reaction parameter K, with, Gr = 2, Gm = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, M = 1.0, t = 1, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and A = 0.5

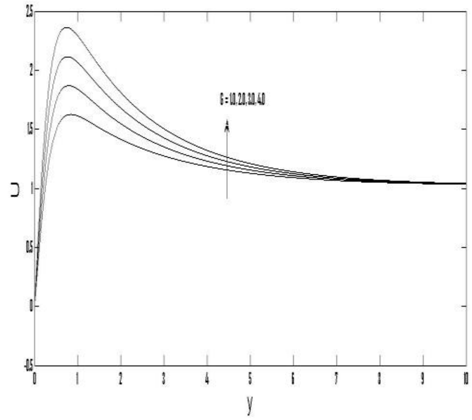

Fig. 3 Variation of Velocity against y for different values of Grashof number G, with, Gm = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, M = 1.0, t = 1, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

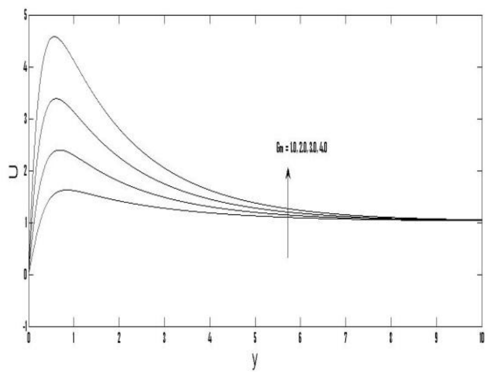

Fig.4 Variation of Velocity against y for different values of modified Grashof number Gm, with, Gr = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, M = 1.0, t = 1, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

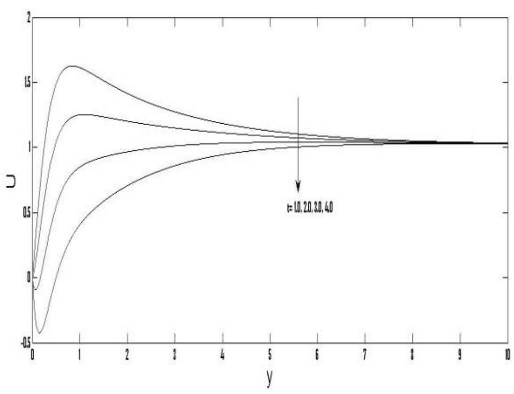

Fig. 5 Variation of Velocity against y for different values of time t, with, Gr = 2,Gm = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, M = 1.0, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

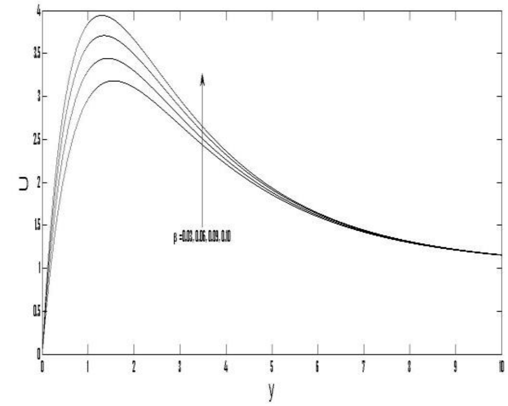

Fig.6 Variation of Velocity against y for different values of Viscosity ratio β, with, Gr = 2,Gm = 2, Pr = 0.71, Sc = 0.2, ε = 0.01, M = 1.0, A = 0.5, n = 0.1, N = 0.01, η = 0.5 and K = 0.5.

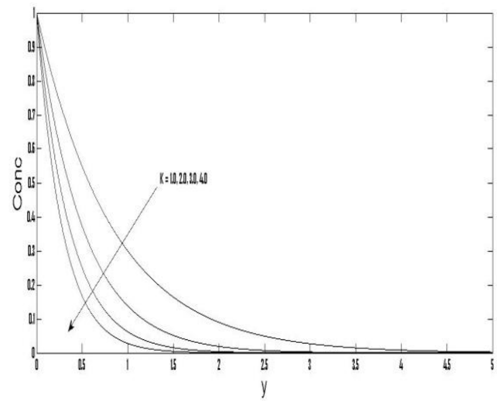

Fig. 7 Variation of Mass Concentration against y for different values of chemical reaction parameter K, with, t = 1, n = 0.1, Sc = 0.65 and ε = 0.02.

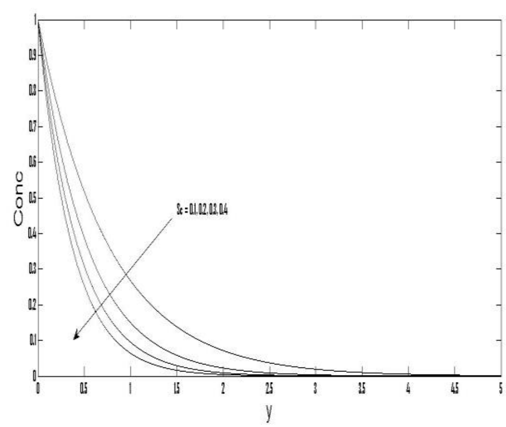

Fig. 8 Variation of Mass Comcentration against y for different values of Schmidts number Sc, with, t = 1, n = 0.1, K = 1.0 and ε = 0.02.

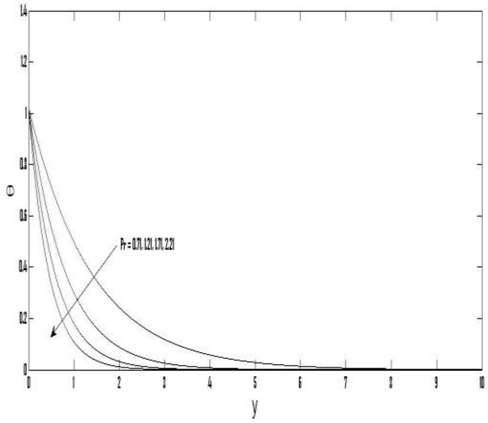

Fig. 9 Variation of Temperature against y for different values of Prandtl number Pr, with, t = 1, n = 0.1and ε = 0.02.

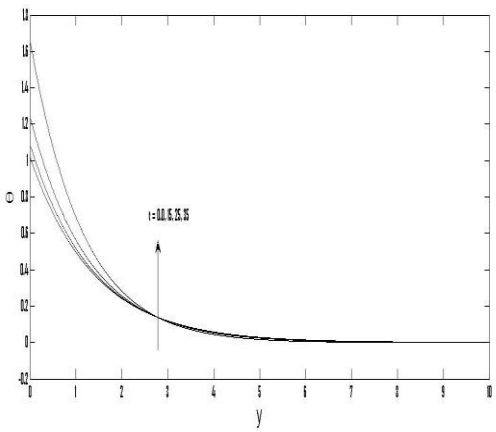

Fig. 10 Variation of Temperature against y for different values of time t, with, Pr = 0.71, 1, n = 0.1and ε = 0.02.

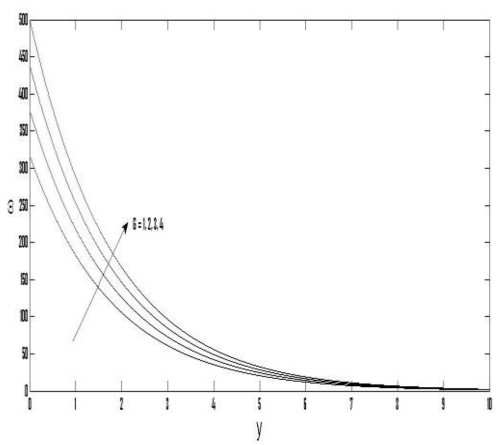

Fig. 11 Variation of Angular velocity against y for different values of Grashof number G, with, Gm = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, t = 1, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

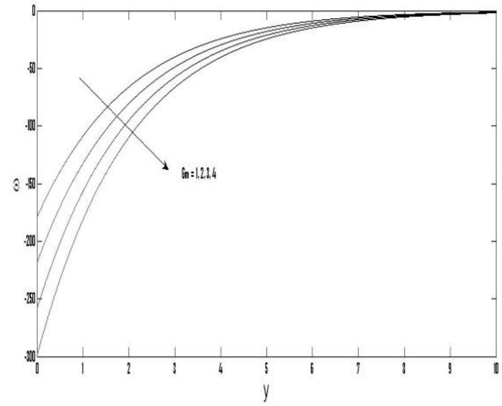

Fig. 12 Variation of Angular velocity against y for different values of modified Grashof number Gm, with, G = 2, Pr = 0.71, Sc = 0.65, ε = 0.02, t = 1, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

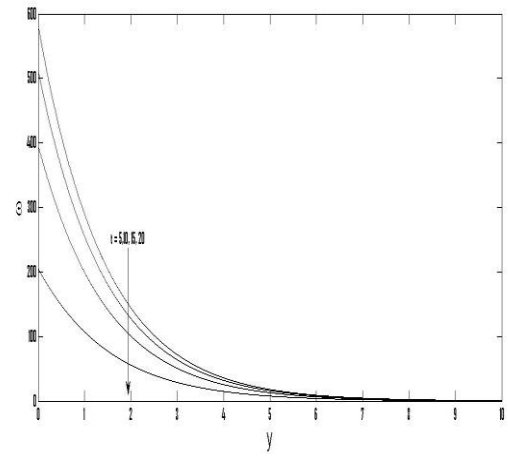

Fig. 13 Variation of Angular velocity against y for different values of time t, with, G = Gm = 4, Pr = 0.2, Sc = 0.65, ε = 0.02, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 0.5.

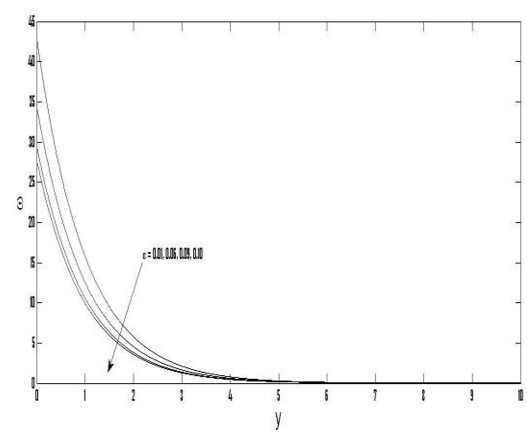

Fig. 14 Variation of Angular velocity against y for different values of epsilon ε, with, G = Gm = 4, Pr = 0.71, Sc = 0.65, ε = 0.02, A = 0.5, n = 0.1, N = 0.01, β = 0.03, η = 0.5 and K = 1.0.

5. CONCLUSION

The governing equations for unsteady MHD micropolar flow and mass transfer flow past a vertical permeable plate with variable suction has been studied. Analytical results are presented to illustrate the details of the flow and heat transfer characteristics and their dependence on the material parameters. It is observed that the streamwise velocity U decreases with an increasing Hartman Magnetic number and time, while an increase in the Grashof number, Modified Grashof number, chemical reaction parameter and viscosity ratio, results to an increase in the streamwise velocity U. The concentration profile decreases with an increasing chemical reaction parameter and Schmidt number. The temperature field increases with an increasing time and decreases with an increasing Prandtl number. Lastly the angular velocity decreases with an increasing Grashof and Modified Grashof numbers, time and epsilon respectively.

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