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Melting Heat Transfer Effects on MHD Chemically Thermally Radiative Micropolar Fluid Flow towards Stretching Exponentially Sheet with Heat Sink/Source

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ABSTRACT

The effective use of non-Newtonian fluids is vital for situations involving heat and mass transfer. For instance, we employ thermal paste, a non-Newtonian fluid, to cool the CPU. By means of a computational approach, the behaviour of non-Newtonian on the surface of a two-dimensional steady MHD boundary layer flow and melting heat and mass transfer over a micropolar fluid is presented here, in conjunction with a partially slipper sheet at the surface providing heat generation/absorption. Further, heat radiation as well as chemical reactions are considered. Using similarity parameters, the governing nonlinear partial differential equations for heat, mass and flow are converted into a series of coupled nonlinear ordinary differential equations, then solved using the Runge–Kutta fourth order integration scheme and the shooting method. For various parameters defining the flow within the boundary layer, the new findings for velocity, microrotation, temperature and concentration are graphed. Graphic representations of local skin friction, Nusselt number and Sherwood number are provided. Boosting the melting parameter decreases fluid velocity, microrotation and temperature significantly. An intensification in slip near the boundary decreases both fluid velocity and microrotation, but opposite effects are observed on temperature.

1. Introduction

The recent discovery of micro-polar fluids has attracted significant attention from engineering and scientific communities due to their unique characteristics compared to Newtonian fluids. Unlike Newtonian fluids, micro-polar fluids exhibit microrotation effects, allowing them to model more complex behaviours in certain applications, including biological and industrial processes. In addition to being non-Newtonian fluids, micropolar fluids exhibit microscopic effects, such as micro rotational

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inertia. In view of its widespread application in manufacturing as well as in trade, micropolar fluids are a popular area of research. Navier-Stokes model has some limitations, notably lists, Fluids with efficient and effective applications cannot be described and explained by it. Sharma *et al.,* [1] in this paper discussed penetrable continuously stretched sheets along with slip impacts as a result of porous media cause thermal mass transfer in MHD micropolar fluids. An Analytical approach by Saraswathy *et al.,* [2] examines nonlinear radiative and dissipative, combine to cause MHD micropolar fluid to flow in porous channels. In this study, they examined the mixed cited impacts with the magnetic field on porous media. Microchannel thermal analysis by Narla *et al.,* [3] examined micropolar liquid flow ambitious with electroosmosis and peristalsis. The significance of micropolar liquids is taken into account when developing a model for heat transfer in thermally micropolar liquids on curved microchannels. Hydrodynamic behaviour analysis and the application of the micropolar fluids model utilizing user-defined functions in FLUENT studied by Wang *et al.,* [4]. Iin this paper they discussed FLUENT software was used to implement user-defined functions and analyse micropolar fluid behaviour and micropolar parameter values. A Poiseuille flow was used to compare user-defined function programs with the correctness of the solutions. An affecting particle, sliders bearing, dam breaks were used to analyse hydrodynamic behaviour in the Poiseuille flow. Many authors like Pasha *et al.,* [5], Karvelas *et al.,* [6], Vanitha *et al.,* [7], Srinivasacharya *et al.,* [8], Kocić *et al.,* [9] and Zhu *et al.,* [10] studied about micropolar fluids.

For the purpose of improving current energy devices and coming up with novel concepts, research on ways to increase heat transfer rate is essential. The key to optimizing cooling efficiency seems to be choosing a suitable working liquid coolant, aside from the sufficiency of the engineering procedure. Water, ethylene glycol and motor oil are examples of working fluids. Their main drawback is that these common fluids have far poorer thermal conductivities when compared to metals, metal oxides or carbon nanotubes, for example. Many new research areas with promising results have been inspired by the idea of suspending materials in the form of nanoparticles in standard base fluids to boost the thermal conductivity. Researchers and scientists are so focused on improving heating and cooling rates. Musa *et al.,* [11] studied analysing magneto-nanofluid through shrinking surfaces using nonlinear thermal radiation and melting heat transfer. Later Akinshilo *et al.,* [12] presented Microchannels embedded in vertical porous layers: the effect of melting and radiation. A porous microchannel within conductive and non-conducting surfaces is examined to determine whether slippery-melting affect mixed convection heat transmission. A detailed review about the melting heat and mass transfers can be found in Lee *et al.,* [13], Ramzan *et al.,* [14], Yang *et al.,* [15], Narender *et al.,* [16], Sushma *et al.,* [17], Anand Kumar *et al.,* [18], Kumar *et al.,* [19] and Ebiwareme *et al.,* [20].

The term magnetohydrodynamics (MHD) refers to the properties of a fluid's magnetic field in reaction to an electromagnetic force. Experts in fluid dynamics have recently become interested in MHD fluid flow along application to permeable media heat exchangers. These occurrences are receiving more attention because to their diverse functions in the scientific and industrial domains. There are many applications in areas of magneto patterns such as nuclear power plants, mining, plasma exploration, polymer exercising, geothermal extraction, production, refinement, radiative activation waste disposals and many others. Several insightful examinations been conducted on nanofluid flow in MHD absorbent medium. Sheikholeslami *et al*., [21] proposed nanofluid flow in a porous channel with a transverse uniform magnetic regime using a Galerkin and least squares approach. A study by Reddy *et al.,* [22] focused on turbulent MHD nanofluid flow in permeable medium near a vertical plane. Bhatti *et al.,* [23] studied stretchable cylinder affected magneto nanofluid flow characteristics. Tistomo *et al.,* [24] studied thermal radiation effect measurement in enclosure calibration. Shah *et al.,* [25] reported a chemical reaction Carreau fluid with MHD boundary layer was discussed regarding radiation on convective heat transfer implications. A detailed study of

MHD in many fields studied by Harish *et al.,* [26], Magyari *et al.,* [27], Bidin *et al.,* [28], Ishak [29] and Khan *et al.,* [30].

Studying heat and mass transport in chemical reactions is necessary due to the increased requirement for chemical reactions in the chemical and hydrometallurgical sectors. Any type of chemical reaction occurs when a foreign substance is present in air or water. This could exist alone or in combination with water or air. The fluid through which the plate is flowing and an external mass react chemically in various chemical engineering operations. These procedures are used in many industrial applications, such as the processing of food, the creation of polymers and the production of ceramics or glassware. Recent studies have focused on coupled heat and mass transfer issues in chemical reactions because of their importance in numerous processes. Khan *et al.,* [31] studied heat-mass transfer on transient Riga plate stagnation point flow with chemical reaction and radiation. Study of chemical reactions between nanofluids and permeable stretching sheets with slip boundary layer flows studied by Vijaya *et al.,* [32]. Li *et al.,* [33] examined activation energy, Darcy–Forchheimer, chemical reaction on dissipative MHD squeezed flow on horizontal channels. In this study, activation energy and chemical reactions are investigated in relation to flow rate in a horizontal channel across which two parallel plates are moving using magnetohydrodynamic Darcy–Forchheimer squeezed Casson fluid flow. Chemical reaction and radiation impact on magneto flow of Oldroyd-B fluid through permeable medium by Salah *et al.,* [34]. Mahabaleshwar *et al.,* [35] conferred Navier's slip on hydromagnetic nano liquid flows and mass transfers. A detailed review of heat and mass transfer found in Singh *et al.,* [36], Roja *et al.,* [37], Mukhopadhyay [38], Mabood *et al.,* [39], Mandal *et al*., [40] and Lavanya *et al.,* [41].

A goal of the application is to scrutinized the melting heat transfer over a micropolar fluid in two dimensions in a magneto steady flow across the boundary layer caused by stretchable expeditiously sheet with partial slip near the surface. Chemical reaction, radiation and heat sink/source are accounted. The consequences of the chemical reaction and thermal radiation are also considered. A set of coupled nonlinear ordinary differential equations is calculated using similarity variables for the nonlinear partial differential equations governing mass, flow and heat transfer. The Runge–Kutta fourth order integration scheme is then used to solve these equations numerically. For several parameters that describe the flow, the innovative results for the temperature, concentration, microrotation and dimensionless velocity within the boundary layer are shown visually. We investigated and visually displayed the Sherwood number, Nusselt number and local skin friction.

2. Methodology

The problem is modelled graphically in Figure 1, which includes the flow configuration and coordinate system, along with a detailed mathematical formulation. In this setup, a micropolar fluid flows steadily over an exponentially stretching sheet that is melting at a constant rate, creating a two-dimensional flow of an incompressible, electrically conducting fluid. The unique properties of the micropolar fluid, along with the exponential stretching and melting conditions, allow for an intricate flow dynamic influenced by the electrical conductivity and micropolar characteristics of the fluid.

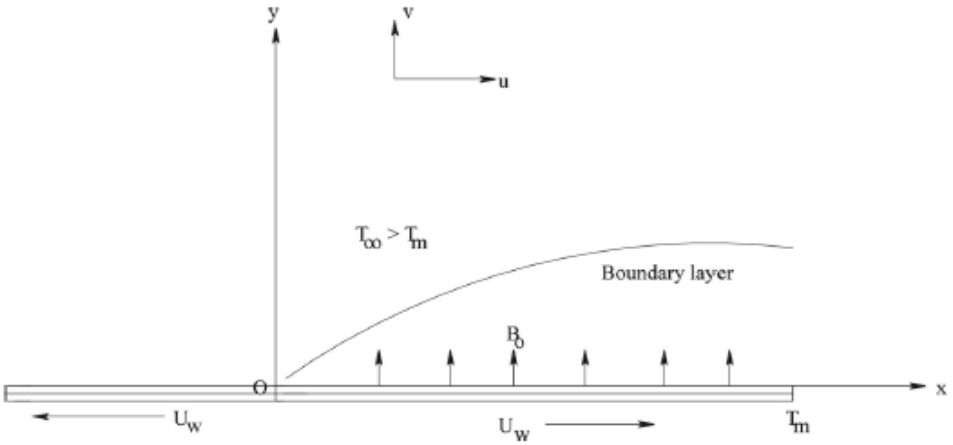


Fig. 1. Physical geometry of the fluid flow

A magnetic field of strength $B = B_0 e^{\frac{x}{2L}}$, B_0 is a constant is imposed in the normal direction of motion. Velocity $U_w = ae^{\frac{x}{L}}$ where *a* (>0) is constant. A laminar flow dissipates less heat than viscous flow. Stress work effects are omitted here as well. Following are the governing equations that represent flow under these assumptions Mandal *et al.,* [40]:

Continuity:

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

Momentum:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = u_e\frac{\partial u}{\partial x} + \left(\frac{\mu+K}{\rho}\right)\frac{\partial^2 u}{\partial y^2} + \frac{K}{\rho}\frac{\partial N}{\partial y} - \frac{\sigma B_0^2 u}{\rho} + g\beta_T(T - T_\infty) + g\beta_C(C - C_\infty), \tag{2}$$

Angular momentum:

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

Energy:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} + \frac{Q_0}{\rho C_p}(T - T_\infty), \tag{4}$$

Concentration:

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - k(C - C_\infty). \tag{5}$$

u, *v* refers the flow velocities , N refers microrotation, $\mu, \rho, \nu = \frac{\mu}{\rho}$ refers fluid viscosity, density, kinematic viscosity, σ refers electrical conductivity, $j, \gamma, K = \frac{\kappa}{\mu}$ refers microinertia, viscosity and material parameter, κ refers vortex viscosity, N refers microrotation, T, T_m, T_∞ refers fluid temperature, melting surface, free-stream, *L* refers length, k refers thermal conductivity, c_p refers specific heat, g refers acceleration, β refers thermal expansion volumetric coefficient, β_T and β_C refers thermal and volumetric expansion coefficients. *C* refers fluid concentration, Q refers heat sink/source coefficient, intended as $Q = Q_0 \exp\left(\frac{x}{L}\right)$, Q_0 refers heat sink/source constant coefficient, ($Q_0 > 0$ & $Q_0 < 0$ refers heat source/heat sink), μ refers dynamic viscosity, D refers molecular diffusivity and $k = k_0 \exp\left(\frac{x}{L}\right)$ refers first-order irreversible chemical reaction variable rate.

Spin gradient viscosity $\gamma = \left(\mu + \frac{k}{2}\right) j = \mu\left(1 + \frac{K}{2}\right) j$, $j = \frac{2Lve^{-\frac{x}{L}}}{a}$. The boundary conditions for the model are as follows

$$u = u_w + u_{Slip}, N = -n\frac{\partial u}{\partial y}, T = T_m, C = C_m at y = 0, \quad (6)$$
$$u \to 0, N \to 0, T \to T_\infty, C \to C_\infty \, as \, y \to \infty.$$

and $k\left(\frac{\partial T}{\partial y}\right)_{y=0} = \rho\left[\lambda + c_s\left(T_m - T_0\right)\right] v(x,0).$

The slip velocity $u_{slip} = \chi(x)\frac{\partial u}{\partial y}, \chi(x) = Ae^{-\frac{x}{2L}}$, *A*, λ, c_s are constants, Rosseland estimate for emission is

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}, \quad (7)$$

where σ^*, k^* are respectively, the Stefan–Boltzman constant and the mean absorption coefficient. We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature. This is accomplished by expanding T^4 in a Taylor's series about T_∞ and neglecting higher-order terms, thus

$$T^4 = T_\infty^4 + 4T_\infty^3(T - T_\infty) = 4T_\infty^3 T - 3T_\infty^4. \quad (8)$$

By using Eq. (7) and Eq. (8), Eq. (4) becomes

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma_1}{3\rho C_p k_1}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho C_p}\left(T - T_\infty\right). \quad (9)$$

Introducing the following dimensionless variables and quantities Mandal *et al.,* [40]:

$$\eta = y\sqrt{\frac{a}{2\nu L}}e^{\frac{x}{2L}}, u = ae^{\frac{x}{L}}f'(\eta), v = -\sqrt{\frac{a\nu}{2L}}e^{\frac{x}{2L}}[f(\eta)+\eta f'(\eta)], \tag{10}$$
$$\psi = \sqrt{2L\nu a}e^{\frac{x}{2L}}f(\eta), N = \frac{a}{2\nu L}\sqrt{2L\nu a}e^{\frac{3x}{2L}}g(\eta),$$
$$\theta(\eta) = \frac{T-T_\infty}{T_m-T_\infty}, \phi(\eta) = \frac{C-C_\infty}{C_w-C_\infty}.$$

Now, the Eq. (2), Eq. (3), Eq. (5) and Eq. (9) simplify into the nonlinear self-similar ordinary differential equations described below:

$$(1+K)f''' + ff'' - f'^2 - Mf' + Kg' = 0, \tag{11}$$

$$(1+K/2)g'' + fg' - f'g - K(2g+f'') = 0, \tag{12}$$

$$\left(1+\frac{4}{3}R\right)\theta'' + Pr(f\theta' - f'\theta + 2\delta\theta) = 0, \tag{13}$$

$$\phi'' + Sc(f\phi' - f'\phi) - ScK_r\phi = 0. \tag{14}$$

The transformed boundary conditions are

$$f'(0) = 1+\chi f''(0), g(0) = -nf''(0), Pr\, f(0) + \alpha\theta'(0) = 0, \theta(0) = 1, \phi(0) = 1,$$
$$f'(\infty) = 0, g(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0. \tag{15}$$

where primes denote differentiation with respect to η and

$$M = \frac{2L\sigma B_0^2}{\rho U_0}, Pr = \frac{\nu}{\alpha} = \frac{\rho\nu c_p}{k} = \frac{\mu c_p}{k},\ \delta = \frac{Q_0 L}{a\rho c_p},$$
$$R = \frac{4\sigma^* T_\infty^3}{k^* k}, Sc = \frac{\nu}{D}, Kr = \frac{K_0 L}{U_0}, \alpha = \frac{kc_p(T_\infty - T_m)}{\rho(\lambda + c_s(T_m - T_0))}. \tag{16}$$

M, Pr, R, δ, Kr, α refers magnetic number, Prandtl number, thermal radiation parameter, heat absorption/generation parameter, chemical reaction parameter and melting parameter respectively

Skin friction coefficient C_f, Couple stress coefficient C_s Nusselt number Nu and Sherwood number *Sh*, presented as:

$$C_f = \frac{\tau_w}{\rho u_w^2}, C_s = \left[(\mu + K/2)j\frac{\partial N}{\partial y}\right]_{y=0}, Nu = \frac{xq_w}{k(T_\infty - T_m)}, Sh = \frac{xq_m}{D(C_\infty - C_0)}. \tag{17}$$

Skin friction, surface heat and mass fluxes (τ_w, q_m and q_n) are:

$$\tau_w = \left[(\mu+k)\left(\frac{\partial u}{\partial y}\right)\right]_{y=0} + K(N)_{y=0},\ q_m = -k\left(\frac{\partial T}{\partial y}\right)_{y=0} \text{ and } q_m = -D\left(\frac{\partial C}{\partial y}\right)_{y=0}. \tag{18}$$

Substituting Eq. (18) into Eq. (17) we obtained,

$$Cf_x = \mathrm{Re}_x^{1/2} C_f = \left[1+(1-n)K\right] f''(0), \tag{19}$$

$$Nu_x = Re_x^{1/2} N u = -\theta'(0), \tag{20}$$

$$Sh_x = Re_x^{1/2} S h = -\phi(0), \tag{21}$$

where Cf_x, Nu_x, Sh_x, $\mathrm{Re}_x = u_e(x)x/\nu$ are local skin friction, Nusselt number, Sherwood number, Reynolds numbers respectively.

3. Numerical Process

In order to resolve transformed Eq. (11) to Eq. (14) with boundary conditions Eq. (15) as an initial value problem:

i. The initial guess values of $f''(0), g'(0), \theta'(0)$ and $\phi'(0)$ are chosen.
ii. Next, Runge–Kutta–Fehlberg method is applied to obtain a solution.
iii. The $f'(\eta), g(\eta), \theta(\eta)$ and $\phi(\eta)$ determined values at η = η_∞ (η_∞ refers sufficient large value of η), compared with boundary conditions $f'(\eta_\infty)=1, g(\eta_\infty)=0, \theta(\eta_\infty)=1$ and $\phi(\eta_\infty)=1$.
iv. For $f''(0), g'(0), \theta'(0)$ and $\phi'(0)$ missing values, the shooting method is utilized.
v. We have fixed *K, M, δ, R, Pr and n*.
vi. With the help of MATHEMATICA 11.0 software for various $\Delta\eta$ size values, velocity, temperature, skin friction coefficient and local Nusselt number changed negligibly for value of $\Delta\eta > 0.01$. Consequently, step-size $\Delta\eta = 0.001$ has been determined by the authors.
vii. Methodology of the problem interpreted through flow chart in Figure 2.

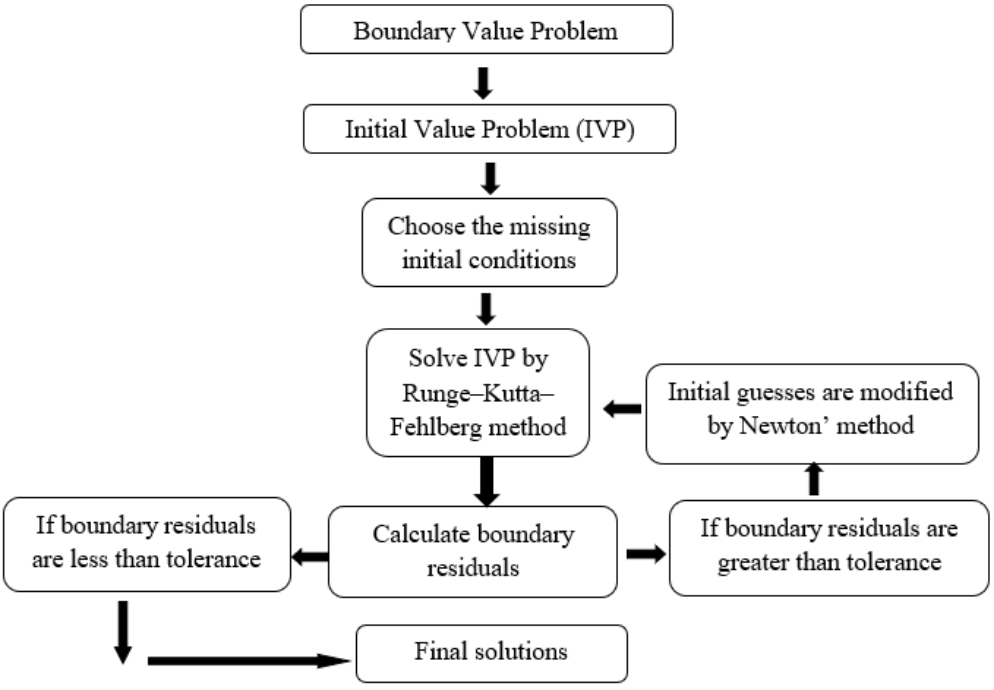


Fig. 2. Flow chart

4. Results and Discussion

To validate the solution of Eq. (11) to Eq. (14) Table 1 is presented.

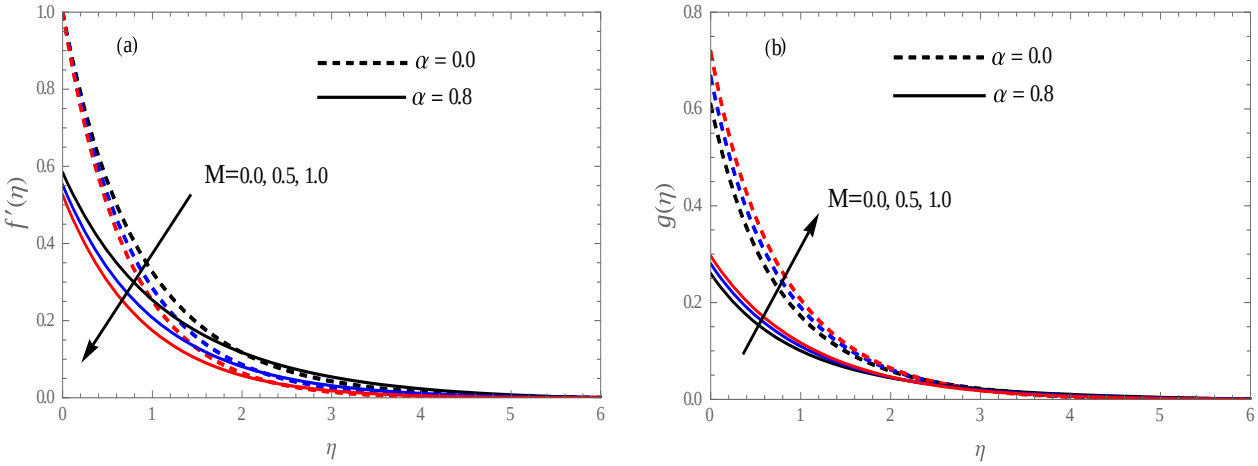
Table 1

Comparison for the values of $\left(-\theta'(0)\right)$ corresponding to the ordinary viscous fluid *(K = 0)* for some specific values of the governing parameters in nonappearance of thermal radiation, heat source/sink, chemical reaction and slip at the boundary

Magnetic Parameter (M)	Pandtl number (Pr)	Magyari *et al.,* [27]	Bidin *et al.,* [28]	Ishak [29]	Mukhopadhyay [38]	Mabood *et al.,* [39]	Mandal *et al.,* [40]	Present
0	1	0.954782	0.9548	0.9548	0.9547	0.95478	0.95475	0.954749
	2		1.4714	1.4715	1.4714	1.47148	1.47148	1.471478
	3	1.869075	1.8691	1.8691	1.8691	1.86907	1.86907	1.869069
	5	2.500135		2.5001	2.5001	2.50011	2.50011	2.500100
	10	3.6604		3.6604	3.6603	3.66039	3.66036	3.660358
1	1			0.8611	0.8610	0.86113	0.86105	0.861001

The influence of the parameters in the equations of the problem is evaluated using Figure 3(a) to 3(b) through Figure 15(a) to 15(b). This evaluation reveals the performance of the velocity, angular velocity, temperature and concentration fields, providing a clearer physical understanding of the problem.

Figure 3(a) and 3(b) illustrate the effects of microrotation and velocity under varying values of M and the melting heat parameter α. As the value of M increases, the fluid velocity decreases. The Lorentz force, which is generated when magnetic fields are applied to flow fields, contributes to this decrease by impeding the motion of the fluid. This force slows down the fluid flow, leading to reduced velocity as the thickness of the momentum layer increases (see Figure 3(a)). Additionally, an increase in the value of M results in greater angular velocity near the sheet (refer to Figure 3(b)).

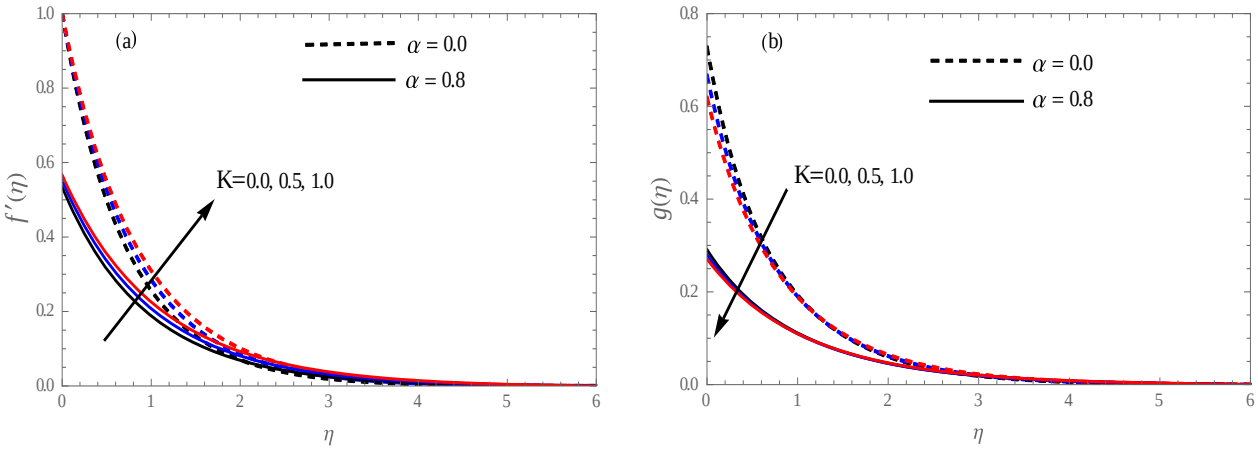


(a) (b)

Fig. 3. (a) Velocity profiles for various *M* values (b) Microrotation profiles for various *M* values

As shown in Figure 4(a) and 4(b), for different values of *K*, there are differences in velocity and angular velocity. Microrotation diminishes as '*K*' grows shown in Figure 4(a) while fluid velocity increases in Figure 4(b). It is the micropolar fluidity parameter (*K*) that determines the velocity profile

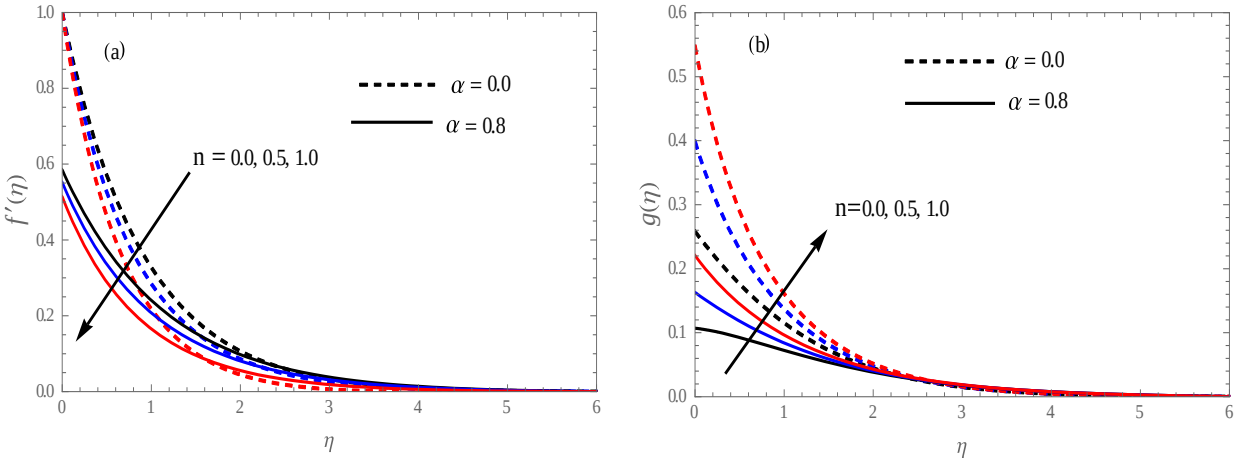
of micropolar fluids physically. The increase in the micropolar fluidity parameter *(K)* indicates a stronger influence of the microstructure on fluid flow.



(a) (b)

Fig. 4. (a) Velocity profiles for various *K* values (b) Microrotation profiles for various *K* values

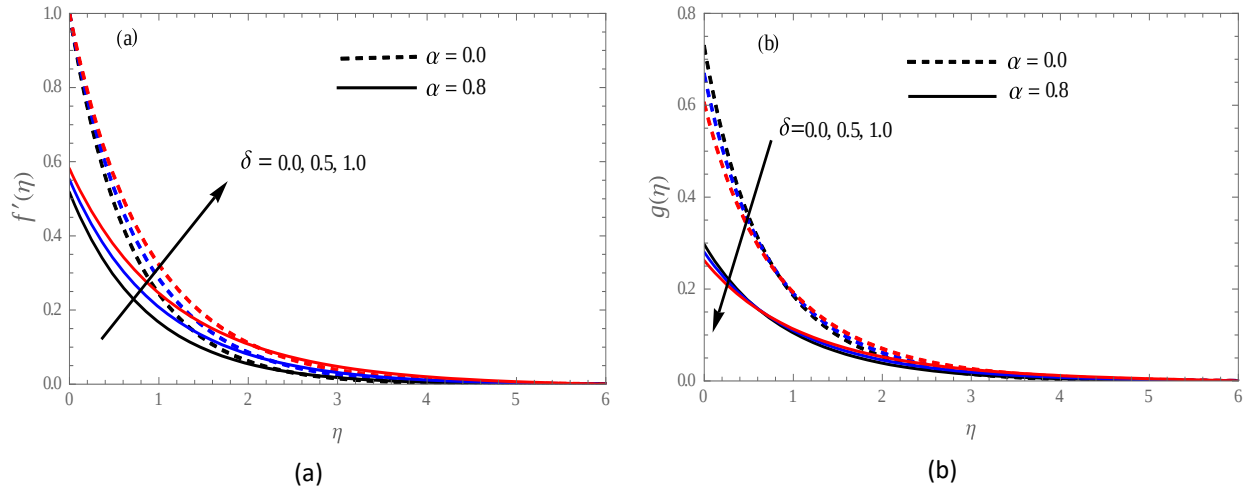
As shown in Figure 5(a) and 5(b), *n* belongs to distributions of velocity and angular velocity. Figure 5(a) shows that velocity decreases with increasing *n*. It is found that microrotation increases with the acceleration value of *n* in Figure 5(b) up to a certain point.



(a) (b)

Fig. 5. (a) Velocity profiles for various *n* values (b) Microrotation profiles for various *n* values

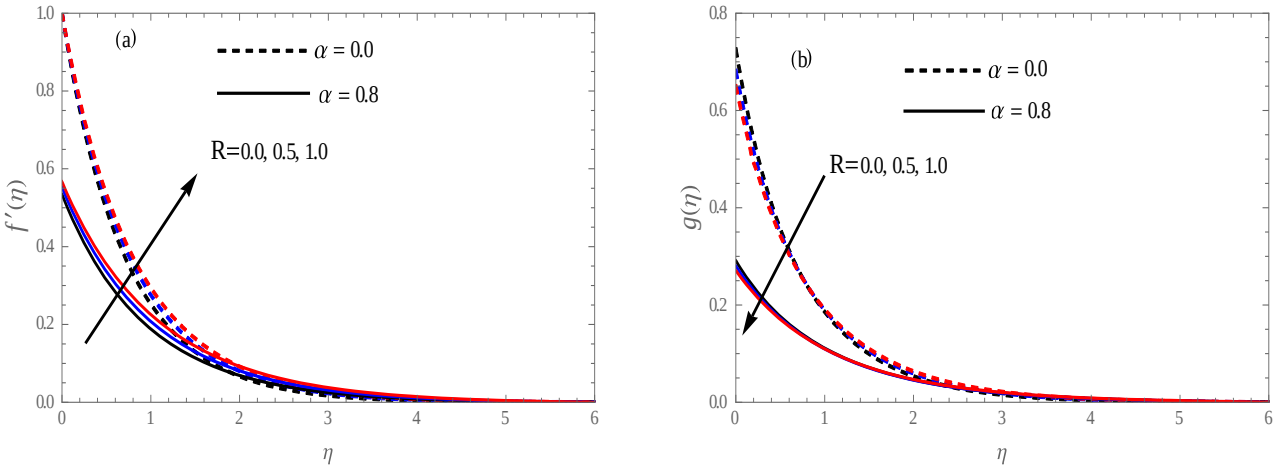
In Figures 6(a) and 6(b) we observe that increase in heat source parameter records the increase in velocity in Figure 6(a) and as rising values of δ we can observe the fall in angular velocity in Figure 6(b). An enhancing in velocity close to the surface occurs due to relative motion between fluid molecules along the surface. Moving from the surface to the bulk of the fluid causes the profile to increase.



(a) (b)

Fig. 6. (a) Velocity profiles for various of δ values (b) Microrotation profiles for various δ values

Figure 7(a) and 7(b) depict that as we increase the values of *R* we can observe velocity rises and microrotation decreases.



(a) (b)

Fig. 7. (a) Velocity profiles for various *R* values (b) Microrotation profiles for various *R* values

As we rise in the values α both velocity and angular velocity collapses that we presented in Figure 8(a) and 8(b). When the melting parameter α increases, the melting parameter α velocity increases as well. Detecting melting parameter α in the presence of the stretched surface partially transmits the drawing into the fluid and thus reduces fluid velocity.

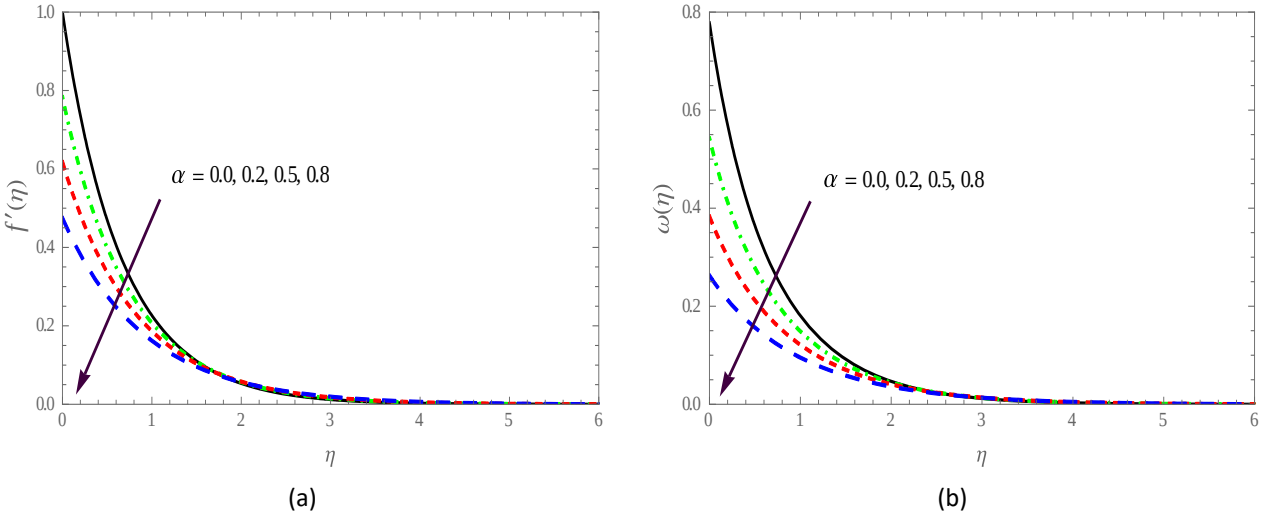


Fig. 8. (a) Velocity profiles for various α values (b) Microrotation profiles for various α values

Figure 9(a) and 9(b) portray the belongings of *n* on temperature and concentration sketches. An increase in the value of *n* depicts the rise in both temperature and concentration sketches, is noticed. It shows the growth in thermal boundary layer.

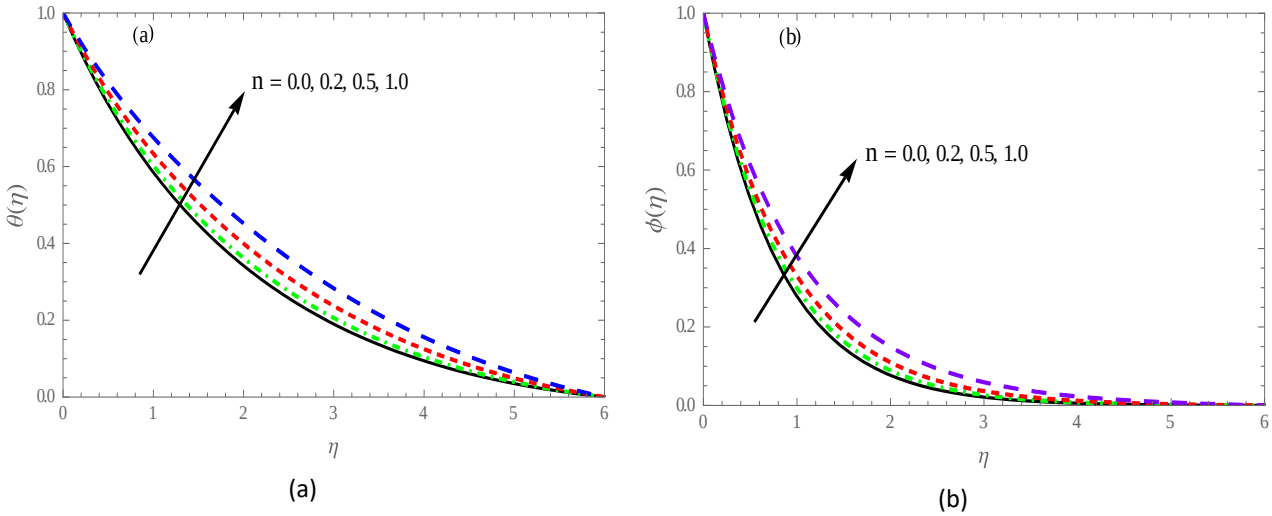
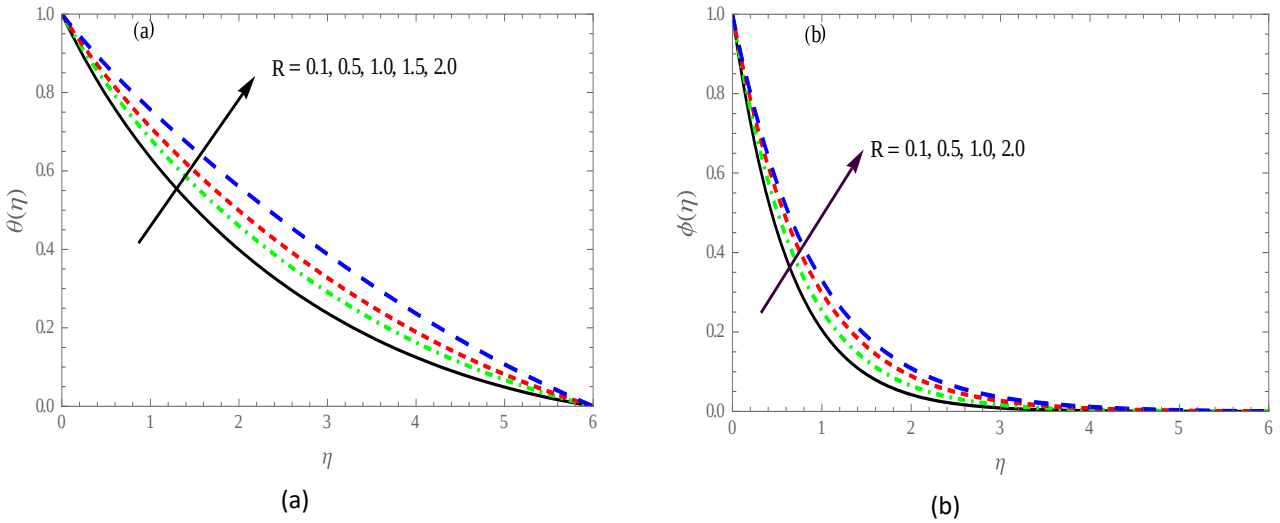


Fig. 9. (a) Temperature profiles for various *n* values (b) Concentration profiles for various *n* values

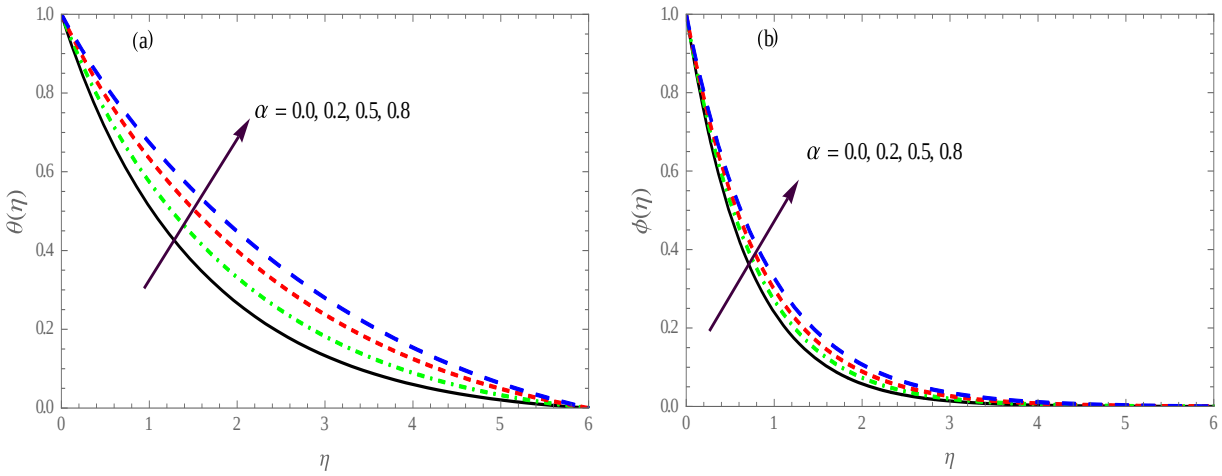
In Figure 10(a), a selection of values of R is shown to indicate a disparity of hotness. An increase in the values of *R* shows the growth in temperature profile, is noted. Melting parameters connected to micropolar fluids positively affect the fluid velocity, temperature and rotational speed of the fluids. Figure 10(b) represents the growth in concentration profiles by increasing *R* values.



(a) (b)

Fig. 10. (a) Temperature profiles for various *R* values (b) Concentration profiles for various *R* values

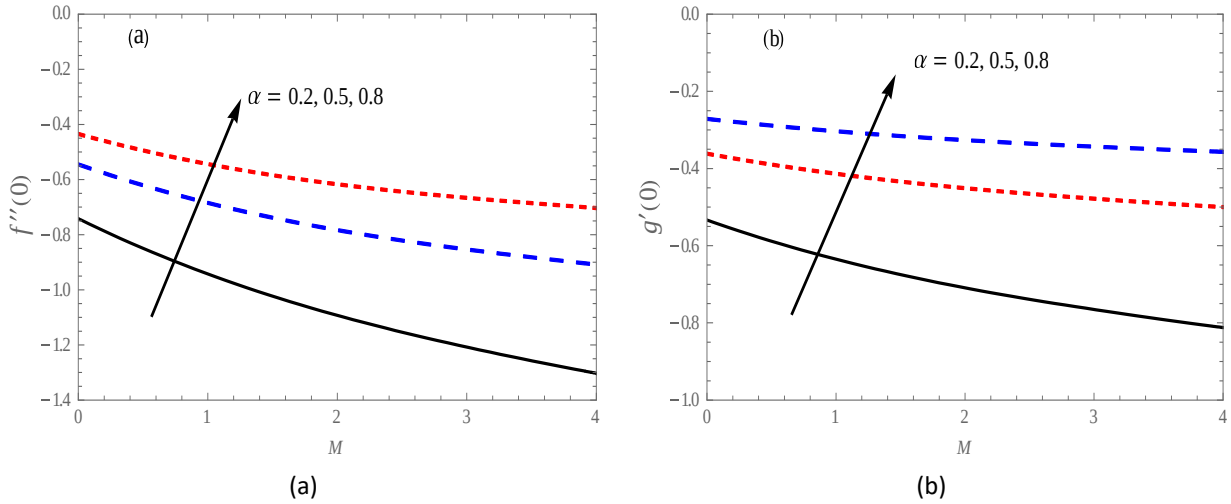
The growth in temperature and concentration with velocity slip parameter sketches is shown in Figure 11(a) and 11(b).



(a) (b)

Fig. 11. (a) Temperature profiles for various α values (b) Concentration profiles for various α values

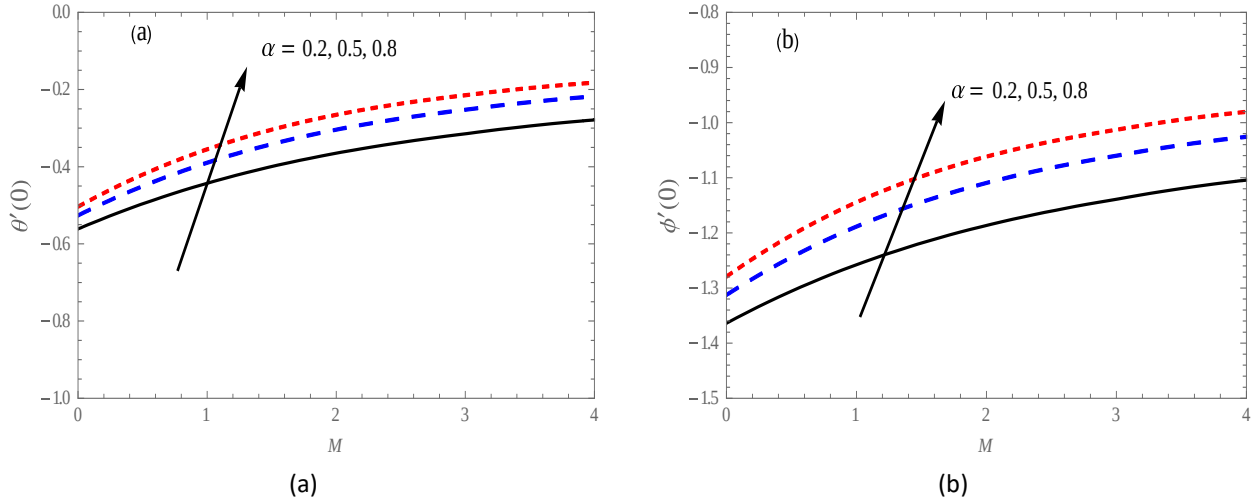
A plot of the variation of skin friction with magnetic field parameter M and melting parameter α is shown in Figure 12(a). It is observed that as melting parameter α is decreased, this decreases with an increase in α. Compressibility, surface roughness and skin friction effects are discussed as are equivalent flat plate methods to calculate component drag in laminar and turbulent flow. Figure 12(b) displays the variation of wall couple stress with Magnetic field parameter M for dissimilar melting factor values α. A frictional drag force opposes the motion of the body through the fluid due to the frictional shear stresses on its surface.



(a) (b)

Fig. 12. (a) Skin friction coefficient for various *M* values (b) Couple stress coefficient for various of *M* values

Figure 13(a) shows the variation of temperature gradient at the wall with changing magnetic field parameter M for varying melting parameter α. From this figure it is observed that Nusselt number increases as magnetic field and melting parameter α increases. Figure 13(b) shows the variation in Sherwood number for different values of magnetic field parameter and melting parameter α. It is noticed that an increasing values of M and α, the concentration gradient is also increase.



(a) (b)

Fig. 13. (a) Nusselt number for various of *M* values (b) Sherwood number for various of *M* values

Skin friction factor and rate of couple stress reduced with increasing of magnetic field parameter, but reverse behaviour observed for radiation parameter in Figure 14(a) and 14(b).

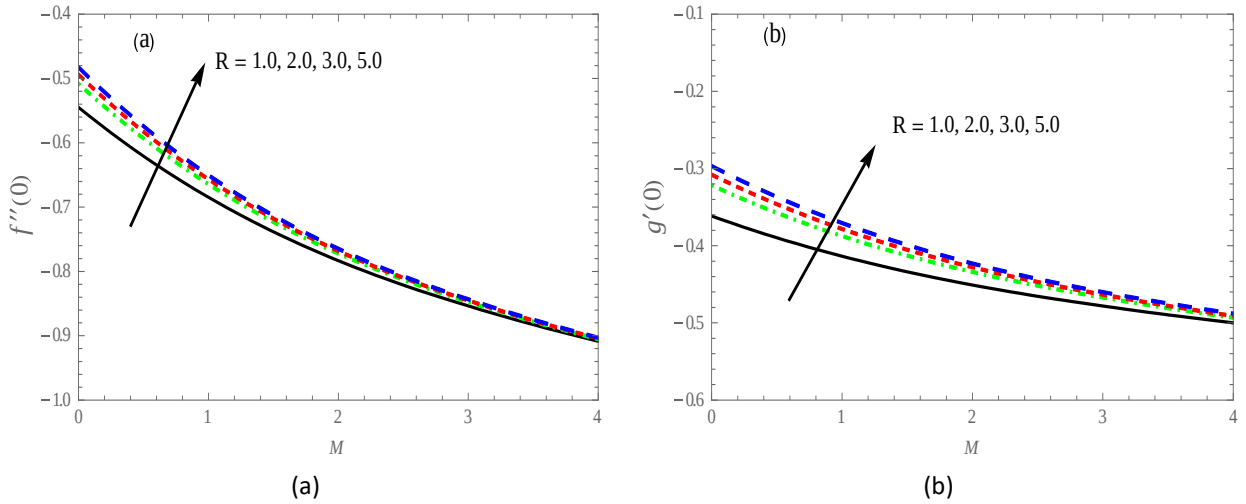


Fig. 14. (a) Skin friction coefficient for various of *M* values (b) Couple stress coefficient for various *M* values

With increasing values of *R* and *M*, the temperature gradient at the wall increases (Figure 15(a)). The concentration gradient close to the wall tends to increase as magnetic field parameter and radiation parameter increases, it is noted in Figure 15(b).

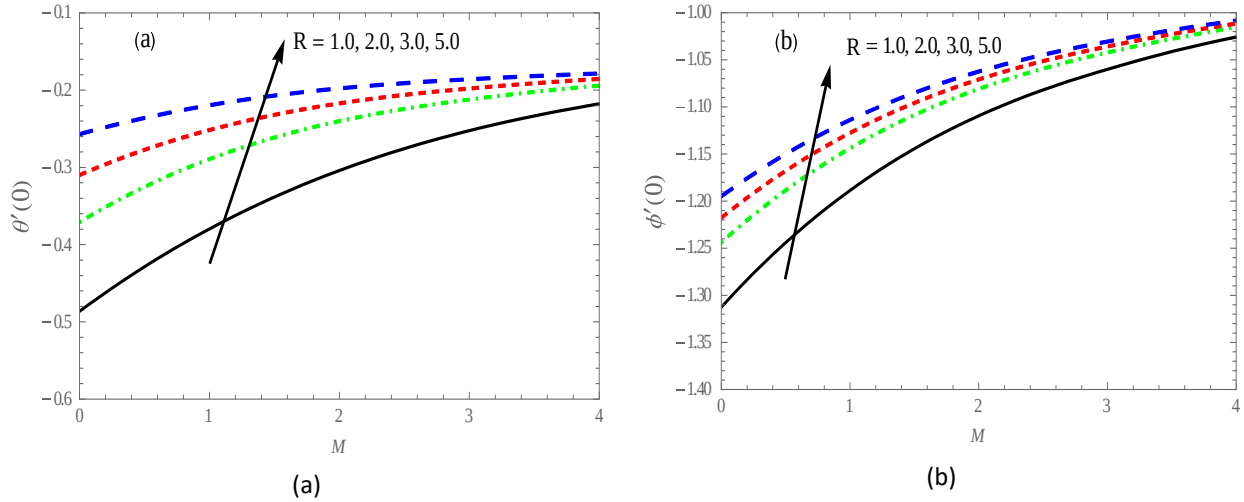


Fig. 15. (a) Nusselt number for various *M* values (b) Sherwood number for various *M* values

5. Conclusions

We have numerically analysed the combined effects of mass and melting energy transfer on the flow of an MHD micropolar fluid through a permeable porous medium. The impacts of thermal radiation, heat sink/source and chemical reactions have also been investigated under slip flow conditions. The main findings are as follows:

i. Increasing the melting parameter leads to a decrease in fluid velocity, angular velocity and temperature.
ii. Both fluid velocity and angular velocity diminish with higher slip at the boundary, while the temperature exhibits an opposite trend.

iii. An increase in the material parameter results in higher fluid velocity but lower angular velocity.
iv. Enhancing the magnetic factor causes a reduction in both velocity and angular velocity, while temperature increases.
v. Velocity is inversely proportional to both the magnetic factor and slip parameter. Microrotation (angular velocity) decreases with the slip parameter and temperature rises with increasing magnetic factor and thermal radiation but decreases with a higher Prandtl number.
vi. The surface shear stress increases with greater magnetic factor and slip parameter values.

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