Volume 22 Issue 20
Originally issued as G5



Global Journal of human-social science: G
Linguistics & Education
Volume 22 Issue 5 Version 1.0 Year 2022
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-460X & Print ISSN: 0975-587X

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By K. Veera Reddy

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GJHSS-G Classification: LCC Code: GB857.2.W2



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Several Slip Effects on MHD Flow of Casson Nanofluid Across a Porous Stretched Sheet in the Presence of Chemical Reactivity and Thermal Radiation

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I. Introduction

Microelectronics, pharmaceutical processes, Fridge, heat transfer, Boiler flue gas temperature reduction, grinding, and machining all seems to be instances of engine cooling/vehicle thermal management.

Nadeem *et al.* [1] demonstrated an oblique Casson-nano fluid flow provided boundary conditions that seem to be convective. Nazari *et al.* [2] investigated propagation of entropy models for Casson nanofluid flow caused by a stretched surface. Haq *et al.* [3] Hari investigated the consequences of heat transmission and MHD on the Casson nanofluid across a shrinking sheet. Rashad [4] studied on the influence of unstable with a convective boundary condition, nano fluid flow across a leaning stretched surface. Within the presence of slip flow, Afify *et al.* [5] over a permeable stretched sheet, the MHD boundary layer flows, the effects of Newtonian heating on scaling group transformation were studied. El-Kabeir *et al.* [6] used a Casson fluid flows in a mixed convective flow around a sphere with partial slip, chemical reaction to demonstrate heat and mass transfer. Afify [7] studied heat transmission of nanofluids over an uneven stretched surface using slip flow and heat generation/absorption. Krishna *et al.* [8] Using a stretched porous sheet, they inquired the impact of chemical reactions on Casson fluid MHD flow. Nagasantoshi *et al.* [9] Nanofluid flow across with the stretching sheet varying viscosity, non-uniform heat source was analyzed. Arundhati *et al.* [10] studied a nanofluid flow within a restricted wavy vertical channel with a flow of dual convective heat, mass transfer which is steadiness. Sivaiah *et al.* [11] in the radiation effect was explored numerically, the MHD Flow of the Boundary Layer model has been used to replicate the movement the transit of a viscoelastic and dissipative fluid thru a porous plate. About *et al.* [12] investigated the numerical assessment of natural disasters and global error estimates of convection effects on bacteria gliding over a porous non-Darcy substance on a power-law basis Slime consisting with nanoparticles. In the presence of a heat sink that is non uniform, Raju *et al.* [13] demonstrated non-Newtonian nanofluid over a cone, convective heat, mass transfer. Gayatri *et al.* [14] studied Carreau fluid over a stretched sheet, flow with viscous dissipation, Joule heating. Vijaya *et al.* [15] investigated a chemical reaction and viscous dissipation driven by a porous elongated sheet yields an electrically conducting Casson fluid flow. Choi [16] looked at using nanoparticles to produce fluids more thermally conductive. Lee *et al.* [17] Thermal conductivity were explored of the fluids using oxide nanoparticles. Many researchers [18-29] have since researched at the wall, there is a velocity fall and a temperature jump with nanofluid and viscous fluids using various geometries.

The purpose of paper is to investigate the boundary conditions on thermal, concentration slip fluid flow, velocity, and chemical reactioned in Casson, heat transfer stretching with nanoparticles on the surface because of Brownian diffusion and thermophoresis in Casson, heat transfer over a stretching. The velocity, temperature, and nanoparticle concentration fields' numerical results are presented. The friction as the heat and mass transfer rates, tabulated and assessed. The nanoparticles imbedded in Casson fluid have a number of practical applications, according to the current study, including nuclear reactors, microelectronics, and chemical production.

II. Formulation of Mathematics

Consider the MHD an inexhaustible Casson nanofluids past a porous stretching surface with a steady boundary layer. The sheet has been stretched at the linear velocity. The x-axis behaves similarly to the

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continuous stretching porous sheet, while the y-direction flows transverses. It is considered that the flow proceeds for a period of time. At the surface, temperature and concentration fixed at exact constant values, T, C are fixed values which are fixed a long way below the surface a 1st order homogeneous chemical reaction of species with a reaction rate constant, K_l, is also assumed. Fig .1 shows a flow diagram.

The rheological equation, for state a Casson fluid flow that also isotropic and incompressible is given by Ramana Reddy et al. [29]:

$$\tau_{ij} = \begin{cases} 2\left(\mu_B + \dfrac{P_y}{\sqrt{2\pi}}\right)e_{ij}, & \pi > \pi_c \\ 2\left(\mu_B + \dfrac{P}{\sqrt{2\pi_c}}\right)e_{ij}, & \pi < \pi_c \end{cases} \tag{1}$$

where μ_B is the non-Newtonian fluid plastic dynamic viscosity, P_y - the yield stress, π - the product of the component of deformation rate and itself, precisely, $\pi = e_{ij}e_{ij}$, e_{ij} = the (i,j)th component of the deformation rate, and c is a critical value of based on non-Newtonian model.

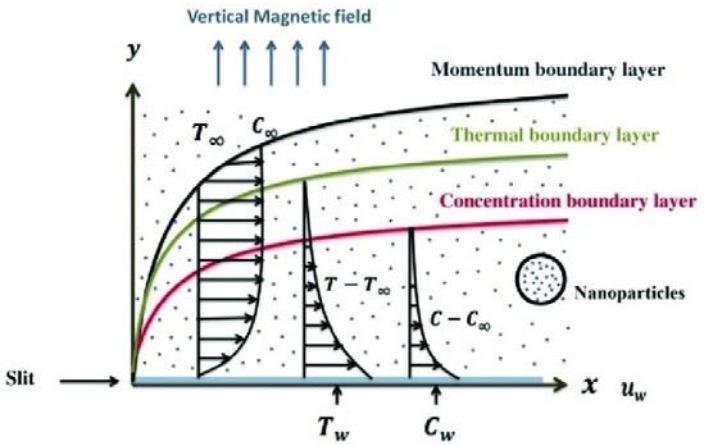


Figure 1: The Physical model and coordinate system.

The governing equations of Casson nanofluid can be expressed with boundary layer approximations:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} = \upsilon\left(1 + \frac{1}{\beta}\right)\frac{\partial^2 u}{\partial x^2} - \left(\frac{\nu}{k}u + \frac{\sigma {B_0}^2}{\rho}u\right) \tag{3}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left\{D_B\left(\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right\} + \left(1 + \frac{1}{\beta}\right)\frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2$$

$$-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{4}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} - K_l\left(C - C_\infty\right) \tag{5}$$

The boundary conditions

$$u = u_w + \left(1 + \frac{1}{\beta}\right)N\rho\nu\frac{\partial u}{\partial y},\ v = 0,\ T = T_w + K_1\frac{\partial T}{\partial y} \quad at\ y = 0$$
$$u = 0,\ T = T_\infty, C = C_\infty \quad as \quad y \to \infty \tag{6}$$

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where u and v are velocity components with the x- and y-axes respectively, ρ is the fluid density, ν is the fluid kinematic viscosity, $\alpha = \frac{k}{pCp}$ is the fluid's thermal diffusivity, $\tau = \frac{(\rho C)_p}{(\rho C)_f}$ - the ratio between the nanoparticles and the heat capacity of fluids, q_r is radiative heat flux, D_B - the Brownian diffusion coefficient, and D_T is the thermophoretic diffusion coefficient. Furthermore, N, K_1, and K_2 are velocity, thermal, and concentration slip factor. In order to simplify the radiative heat flux on the flow, we have given the preference to the application of Roseland diffusion approximation as follows:

$$q_r = -\frac{4\sigma_s^*}{3k_e^*}\frac{\partial T^4}{\partial y} \tag{7}$$

where σ_s^* = Stefen-Boltzman constant and k_e^* = the mean absorption coefficient. The study is focused to thin fluids owing to the Roseland approximation. eqn (7) can be mathematically expressed if the temperature differential within the flow is tiny indeed by extending T^4 using Taylors series about T_∞ and neglecting higher order terms, we obtain

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

In view of equations (7) and (8), equation (4) reduces to

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left\{D_B\left(\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right\} + \left(1+\frac{1}{\beta}\right)\frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2$$
$$+ \frac{16\sigma_s T_\infty^3}{3\rho c_p k_e}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

The non-dimensional variables enumerated are expressed as follows:

$$\eta = y\sqrt{b/\nu}, \quad \psi(x,y) = x\sqrt{b\nu}\, f(\eta), \quad \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty},$$
$$\varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, \; M = \frac{\sigma B_0{}^2 \nu}{\rho \nu_0{}^2}, \; K = \frac{K'\nu_0{}^2}{\nu^2}, \; R = \frac{16\sigma^* T_\infty{}^3}{3K_s} \tag{10}$$

The stream function (x, y) is provided to obey the equation continuity (2).

$$u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x} \tag{11}$$

As a function of the above modifications (3), (5), (9), are reduced to

$$\left(1+\frac{1}{\beta}\right) f''' + ff'' - f'^2 + \left(M + \frac{1}{K}\right) f' = 0 \tag{12}$$

$$\left(\frac{1+R}{\mathrm{P}_r}\right)\theta'' + \theta' f + Nb\theta'\varphi' + Nt\theta'^2 + E_c\left(1+\frac{1}{\beta}\right) f''^2 = 0 \tag{13}$$

$$\varphi'' + Le\, f\, \varphi' + \frac{Nt}{Nb}\theta'' - Le\, Kr\varphi = 0 \tag{14}$$

boundary circumstances are:

$$f(0) = 0,\; f'(0) = 1 + L_1\left(1+\frac{1}{\beta}\right) f''(0), \theta(0) = 1 + L_2\theta'(0), \varphi(0) = 1 + L_3\varphi'(0)$$
$$f'(\infty) = 0, \theta(\infty) = 0, \varphi(\infty) = 0 \tag{15}$$

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Differentiation with respect η is expressed by the term prime, f is function of similarity, θ is the temperature that has dimensionless, ϕ is the volume percentage of dimensionless nanoparticles, $P_r = \nu/\alpha$ is Prandtl number, $L_e = \nu/D_B$ is Lewis number, $\gamma = K_1\sqrt{(b/\nu)}$ is the thermal slip parameter, $\beta = \mu_B\sqrt{2\pi_c}/P_y$ is the Casson parameter, $\lambda = N\rho\sqrt{(\nu b)}$ is the slip parameter, $\delta = K_2(b/\nu)^{1/2}$ is the concentration slip parameter, $E_c = u_w^{\,2}/C_p(T_w - T_\infty)$ is the Eckert number, $Kr = K_0/b$ is the chemical reaction parameter, $Nb = (\rho C)_p D_B(C_w - C_\infty)/(\rho C)_f \nu$ is the Brownian motion parameter, and $Nt = (\rho C)_p D_T(T_w - T_\infty)/(\rho C)_f \nu T_\infty$ is the thermophoresis parameter, respectively. The quantities of physical interest in this problem are the local skin friction coefficient C_{fx}, the local Nusselt number Nu_x, and local Sherwood number Sh_x, Magnetic field parameter M, Radiation parameter R, permeability parameter K, which are defined as

$$C_{fx} = \frac{\tau_w}{\rho u_w^{\,2}},\ Nu_x = \frac{xq_w}{K(T_w - T_\infty)},\ Sh_x = \frac{xq_m}{D_B(C_w - C_\infty)} \tag{16}$$

where τ_w is the shear stress, q_w and q_m are the surface heat and mass flux which are given by the following expressions:

$$\tau_w = \left(\mu_B + \frac{P_y}{\sqrt{2\pi_c}}\right)\left(\frac{\partial u}{\partial y}\right)_{y=0},\ q_w = -K\left(\frac{\partial T}{\partial y}\right)_{y=0},\ q_m = -D_B\left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{17}$$

The dimensionless forms of skin friction, the local Nusselt number, and the local sherwood number become

$$\sqrt{\mathrm{Re}_x}\ C_f = \left(1 + \frac{1}{\beta}\right) f''(0),\ \frac{Nu_x}{\sqrt{\mathrm{Re}_x}} = -\theta'(0),\ \frac{Sh_x}{\sqrt{\mathrm{Re}_x}} = -\varphi'(0)$$

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

a) Numerical Solution

The dimensionless equations are the beginning and boundary conditions, were numerically solved using the 4th order R-K method and the shooting approach. By assigning various numerical values to the dimensionless governing parameters, the effect of dimensionalless governing variables on velocity, temperature, and concentration fields, skin friction factor, Nussult number, and shearwood number has been shown. The outcomes are reviewed and presented in the form of tables and graphs. Dimensionless governing parameters include the flow slip variable (L1), the thermal slip parameter (L2), the concentration slip parameter (L3), the magnetic (M), the Casson fluid (β)

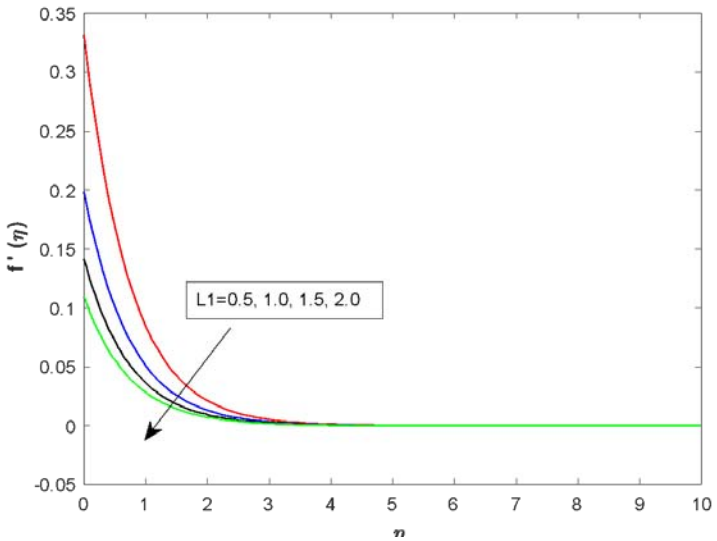


Fig. 2: Velocity profiles

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Fig.2 represents the velocity profiles for various values of flow slip parameter. It has been noticed that as the slip parameter increases, velocity decreases. Because of the slip parameter, resistance pressure is produced adjacent to the stretching porous sheet, lowering the Friction factor, heat transfer rate, and mass transfer rate are all factors to consider.

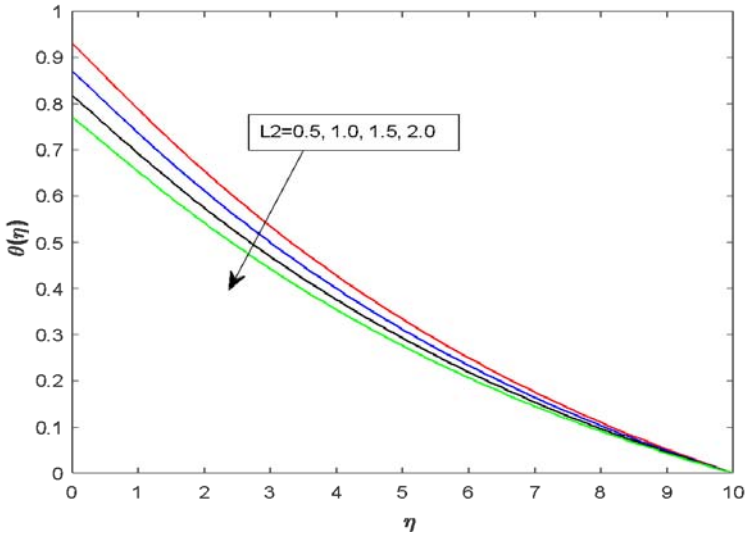


Fig. 3: Temperature plot

Fig. 3 depicts the effect of thermal slip parameter on the temperature plot. The temperature drops as the thermal slip parameter (L2) grows, as shown in the figure. As the thermal slip parameter is raised, the heat transfer rate falls.

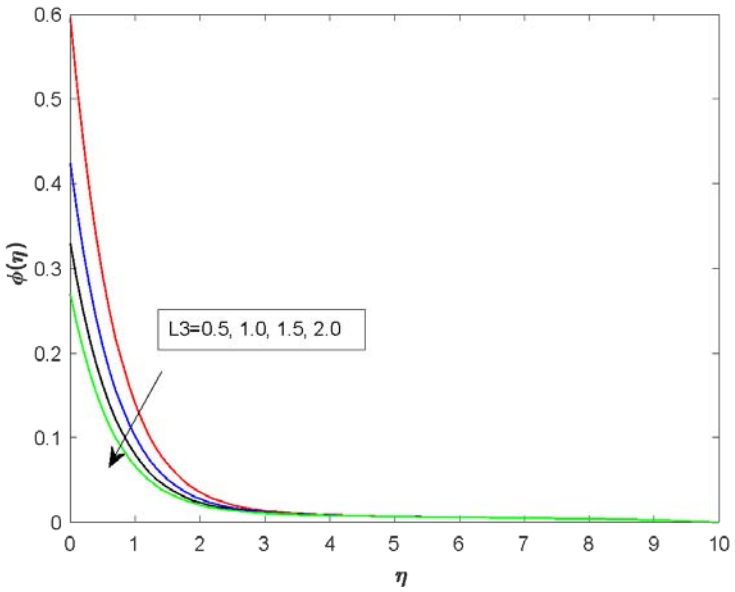


Fig. 4: Concentration profiles

The effect of concentration slip parameter (L_3) on the concentration profiles is shown in Fig.4. It is observed that the slip parameter increases, the concentration distribution decreases. The mass transfer rate reduces as a consequence.

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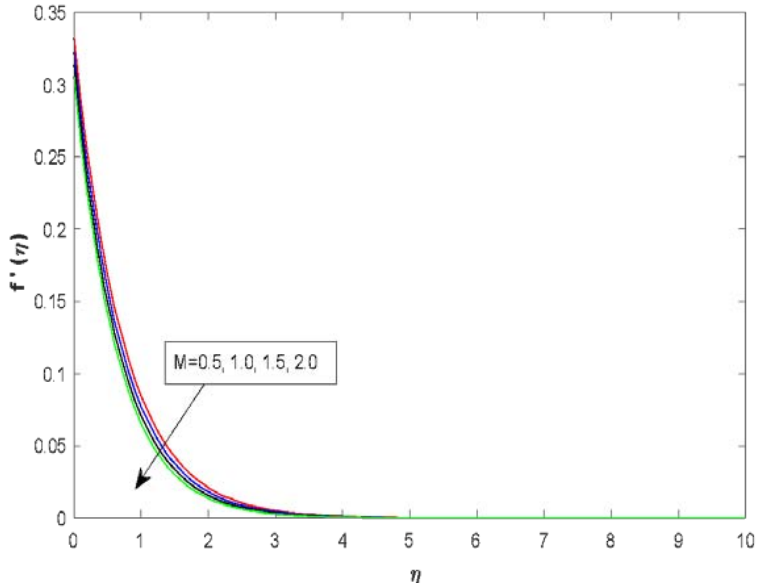


Fig. 5: Velocity profile

Fig. 5 presents the outcomes of external magnetic field (M) on the velocity profile. It should be emphasized that as M grows, the fluid velocity reduces. This is owing to the presence of a transverse magnetic field, which causes a sudden drag force (Lorenz force) opposing the Casson fluid's motion and so delays the flow velocity.

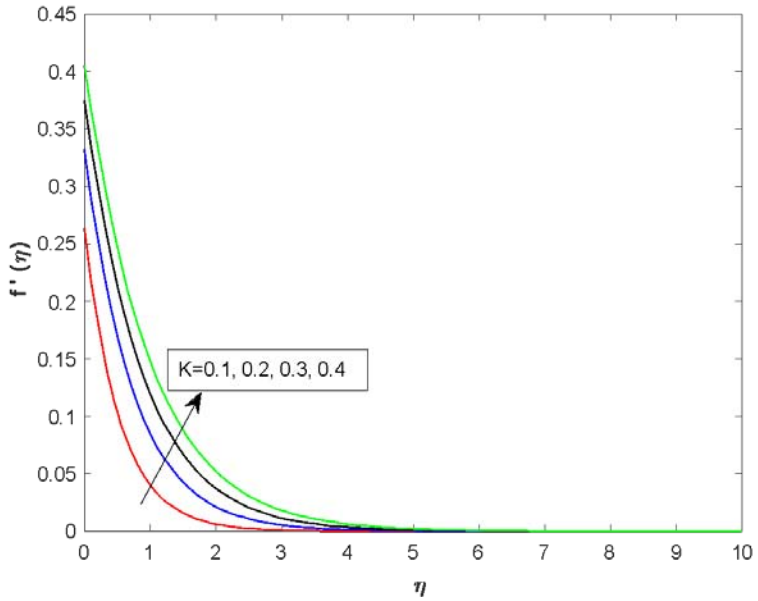


Fig. 6: Velocity profiles

The impact of the permeability plot on dimensionless velocity is shown in Fig. 6. It is worth noting that an increase in porous medium, the results of the fluid velocity increases.

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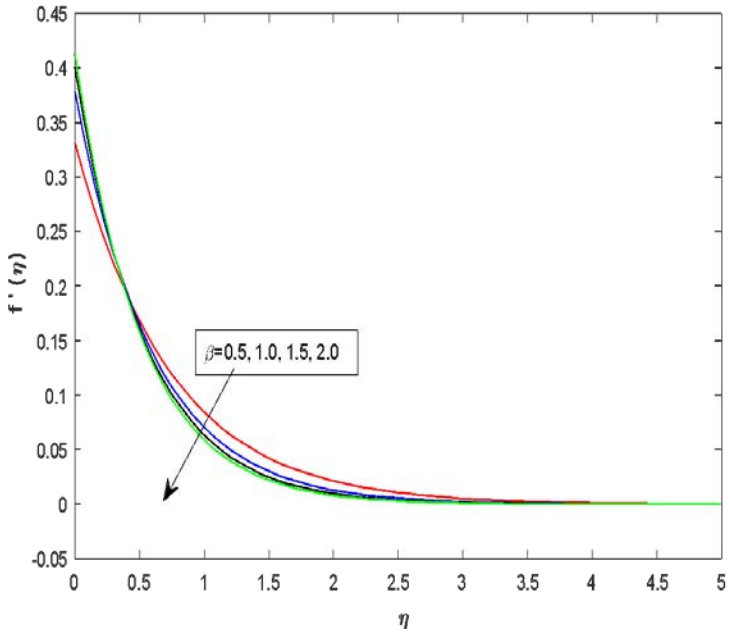


Fig. 7: Velocity profiles

The effect of Casson fluid plot on dimensionless velocity is shown in Fig. 7 and observed that the velocity decreases with an increase of Casson fluid parameter $0.5 \leq \beta \leq 3.0$. It is necessary because the lowering of the yield stress of the Casson fluid decreases. Physically, an increase in the Casson parameter to minimize the yield stress which means that plastic dynamic viscosity of the fluid is increased and that the momentum boundary layer becomes thicker.

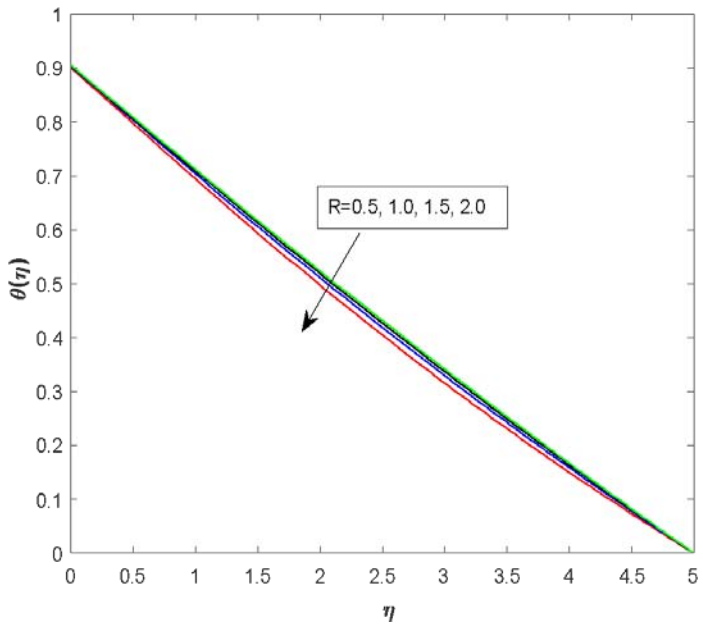


Fig. 8: Temperature profiles

Fig. 8 shows the effect of radiation parameter on the temperature profiles. When the radiation parameter is enhanced, the temperature decreases. This is owing to the thinness of the temperature boundary layer.

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Table 1: Comparison table $\left(1+\frac{1}{\beta}\right) f''(0)$, $-\theta'(0)$, $-\phi'(0)$ different values of $L1, L2, L3, \beta$

L1	L2	L3	β	$\left(1+\frac{1}{\beta}\right) f''(0)$ Afify	$\left(1+\frac{1}{\beta}\right) f''(0)$ Present	$-\theta'(0)$ Afify	$-\theta'(0)$ present	$-\phi'(0)$ Afify	$-\phi'(0)$ Present
0	0.2	0.2	0.5	-1.733100	-1.733105	0.628232	0.628235	1.324400	1.324412
1	0.2	0.2	0.5	-0.541057	-0.541053	0.587859	0.587857	1.047300	1.047350
3	0.2	0.2	0.5	-0.243961	-0.243963	0.473596	0.473590	0.972528	0.972530
0.2	0	0.2	0.5	-1.164996	-1.164999	0.763040	0.763042	1.172730	1.172735
0.2	1	0.2	0.5	-1.164996	-1.164998	0.411102	0.411108	1.241970	1.241972
0.2	3	0.2	0.5	-1.164996	-1.164998	0.208327	0.208329	1.288470	1.288476
0.2	0.2	0	0.5	-1.164996	-1.164997	0.620139	0.620142	1.639360	1.639362
0.2	0.2	1	0.5	-1.164996	-1.164998	0.707216	0.707220	0.569352	0.569354
0.2	0.2	3	0.5	-1.164996	-1.164999	0.734532	0.734538	0.246761	0.246762
0.2	0.2	0.2	0.3	-1.319520	-1.319525	0.651801	0.651808	1.188420	1.188421
0.2	0.2	0.2	4	-0.846526	-0.86530	0.655087	0.655082	1.185290	1.185292
0.2	0.2	0.2	∞	-0.776388	-0.776385	0.652042	0.652048	1.179710	1.179713

III. Conclusions

The following are the key findings of this study:

1. As the slip variable increases, the velocity reduces.
2. The temperature drops as the thermal slip plot is increased.
3. The concentration distribution shrinks as the slip parameter grows.
4. As the magnetic parameter increases, the fluid velocity decreases.
5. As the Casson fluid parameter is increased, the velocity falls.

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