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The Effect of Thermophoresis on MHD Stream of a Micropolar Liquid Through a Porous Medium with Variable Heat and Mass Flux and Thermal Radiation

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ABSTRACT

In this paper, the combined possessions of thermal radiation and thermophoresis on stable Magnetohydrodynamic free convection stream of a micropolar liquid past an erect porous laminate during a porous medium in the occurrence of variable heat and mass fluxes are engaged into report is measured. The leading non-linear partial differential equations of the crisis are changed into a scheme of nonlinear ordinary differential equations during suitable similarity conversion and Runge–Kutta Fourth order with shooting procedure scheme. The possessions of a variety of substantial parameters on the dimensionless stream, microrotation, temperature, and concentration profiles are discussed and offered graphically. In the end, numerical ideals of the substantial quantities, such as the limited skin factor, the combine stress coefficient, the local Nusselt quantity and the local Sherwood quantity are tabulated with the variant of magnetic constraint, coupling invariable, Darcy constraint, modified Forchheimer number, radiation constraint, and thermophoretic constraints.

1. Introduction

The hypothesis of micropolar has inward massive courtesy throughout the current lifetime since the conventional Newtonian liquids cannot explicitly portray the quality of liquid with suspended particles, polar liquids, suspension solutions, liquid crystals, colloidal solutions and liquid containing minute additives. Actually, micropolar liquids may present the non-Newtonian liquids consisting of tiny inflexible cylindrical fundamentals or dumb-bell molecules, polymer liquids, liquids suspensions and animal blood. The survival of grime or smoulder exacting in a gas may also be modelled by means of micropolar liquid dynamics. Eringen [1] earliest imitative the hypothesis of micropolar liquids, which illustrates the microrotation possessions to the microstructures. Eringen [2] extensive his proposal to the hypothesis of thermomicropolar liquids, which attention to the particular possessions

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of microstructures on the liquid stream. The mathematical hypothesis of equations of micropolar liquids and applications of these liquids in the hypothesis of lubrication and in the hypothesis of porous media are given in latest books by Eringen [3] and Lukaszewicz [4].

Free convection in the border layer stream of a micropolar liquid along a vertical wavy shell was developed by Chiu and Chou [5]. Hassanien and Gorla [6] derived the heat transport to a micropolar liquid from a non-isothermal elongating area with suction and blowing. Mixed convection border layer stream of a micropolar liquid on a flat laminate was derived by Gorla [7]. Besides, the stream description of the border layer of micropolar liquid over a semi-infinite laminate in altered situations has been studied by numerous authors [8-15]. In the beyond mentioned mechanism the consequence of the induced magnetic field was ignored.

The crisis of the heat and mass transport for non-Newtonian liquids in porous media is off to large extent significance appropriate to its realistic manufacturing applications, such as lubricate healing, food dispensation, and resources dispensation [16-22]. The kind of convective heat and mass transport of non-Newtonian liquids in porous media are moderately altered those that of Newtonian liquids in porous media as of the non-linear scenery of non-Newtonian liquids.

A latest measurement is added to the border layer stream and heat transport by taking into consideration the thermal radiation. At high effective temperature, radiation consequence can be moderately considerable. Various processes in manufacturing areas occur at high temperature and facts of radiation heat transport becomes extremely significant in electrical power production, astrophysical streams, solar power technology, nuclear plants, gas turbines and various propulsion devices or aircraft and other manufacturing areas. Cogley *et al.,* [23] showed that in the optically lean boundary, the liquid does not attract it is possessed emitted radiation but the liquid does suck up radiation emitted by the boundaries. Kim and Fedorov [24] moderated the case of mixed convection stream of a micropolar liquid past a semi-infinite, steadily stirring porous laminate with varying suction flow normal to the laminate in the occurrence of thermal radiation. The transient free convection interface with thermal radiation of an absorbing emitting liquid besides moving vertical leaky laminate was navigated by Makinde [25]. Ibrahim *et al.,* [26] explained the case of mixed convection stream of a micropolar liquid past a semi infinite, steady moving porous plate with changing suction flow regular to the laminate in occurrence of thermal radiation and viscous dissipation. Rahman and Sattar [27] derived passing convective heat transport stream of a micropolar liquid past a constantly moving vertical porous laminate with time reliant suction in the occurrence of radiation.

Most of the valid time manufacturing processes occupy heat and mass transport. Heat or mass flux ought to be isolated, added or moved from one stream procedure to a further. This is a foremost task during any valid time manufacturing industries such as fuel industries, oceanic manufacturing, pharmaceutical, nuclear up and down processes, and distillation columns etc. The improvement of cooling or heating in manufacturing procedure creates economy in energy, raises thermal score, reduces process time and helps to elongate the operational life of the tools. Consequently, there has been a considerable stipulate for the inventive technologies that will assist in the heat and mass transport fluxes. The heat and mass transport on an elongating/shrinking sheet becomes more attractive when the heat flux and mass flux circumstances at the border are taken into consideration. In heat transport manufacturing, the heat flux occurrence plays a crucial position in controlling the rate of heat transport. In several realistic situations transpire in which the hot plane is subject to an invariable heat flux instead of being at a prescribed temperature. Dutta *et al.,* [28] primary investigated the effect of uniform heat flux on the temperature field in case of stream due to elongating sheet. After that many researchers measured uniform or non- uniform heat flux at the border for elongating sheet stream; Elbashbeshy [29], Elbashbeshy and Bazid [30], Rahman and

Sultana [31]. The MHD stream towards a permeable plane with prescribed wall heat flux was measured by Ishak *et al.,* [32]. Mandal and Mukhopadhyay [33] reported the mutual consequences of porous medium and heat flux on border layer stream and heat transport due to a sheet elongated with exponential flow. Ganesan and Palani [34] offered a numerical solution of the transient free convection MHD stream of an incompressible viscous liquid past a semi infinite inclined laminate with variable surface heat and mass flux.

Thermophoresis is an admirable trend by which tiny sized particles suspended in a non-isothermal gas acquire a flow relative to the gas in the path of declining temperature. The flow acquired by the particles is called thermophoretic flow and the force skilled by the pendant particles due to the temperature rise is known as thermophoretic force. Goren [35] was the initial to study the character of thermophoresis in laminar stream of a viscous incompressible liquid. He used the classical problem of stream over a flat laminate to estimate the deposition rates and showed that considerable changes in surface deposition can be obtained by increasing the variation between the plane and free stream temperature. Thermophoretic deposition of radioactive particles is measured to be one of the significant factors causing accidents in nuclear reactors. Epstein *et al.,* [36] investigated the thermophoretic transport of tiny particles through a free convection border layer bordering to a cold, vertical deposition plane in a viscous incompressible liquid. Garg and Jayaraj [37] studied the thermophoretic transport of tiny particles in forced convection stream over an inclined plate. Opiolka *et al.,* [38] analyzed the mutual consequences of electrophoresis and thermophoresis on particle evidence onto flat plane. The consequence of plane mass transport on mixed convection stream past a heated vertical flat permeable plate with thermophoresis was studied by Selim *et al.,* [39]. Wang [40] discussed the mutual consequences of inertia and thermophoresis on particle deposition onto a wafer with wavy plane. Thermophoresis causes tiny particles to deposition cold surfaces. Alam *et al.,* [41] examined the consequences of variable suction and thermophoresis on steady MHD mutual free-forced convective heat and mass transport stream over a semi-infinite permeable inclined laminate in the existence of thermal radiation. Duwairi and Damesh [42] developed the consequences of thermophoresis particle deposition on mixed convection from vertical surfaces surrounded in saturated porous medium. Pakravan and Yaghoubi [43] theoretically proved that the mutual thermophoresis, Brownian movement and Dufour consequences on natural convection of nanoliquids. Mehdi and Hosseinalipour [44] examined particle movement in nanoliquids considering thermophoresis and its consequence on convective heat transport. Lately Anbuchezhian *et al.,* [45] have derived thermophoresis and Brownian movement consequences on border layer stream of nanoliquid in the occurrence of thermal stratification due to solar energy. To our awareness, there are no published results that include the consequences of thermal radiation and viscous dissipation on MHD mixed convection stream of micropolar liquid in the occurrence of thermophoresis.

Most of earlier works are not deliberated heat and mass transport MHD free convective stream of micropolar liquid through a porous medium with heat and mass fluxes in the occurrence of the thermophoresis. Consequently, in the present work, we have performed a numerical investigation on the mutual consequences of thermal radiation and thermophoresis on steady Magnetohydrodynamic free convective heat and mass transport stream of a micropolar liquid past a past a vertical porous laminate with heat and mass flux border conditions.

2. Mathematical Analysis

Consider a 2D steady MHD free convective stream of viscous incompressible electrically conducting liquid past a semi-infinite permeable inclined smooth laminate; while a magnetic field of uniform strength B0 is applied in the y-direction which is normal to the stream direction (see Figure

1). Liquid suction is imposed at the laminate plane and the suction whole size is taken to be constant. The temperature of the plane is supposed consistent at Tw which is higher than the ambient temperature. The Rosseland estimate is used to illustrate the radioactive heat flux in the x-direction which is considered negligible in assessment to the y-direction. The consequences of thermophoresis are being taken into account to assist in the thoughtful of the mass deposition difference on the plane. Under the above assumptions, the leading equations for this problem can be written as:

(i) Continuity:

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

(ii) Momentum:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v_a\frac{\partial^2 u}{\partial y^2}+\frac{S}{\rho}\frac{\partial N}{\partial y}+g\beta_T 2\left(T-T_\infty\right)+g\beta_C\left(C-C_\infty\right)-\frac{\sigma B_0^2 u}{\rho}-\frac{v_a}{K'}(u-U_\infty)-\frac{b}{K'}(u-U_\infty)^2 \tag{2}$$

(iii) Angular momentum:

$$u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}=\frac{v_s}{\rho j}\frac{\partial^2 N}{\partial y^2}-\frac{S}{\rho j}\left(2N+\frac{\partial u}{\partial y}\right)=0 \tag{3}$$

(vi) Energy:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{4}$$

(v) Concentration:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}-\frac{\partial}{\partial y}(V_T C) \tag{5}$$

where u and v are the flow apparatus in the *x*, y directions, $v_a=(\mu+s)/\rho$ is the noticeable kinematic viscosity, *g* is the acceleration due to gravity, *T* is the temperature of the liquid in the border layer, g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, β_T and β_C are the coefficient of thermal and volumetric expansions , correspondingly, $v_s=\left(\mu+s/2\right)j$ (see Rees and Bassom [46]) is the microrotation viscosity or spin-gradient viscosity, *j* is the micro-inertia density,T is the temperature of thermal border layer liquid , *C* is the concentration of the liquid in the border layer, T_∞ is the temperature far away from the laminate, C_∞ is the concentration of the solute far away from the laminate, U_∞ is the flow of the liquid far away from the laminate,. σ is the electrical conductivity, B_0 is the magnetic induction, k is the liquid thermal conductivity, ρ is the liquid density, C_p is the specific heat at constant pressure, q_r is the radiative heat flux in the *y*-direction,

μ is the dynamic viscosity, D is the molecular diffusivity of the species concentration and V_T is the thermophoretic flow.

The border conditions for the sculpt are as follows

$$u=0,\ v=\pm v_w(x),\ N=-n\frac{\partial u}{\partial y},\ \frac{\partial T}{\partial y}=-\frac{q_m}{k},\ \frac{\partial C}{\partial y}=-\frac{m}{D_m}\ \ at\ y=0$$
$$u\to U_\infty,\ N\to 0,\ T\to T_\infty,\ C\to C_\infty \text{ as } y\to\infty \tag{6}$$

where U_0 is the uniform laminate flow and $v_w(x)$ represents liquid suction/injection on the porous plane. The transpiration function variable $v_w(x)$ of order $x^{-1/2}$ 1/2 is considered, while $v_w=0$ corresponds to an impermeable laminate. When microrotation constraint $n=0$ we obtain $N=0$ which represents no-spin situation i.e., the microelements in a concentrated particle stream-close to the wall are not able to spin as assured by Jena and Mathur [47]. The case $n=0.5$ represents diminishing of the anti-symmetric part of the stress tensor and represents weak concentration. For this case Ahmadi [8] optional that in a fine particle suspension the particle rotate is equal to the liquid flow at the wall. The case consequent to $n=1.0$ be representative of turbulent border layer streams [48]. In Eq. (8), the last two circumstances represent non-uniform heat and mass fluxes at the surface of the laminate.

By means of the Rosseland estimate, the radiative heat flux in the y' direction is given by [49]

$$q_r=-\frac{4\sigma_1}{3k_1}\frac{\partial T^4}{\partial Y} \tag{7}$$

where σ_1 is the Stefan-Boltzmann invariable and k_1 is the mean absorption coefficient.

Presumptuous that the temperature differences surrounded by the stream are adequately tiny so that T^4 can be extended in Taylor series about the free stream temperature T_∞ to yield

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \tag{8}$$

where the higher-order terms of the expansion are ignored.

By using Eq. (6) and Eq. (7), Eq. (4) gives

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_e}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\frac{16\sigma_1 T_\infty^3}{3\rho c_p k_1}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

Now the thermophoretic flow V_T, which appears in the Eq. (4) can be written as [35]:

$$V_T=-kv\frac{\nabla T}{T_{ref}}=\frac{-kv}{T_{ref}}\frac{\partial T}{\partial y} \tag{10}$$

where T_{ref} is an orientation temperature and *k* is the thermophoretic coefficient with variety of value from 0.2 to 1.2 as indicated by Batchelor and Shen [36] and is defined from the hypothesis of Talbot *et al.,* [35] by

$$k = \frac{2Cs\left(\lambda_g / \lambda_p + C_t K_n\right)\left[1 + K_n\left(C_1 + C_2 e^{-C_3/K_n}\right)\right]}{\left(1 + 3C_m K_n\right)\left(1 + 2\lambda_g / \lambda_p + 2C_t K_n\right)} \tag{11}$$

where C_1, C_2, C_3, C_m, C_s, C_t are constants, λ_g and λ_p are the thermal conductivities of the liquid and diffused particles correspondingly and K_n is the Knudsen number.

A thermophoretic constraint τ can be defined as follows [35]:

$$\tau = \frac{-k\left(T_w - T_\infty\right)}{T_r} \tag{12}$$

Characteristic values of τ are 0.01, 0.05 and 0.1 consequent to estimated values of $-k\left(T_w - T_\infty\right)$ equal to 3K, 15K and 30 K for an indication temperature of $T_r = 300K$.

3. Similarity Transformation

The solutions of the leading equations are obtained by introducing the subsequent non-dimensional variables:

$$\begin{aligned} &\eta = \left(\frac{U_\infty}{2\nu_a x}\right)^{1/2} y,\ u = U_0\, f'(\eta),\ \theta(\eta) = \frac{T - T_\infty}{Q/k}\sqrt{\frac{U_\infty}{2\nu_a x}},\ \phi(\eta) = \frac{C - C_\infty}{m/D_m}\sqrt{\frac{U_\infty}{2\nu_a x}}, \\ &\psi = \left(2\nu_a U_\infty x\right)^{1/2} f(\eta), v = -\sqrt{\frac{2\nu_a U_\infty}{x}}\left[f(\eta) - \eta f'(\eta)\right],\ N = \left(\frac{U_\infty^3}{2\nu_a x}\right)^{1/2} g(\eta) \end{aligned} \tag{13}$$

If the dimensional stream function $\psi(x, y)$ then $u = \dfrac{\partial \psi}{\partial y}$ and $u = -\dfrac{\partial \psi}{\partial x}$.

The continuity equation is involuntarily fulfilled and the scheme of Eq. (2), Eq. (3), Eq. (5) and Eq. (9) becomes:

$$f''' + ff'' + Kg' + Gr\,\theta + Gc\,\phi - Mf' - 2\lambda\left(f' - 1\right) - Fs\left(f' - 1\right)^2 = 0 \tag{14}$$

$$G_2 g'' - 2G_1(2g + f'') + f'g + fg' = 0 \tag{15}$$

$$\left(3R + 4\right)\theta'' + 3R\,\mathrm{Pr}\, f\theta' + 3R\,\mathrm{Pr}\, f'\theta = 0 \tag{16}$$

$$\phi'' + Sc(f - \tau\theta')\phi' - Sc\tau\theta''\phi = 0 \tag{17}$$

The primes indicate differentiation with respect to η, $M=\dfrac{\sigma B_0^2 2x}{\rho U_\infty}$ is the is the magnetic field constraint, $Gr=g\beta_T\sqrt{\dfrac{\nu_a(2x)^3}{U_\infty^5}}\dfrac{Q}{k}$ is the local thermal Grashof number, $Gc=g\beta_c\sqrt{\dfrac{\nu_a(2x)^3}{U_\infty^5}}\dfrac{m}{D_m}$ is the local solute Grashof number, $K=\dfrac{s}{\rho\nu_a}$ is the coupling constraint, $\lambda=\dfrac{1}{Da}$ is the Darcy constraint, *Da* = is the modified Darcy number, $Fs=\dfrac{bx}{K'}$ is the modified Forchheimer number, $G_1=\dfrac{sx}{\rho jU_\infty}$ is the vortex viscosity constraint, $G_2=\dfrac{\nu_s}{\rho j\nu_a}$ is the spin gradient viscosity constraint, $G=\dfrac{G_1U_0}{2\nu x}$ is the micro-rotation constraint, $\Pr=\dfrac{\rho\nu c_p}{k}$ is the Prandtl number, $R=\dfrac{kk_e}{4\sigma_s T_\infty^3}$ is the thermal radiation constraint, $Sc=\dfrac{\nu}{D_m}$ is the Schmidt number constraint.

The transformed border conditions Eq. (6) are given by

$$\begin{aligned}&f(0)=\pm f_w,\ f'(0)=0,\ g(0)=0,\ \theta(0)=-1,\ \phi(0)=-1\\&f(\infty)=0,\ g(\infty)=0,\ \theta(\infty)=0,\ \phi(\infty)=0\end{aligned} \tag{18}$$

Where $f_w=-v_w(x)\sqrt{\dfrac{2x}{\vartheta U_0}}$ is the permeability of the porous plane which is positive for suction and negative for injection.

The substantial quantities of awareness are the local friction factor, the wall heat transport coefficient (or the local Nusselt number) and the wall deposition flux (or the local Stanton number) which are distinct as correspondingly where the skin friction C_f, the heat transport $q_w(x)$ and the mass transport Sh_x from the wall are given by

$$C_f\,\mathrm{Re}_x^{-1/2}=\frac{\tau_w}{(1/2)\rho U_o^2}=2f''(0),\ \tau_w=\mu\left(\frac{du}{dy}\right)_{y=0} \tag{19}$$

The equation defining the laminate couple stress is

$$M_w=\nu_s\left(\frac{\partial N}{\partial y}\right)_{y=0} \tag{20}$$

The dimensionless couple stress is defined by

$$M_s=\frac{M_w}{1/2\,\rho\nu_a U_\infty}=\frac{G_2K}{G_1}g'(0) \tag{21}$$

Thus, the local couple stress in the border layer is relative to $g'(0)$.

From the temperature field, we can study the rate of heat transport which is given by

$$Nu_x \mathrm{Re}_x^{-1/2}\left(\frac{3R}{3R+4}\right)=\frac{q_w(x)}{\lambda\left(T_w-T_\infty\right)}=-\frac{1}{2}\theta'(0);q_w(x)=-k\left(\frac{\partial T}{\partial y}\right)_{y=0}-\frac{4\sigma_1}{3k_1}\left(\frac{\partial T^4}{\partial y}\right)_{y=0} \quad (22)$$

From the concentration field, we can study the rate of mass transport which is given by

$$Sh_x St\,\mathrm{Re}_x^{-1/2}=-\frac{J_s}{U_0 C_\infty};J_s=-D\left(\frac{\partial C}{\partial y}\right)_{y=0}=-\phi'(0) \quad (23)$$

where $\mathrm{Re}_x = U_0 x/\nu$ the local Reynolds number.

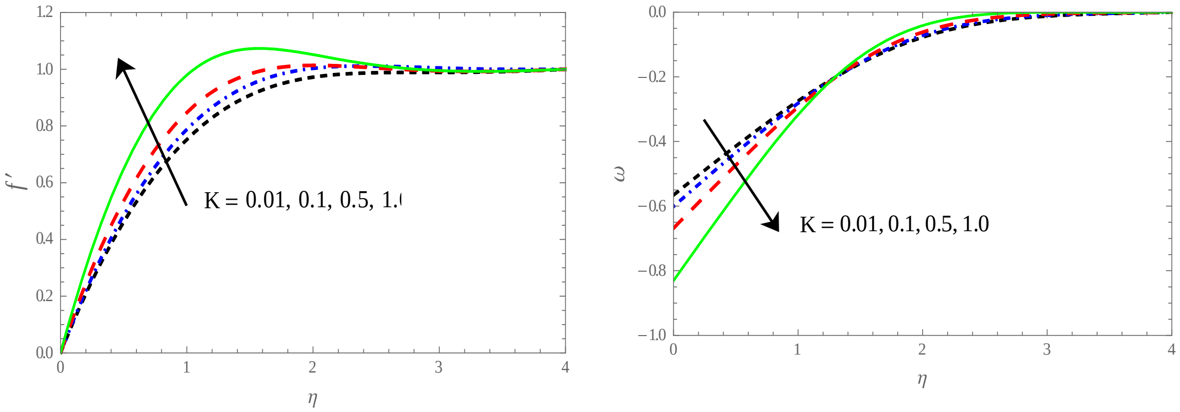
4. Method of Solution

The structure of ordinary differential Eq. (14) to Eq. (17) subject to the border surroundings Eq. (18) are solved numerically with Runge – Kutta fourth-order with shooting iteration procedure. A step size of was selected to be satisfactory for a convergence standard of 10^{-6} in all belongings. The results are presented graphically in Figure 1 to Figure 12 and conclusions are drained for stream field and other substantial quantities of attention that have considerable consequences.

5. Results and Discussion

Eq. (11) to Eq. (13) comprise extremely non-linear coupled border value problem of third and second order. Thus, we have used the shooting iteration procedure with Runge–Kutta fourth-order integration algorithm. For numerical results we measured the non-dimensional constraint ideals as M =1.0, K=0.01, Gr=2.0, Gc=2.0, fw =0.2, G1=1.0, G2=2.0, Pr=0.71, R=0.01, Sc = 0.6 and These ideals are kept as invariable in complete study except the varied constraints as showing in Figure 1 to Figure 12 and Table 1. The results obtained shows the influences of the non-dimensional leading constraints, specifically magnetic field constraint, thermal and solutal Grashof numbers, coupling constraint, Darcy constraint, vortex viscosity constraint, spin-gradient viscosity constraint, modified Forchheimer number, radiation constraint, Schmidt number and thermophoretic constraint on flow, microratation, temperature and concentration profiles.

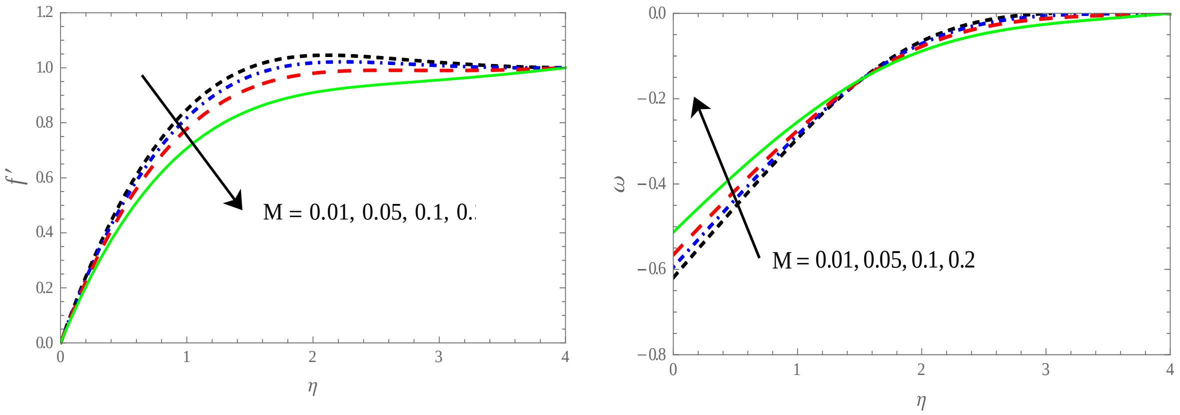
For dissimilar values of coupling invariable on the flow and microrotation profiles are obtained in Figure 1(a) Figure 1(b). It is established that the liquid flow amplifies when the coupling constant is enlarged (See Figure 1(a)). The results also show that the microrotation declines near the porous laminate and contradictory trends far away from the laminate as coupling constant amplifies.



(a) (b)

Fig. 1. (a) Consequences of *K* on flow distribution $f'(\eta)$, (b) Consequences of *K* on microrotation distribution $\omega(\eta)$

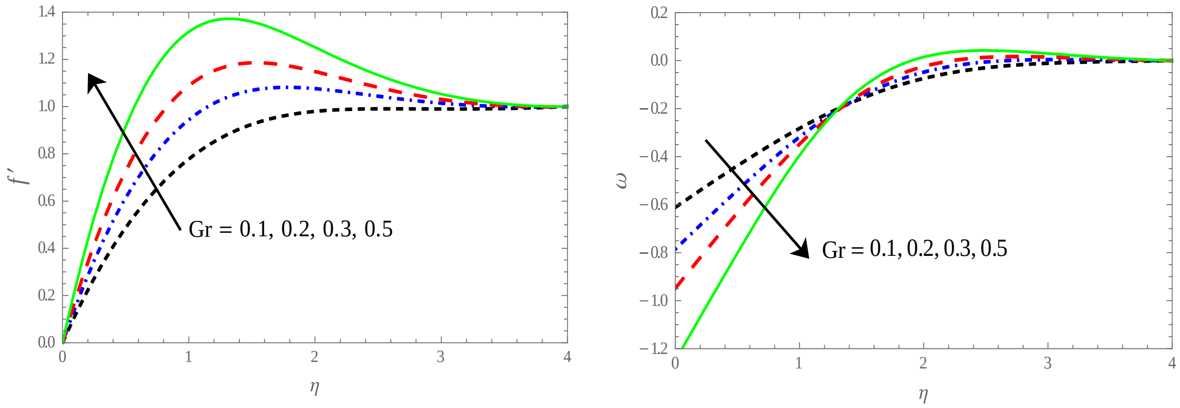
The consequences of the magnetic constraint M on the flow and microrotation profiles are publicized in Figure 2(a) to Figure 2(b), correspondingly. It is obviously seen From Figure 2(a) that the flow profiles dwindle with mounting values of magnetic constraint M. It is also seen Figure 2(b) that the microrotation amplifies near the porous plate and then declines far away from the laminate as magnetic constraint M raises.



(a) (b)

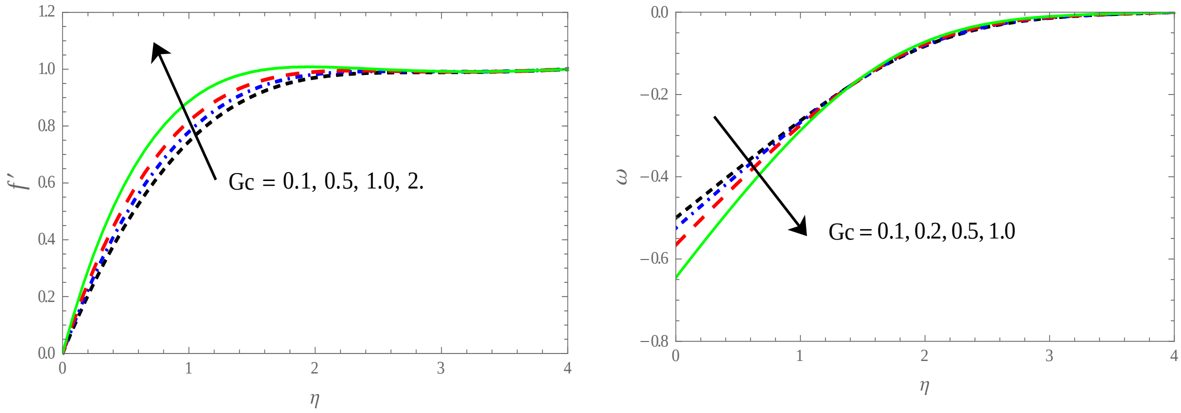
Fig. 2. (a) Consequences of *M* on flow distribution $f'(\eta)$, (b) Effect of *K* on microrotation distribution $\omega(\eta)$

The liquid flow and microrotation profiles for dissimilar values of thermal Grashof number Gr and solutal Grashof number Gc are exhibited in Figure 3 and Figure 4, correspondingly. It is observed that mounting in Gr or Gc leads to escalating in the values of flow, whereas microrotation dwindles near the porous laminate and then amplifies far away from the laminate.



(a) (b)

Fig. 3. (a) Consequences of Gr on flow distribution $f'(\eta)$, (b) Consequences of Gr on microrotation distribution $g(\eta)$



(a) (b)

Fig. 4. (a) Consequences of Gc on flow distribution $f'(\eta)$, (b) Consequences of Gc on microrotation distribution $\omega(\eta)$

For dissimilar values of suction constraint on the flow, microrotation and concentration profiles are obtained in Figure 5(a) to Figure 5(c). It is observed that the flow profiles amplify with the raise of suction constraint representative the usual fact that suction stabilizes the border layer expansion. (See Figure 5(a)). The results also show that the microrotation profile dwindles near the porous laminate and contradictory trends far away from the porous laminate as suction constraint amplifies where viscosity is overriding. From Figure 5(c) it is scrutinized that the concentration profiles diminish with enlarge of the suction constraint.

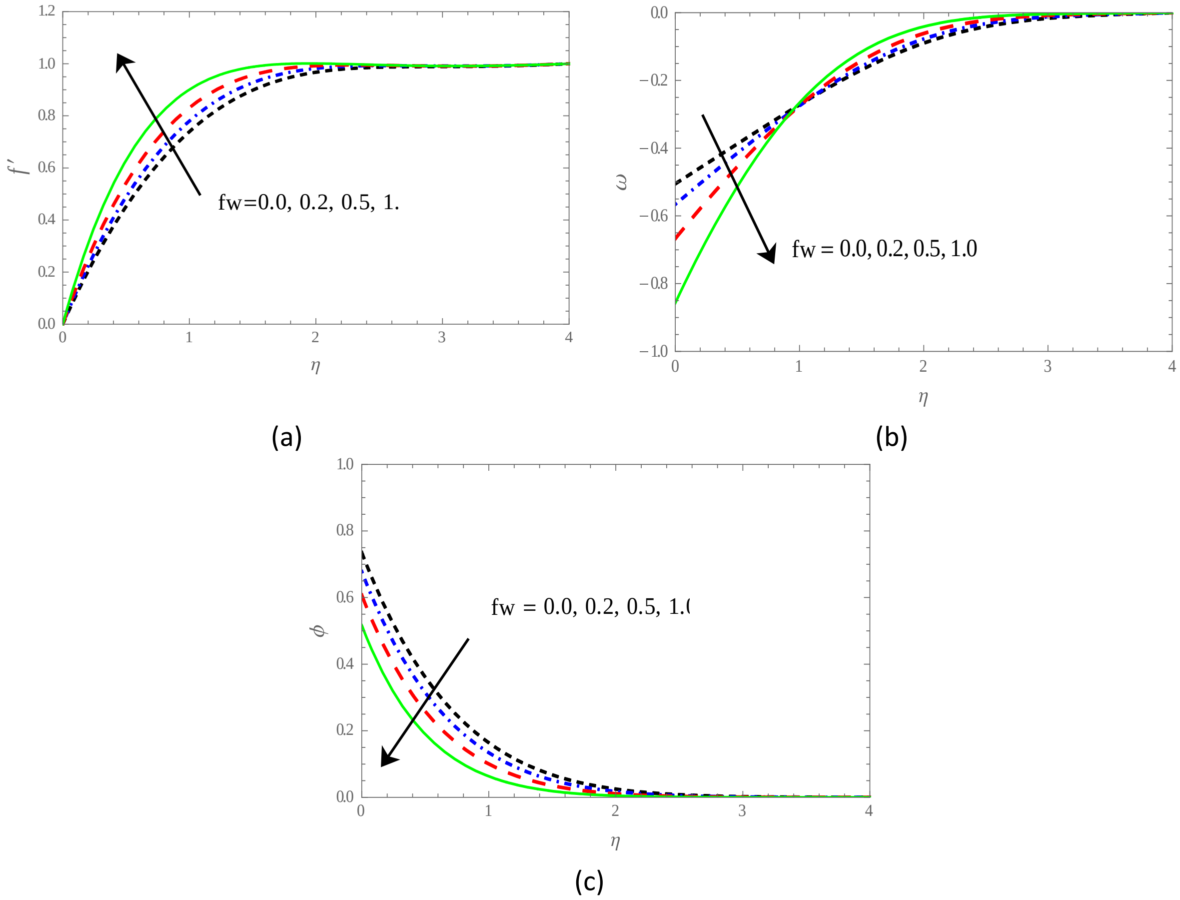


Fig. 5. (a) Consequences of fw on flow distribution $f'(\eta)$, (b) Consequences of fw on Microrotation distribution $\omega(\eta)$, (c) Consequences of fw on concentration distribution $\phi(\eta)$

The consequence of the local Darcy constraint on the flow field is publicized in the Figure 6(a). From this outline we observed that flow profiles decline with the raise of. Darcy number is the quantity of the porosity of the medium, as the porosity of the medium enlarges, the value of Da raises and hence diminishes. For large porosity of the medium liquid gets more space to stream, subsequently liquid flow amplifies. Figure 6(b) illustrates that microrotation amplifies with the raise of local Darcy constraint.

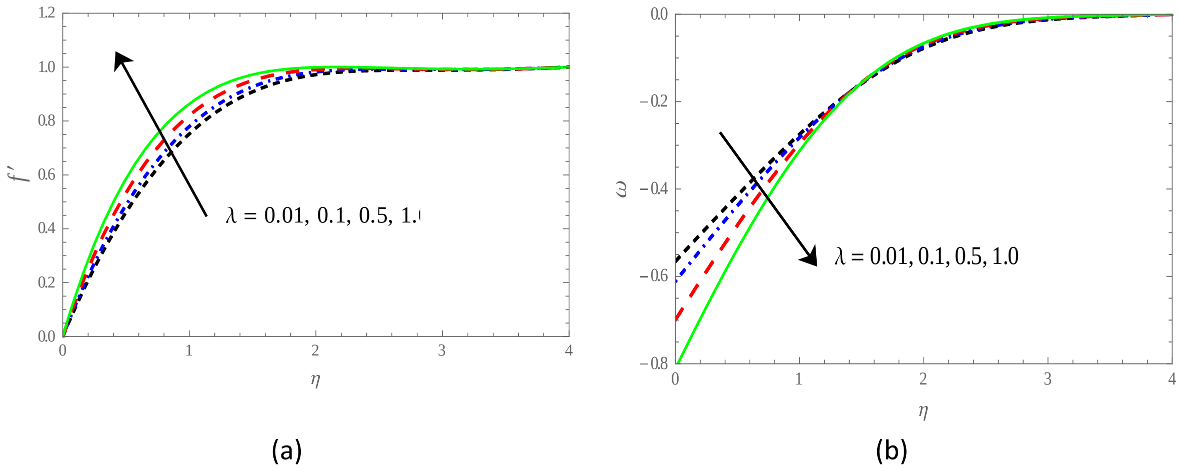


Fig. 6. (a) Consequences of λ on Flow distribution $f'(\eta)$, (b) Consequences of λ on microrotation distribution $\omega(\eta)$

For different values of the vortex viscosity constraintG1 on the microrotation distribution plotted in Figure 7. It is observed from figure that the escalating values of the vortex viscosity constraintG1, the microrotation distribution boost-up.

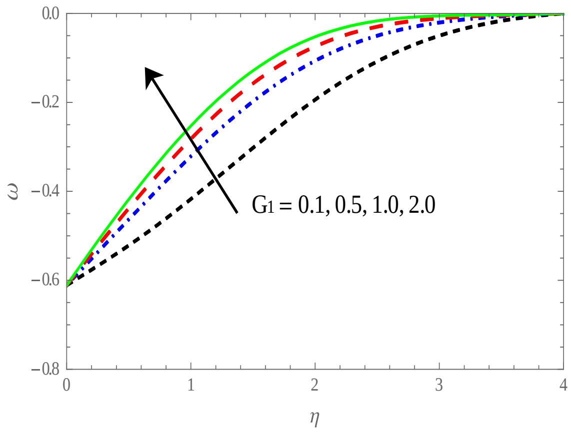


Fig. 7. Consequences of G_1 on microrotation distribution $\omega(\eta)$

The influences of the spin-gradient viscosity constraintG2 on the microrotation distribution are painted in Figure 8. From this outline, we observed that microrotation distribution decline with the mounting values of spin-gradient viscosity constraintG2.

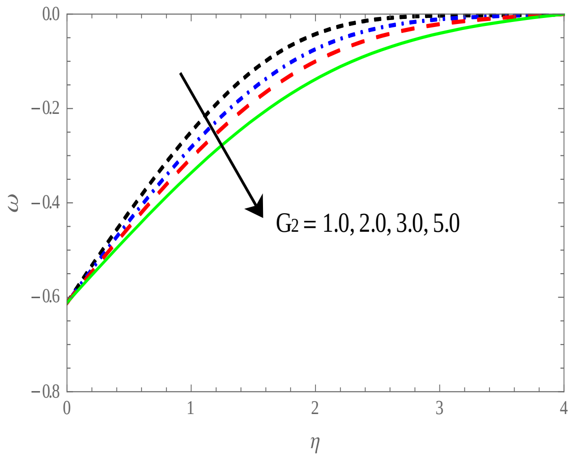
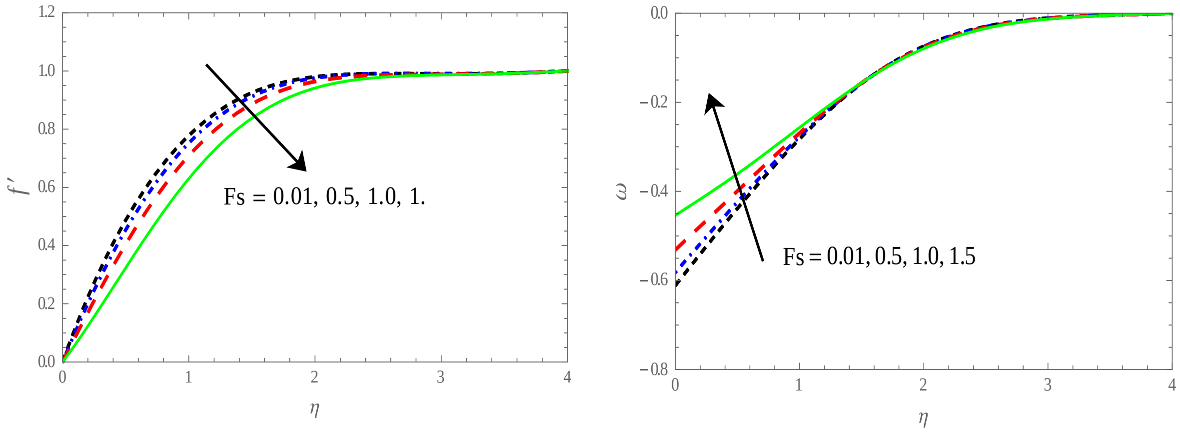


Fig. 8. Consequences of G_2 on microrotation distribution $\omega(\eta)$

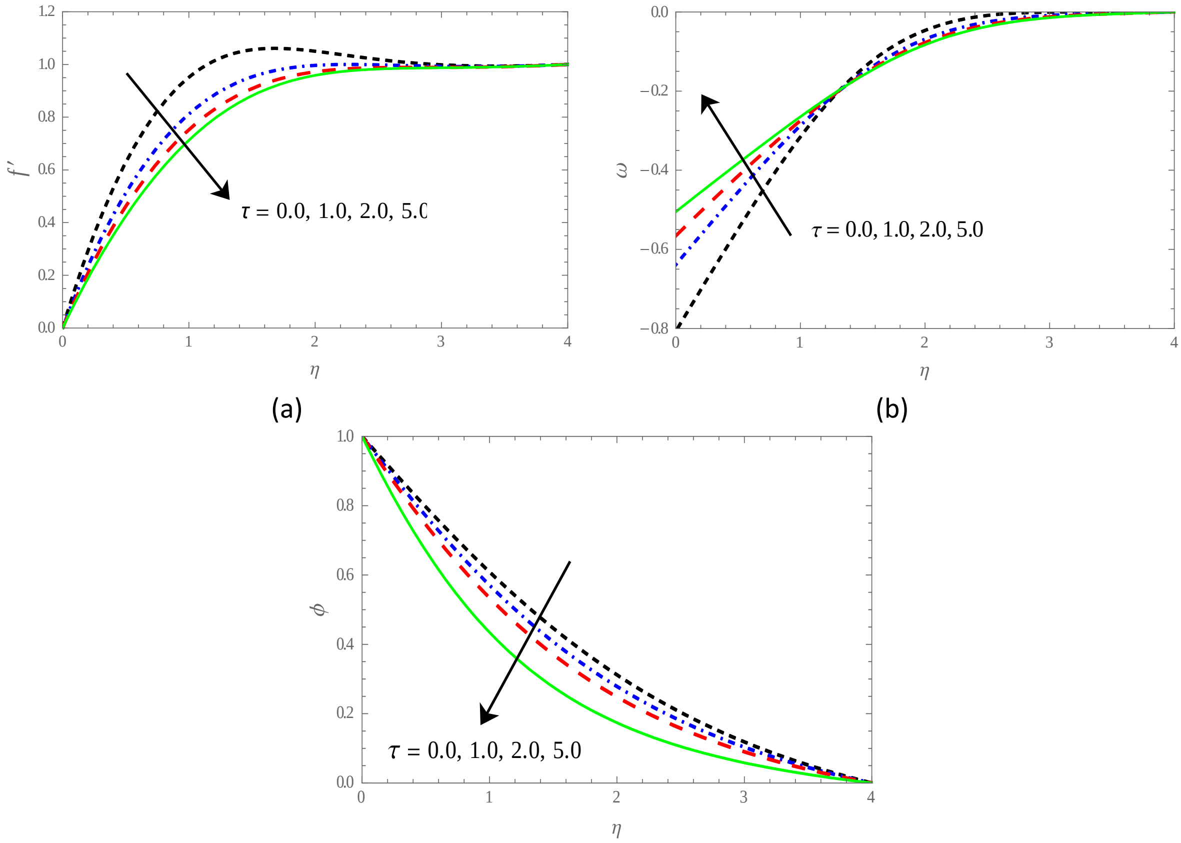
Figure 9(a) and Figure 9(b) correspondingly, show the flow and microrotation, profiles for different values of customized Forchheimer number Fs. From Figure 9(a), we see that flow diminishes with the amplify of Fs. Figure 9(b) shows the effect of in the microrotation profiles. From this figure we scrutinize Fs as escalating effect on the microrotation profiles.



(a) (b)

Fig. 9. (a) Consequences of Fs on flow distribution $f'(\eta)$, (b) Consequences of Fs on Microrotation distribution $\omega(\eta)$

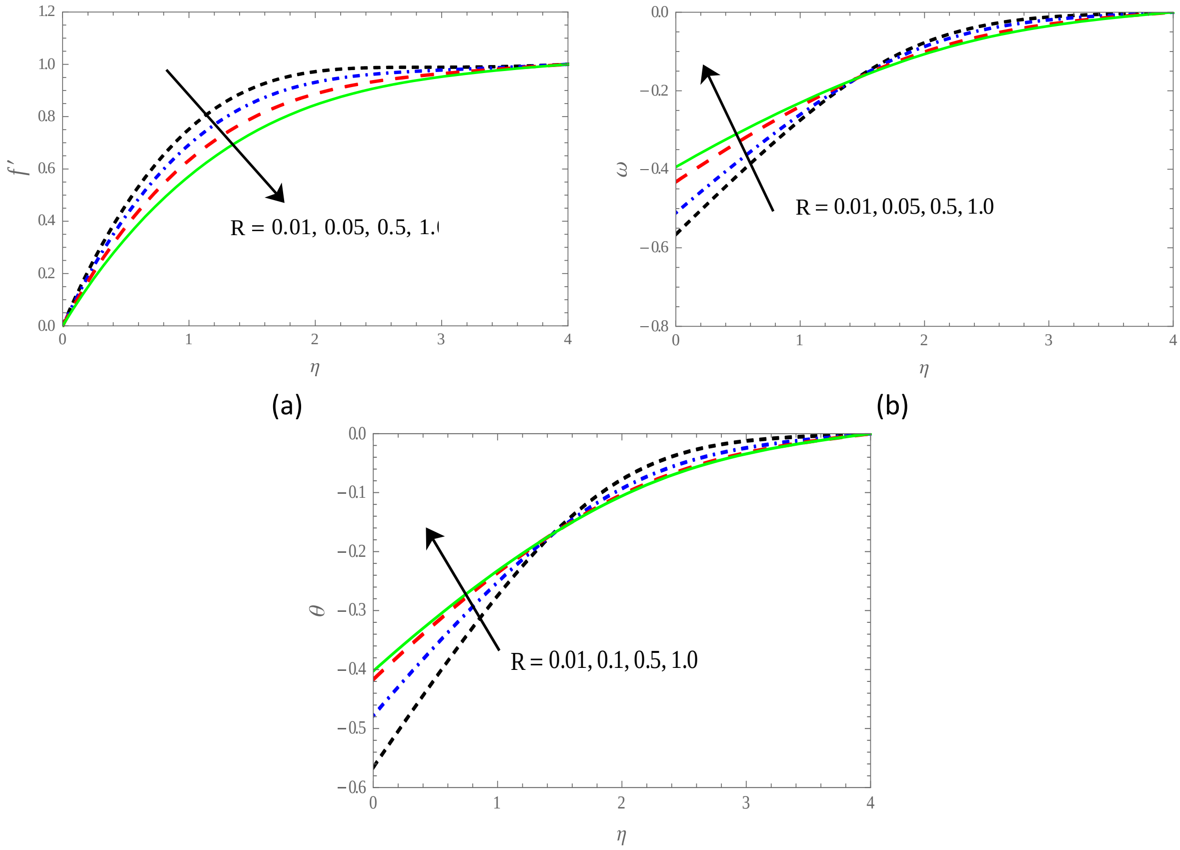
For a variety of values of thermophoretic constraint on the flow, microrotation and concentration profiles are plotted in Figure 10(a) to Figure 10(c). It can be seen that the liquid flow declines with the raise of thermophoretic parameter. The results also show that the microrotation profiles raises near the porous laminate and contradictory trends far away from the laminate as thermophoretic constraint enlarges. From Figure 10(c) we scrutinized that the concentration profiles diminish with escalating values of the thermophoretic constraint.



(c)

Fig. 10. (a) Consequences of τ on flow distribution $f'(\eta)$, (b) Consequences of τ on microrotation distribution $\omega(\eta)$, (c) Consequences of τ concentration distribution $\phi(\eta)$

For dissimilar values of thermal radiation constraint R, the flow, microrotation and temperature profiles are plotted in Figure 11(a) to Figure 11(c). It is evident that the liquid flow distribution transversely the border layer diminishes with the mounting values of radiation constraint R. The results also show that both the microrotation and temperature on the vertical laminate amplifies near the porous laminate and contradictory trends far away from the laminate as escalating radiation constraint.



(c)

Fig. 11. (a) Consequences of R on flow distribution $f'(\eta)$, (b) Consequences of R on microrotation distribution $\omega(\eta)$, (c) Consequences of R on temperature distribution $\theta(\eta)$

The consequences of a variety of values of Schmidt number Sc on the flow, microrotation and concentration profiles are accessible in Figure 12(a) to Figure 12(c). It is publicized that the liquid flow transversely the border layer diminishes with escalating values of Sc. The results also, it is emerged that the microrotation rises near the porous laminate and contradictory trends far away from the laminate as Sc enlarges. From Figure 12(c) we scrutinized that the concentration profiles decline with escalating values of the Schmidt number Sc.

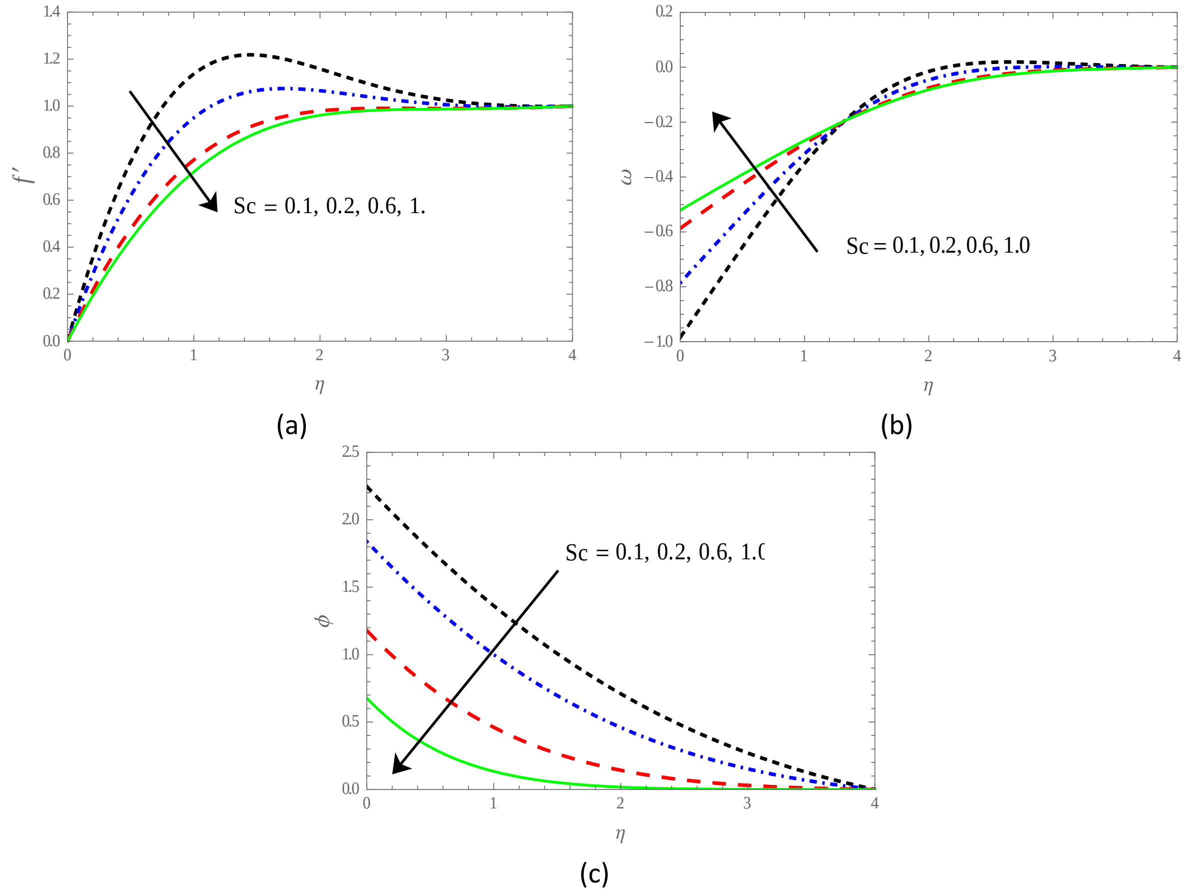


Fig. 12. (a) Consequences of Sc on flow distribution $f'(\eta)$, (b) Consequences of Sc on microrotation distribution $g(\eta)$, (c) Consequences Sc of on concentration distribution $\phi(\eta)$

The numerical values of the skin-friction factor, local Nusselt number and local Stanton number are tabulated in Table 1 for dissimilar values of magnetic constraint *M* and coupling constant *K*, local Darcy constraint λ, modified Forchheimer number *Fs*, radiation constraint *R* and thermophoretic constraint τ. Scrutiny of the tabular data Table 1 shows that magnetic constraint, modified Forchheimer number, radiation constraint *R* and thermophoretic constraint τ, increase the values of the skin-friction factor, whereas reverse trend is seen by escalating the values of *K,* λ. It is also observed that the couple stress coefficient enlarge with escalating values of *K,* λ. while contradictory consequence is seen with escalating of *M*, *Fs*, *R*, τ. Additional, it is clear that the local Nusselt number amplifies with raise *M, Fs* and τ while reverse trend is seen by escalating values of *K,* λ and *R*. Finally, the consequence of escalating the value of M, *Fs*, τ has the tendency to amplify local Stanton number but the other constraints like *K,* λ and *R* have the effect of declining $-\phi'(0)$.

Table 1
Numerical standards of friction factor, couple stress coefficient, local Nusselt number and local Sherwood number for dissimilar constraints $\lambda = 0.01$, $Fs = 0.01$, *M*=0.1, *K=0.01*, *Gr*=0.1, *Gc*=0.5, G_1=1.0, G_2=2.0, *Pr*=0.71, *R*=0.1, *Sc*=0.22, $\tau = 2.0$

M	*K*	λ	*Fs*	R	τ	C_f	C_w	Nu_x	Sh_x
0.1	-	-	-	-	-	-1.26648	0.408349	0.924601	0.750603
0.2						-1.24389	0.384579	0.928207	0.751901
0.5						-1.22389	0.336181	0.937051	0.755149
	0.1	-	-	-	-	-1.42553	0.424223	0.776691	0.540305
	0.5					-1.46607	0.511458	0.759985	0.535309
	1.0					-1.53191	0.679302	0.732618	0.526823
	-	0.1	-	-	-	-1.12245	0.408349	0.984603	0.899218
		0.5				-1.12826	0.449561	0.984031	0.898127
		1.0				-1.13418	0.493023	0.983447	0.898031
	-	-	0.1	-	-	-1.41585	0.393671	0.781246	0.541941
			0.5			-1.40742	0.324814	0.787479	0.543919
			1.0			-1.39362	0.227774	0.797479	0.547239
	-	-	-	0.1	-	-1.41751	0.408349	0.779991	0.541531
				0.5		-1.39024	0.360379	0.584137	0.499207
				1.0		-1.38516	0.348689	0.500063	0.481113
	-	-	-	-	2.0	-1.49978	0.122987	0.508741	0.275812
					3.0	-1.48151	0.119315	0.528991	0.184856
					5.0	-1.46029	0.113910	0.554104	0.095341

6. Conclusions

The mutual consequences of thermal radiation and thermophorises on MHD free convection heat and mass transport stream of a micropolar liquid past a vertical porous laminate during a porous medium with heat and mass fluxes are investigated. The consequential partial differential equations, describing the problem are transformed into ordinary differential equations by using similarity transformations. These equations are more expediently solved numerically by Runge-Kutta fourth order with shooting iteration procedure for the calculation of stream, heat and mass transport description, the friction factor, the couple stress, heat and mass transport coefficients at vertical laminate in a porous medium for a variety of values of magnetic constraint, local Darcy constraint, modified Forchheimer number, radiation constraint, and thermophoretic constraint.

The foremost outcomes of this study can be outlined as:

I. The flow diminishes with raise in magnetic constraint M, modified Forchheimer number Fs, thermophoresis constraint radiation constraintR and Schmidt number Sc but raises with enlarge in coupling constant K, suction constraint local Darcy constraint
II. The microrotation raise near the surface and then decline far away from the surface with amplify in magnetic constraintM, modified Forchheimer number Fs, thermophoresis constraint radiation constraint R and Schmidt number Sc but reverse trends observed for the coupling constant K, suction constraint local Darcy constraint
III. The Temperature rises near the surface and then declines way from the surface with amplify in radiation constraint R.
IV. The concentration dwindles with enlarge in suction constraint thermophoresis constraint and Schmidt number Sc.
V. The friction factor coefficient amplifies with raise in M, Fs, R and decline for the values of K and but reverse trends observed for the couple stress coefficient.

VI. Both the rate of heat and mass transport coefficients dwindles with raise in K, and R and they amplifies with in M and Fs.

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