Heat Transfer and Magnetohydrodynamic Casson Nanofluid Flow Over a Linear Stretching Sheet in a Porous Medium

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Abstract: ***In this paper we investigated the convective heat transfer of the flow of a Cassonnanofluid with the effects of chemical reaction and magnetic field over a porous stretching sheet. By employing appropriate transformation the nonlinear ordinary differential equations obtained from the basic governing equations. The obtained equations are solved by using Keller-Box method. Numerical results have been done good agreement with earlier published results. Cassonnanofluid can be used as a coolant because its rate of heat transfer increases as the permeability of the porous medium increases. The influence of different parameters like Casson parameter, magnetic parameter, prandtl number, porosity and chemical reaction parameter on concentration, temperature and velocity are explained in detail and depicted through graphs and also variations of mass and heat transfer rates are computed and depicted in tables. It is observed that the upsurge in values of Casson parameter drops the velocity profile but it enhances the temperature and concentration profile. Velocity ratio parameter decreases the temperature whereas, increases the concentration profile. Chemical reaction decreases the concentration profile.***

Keywords: Casson Fluid, Porosity, Magnetic Field, Chemical Reaction

1. Introduction

Nanofluid is made up of particles suspended in a base fluid at nanometer scales. Water, engine oil, and other poor heat transfer fluids with low thermal conductivity are thought to be necessary for a high heat transfer coefficient between the heat transfer medium and the heat transfer surface. The concept of nanofluid was first introduced by Choi S.U.et al [1]. The Cassonnanofluid model describes the behavior of certain types of fluids, includes few paints, and lubricants, etc. The model suitable for the fluids has a yield stress. If the yield stress is higher than the shear stress that has been applied to the fluid, it behaves like a solid. On the other hand, it acts more like a liquid if the yield stress is lower than the shear stress that has been applied. Fluids like food stuffs, polymeric liquids, slurries, artificial fibers, jelly, honey, soup, blood are considering the Cassonnanofluids. These fluids attracted consider interest by engineers and scientists for study of fluid models then deliberated its flow of boundary layer condition of several physical effects of magnetic field and chemical reaction etc. ([2], [3], [4]). Heat, mass and momentum transfer of boundary layer near linear stretching surface have received attention in recent decades due to the potential industrial applications. In specifically, chemical, manufacturing processes like polymer extrusion, metal spinning, transpiration cooling, continuous casting of metals etc.This model predicts the fluid's behavior changes from solid-like (no flow) to liquid-like (flow) abruptly at a certain shear stress, yield stress. This behavior is often observed in materials such as ketchup or toothpaste, which are thick and viscous when at rest, but can flow easily under shear stress. Overall, the Cassonnanofluid model provides a useful way to describe and understand the non-Newtonian characteristics of fluids with yield stress, is widely used in industrial applications.

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et al. [15] investigated the effect of MHD boundary layer mass and heat transfer on a chemically reacting Casson fluid passing over a permeable stretching heat sources and sinks. Mukhopadhyay et al. [16] Casson parameter was studied to see how it affected the flow of a 2-D boundary layer of Casson fluid past a nonlinearly stretching sheet. The researchers came to the conclusion that the Casson parameter decreased fluid velocity while increasing temperature. Man authors are studied the characteristics of Cassonnanofluid along a stretching sheet in the presence of chemical reaction ([17], [18]). Das and Nadeem group ([19], [20]) explained the study of hydromagneticnanofluid flow past a stretching sheet with convective boundary condition. Yazdi et al. [21] studied the electrically conducting fluid flow passes through a porous stretching sheet with chemical reaction. The chemical reactions are the process involves one or more substances are transformed into one or more different substances. Chemical reactions involve the breaking and forming of chemical bonds between its constituents. The chemical reactions are either homogeneous or heterogeneous. Chemical reaction plays a vital role, and are designed based on chemical process equipment, food process, and towers cooling.study of flow and chemical reaction became significant in recent years.. The chemical reaction effects are elaborately studies by few research groups ([22], [23], [24] and [25]). A report based on the magnetohydrodynamic effect of heat transfer over a non-linear permeable stretching surface. Yazdi, M.H. et al. [26]. It has been reported that heat can be transferred via the mixed convection even though the fluid properties change by Prasad K. V. et al. [27]. There have been reports in the scientific literature of a magnetic field effect on the nanofluid flow of stagnation point along stretching surface ([28], [29]). In the presence of nanoparticle fractions, effects of the second order velocity slip and temperature variation boundary conditions on MHD flow and heat transfer are reported by Jing Zhu group [30]. Study of the boundary layer flows with heat transfer of an incompressible fluid over an inclined stretching surface have numerous potential applications includes aeronautics and chemical engineering. These are flight magneto-hydrodynamics, MHD power generators, gas turbines, the boundary layer along a liquid film condensation process, glass and polymer industries, the extrusion of plastic sheets from a die, the cooling process of metallic plate in a cooling bath and as in the field of planetary magnetosphere, etc.

Because of the motivation provided by the literature survey that was cited earlier as well as the numerous potential technological and industrial applications, investigating how chemical reactions affect the Cassonnanofluids electrically conducting natural convection flow, which is brought on by linearly stretching a sheet through a porous medium in the presence of convective heat transfer with its boundary conditions, is crucial. The present work addresses flow of a Cassonnanofluid over a linear stretching sheet in the presence of MHD, chemical reaction and porous medium. The governing flow equations are solved numerically by means of Keller-Box method. The influence that the various flow parameters have on the flow fields is illustrated through the use of graphs and tables.

2. Formulation of the problem

Consider an incompressible Cassonnanofluid flow through a stretching sheet along the plane $y = 0$, with surface temperature and concentration are respectively T_w, C_w. By applying two forces along x-axis, which are equal and opposite due to this the sheet is stretched horizontal. The velocity of the stretching sheet is $u_w(x) = ax$ where $a > 0$ constant. The induced magnetic field was ignored because it was thought to be much smaller than the magnetic field. $u_\infty(x) = bx$, is ambient velocity (where$b > 0$ is a constant) and concentration and temperature are respectively, C_∞ and T_∞. Shear stress of incompressible flow of a Casson fluid is given by [31]

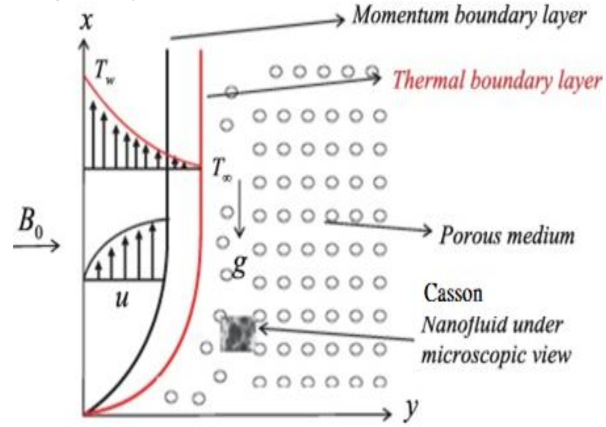

Figure a: Fluid flow model

$$\tau_{ij} = \begin{cases} 2(\mu_B + P_y/\sqrt{2\pi})e_{ij}, & \pi > \pi_\tau \\ 2(\mu_B + P_y/\sqrt{2\pi})e_{ij}, & \pi < \pi_\tau \end{cases}$$

Here $\mu_B$is the plastic dynamic viscosity of the non-Newtonian fluid, π is the product of the component of deformation rate of $(i,j)$the component $P_y$is the yield stress of fluid and $\pi = e_{ij}e_{ij}$, π_τ is the critical value ofπ based on non-Newtonian model. The flow equations [32] are given by

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\left(1 + \frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2} + U_\infty\frac{\partial U_\infty}{\partial x} - \left(\frac{\sigma B_0^2}{\rho_f}\right)(U_\infty - u) - \frac{\upsilon}{k_1}u \quad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left\{D_B\left(\frac{\partial c}{\partial y}\frac{\partial T}{\partial y}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right\} + \frac{D_m K_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2} \quad (3)$$

$$u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = D_B\frac{\partial^2 c}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} - K_0(C - C_\infty) \quad (4)$$

The boundary conditions are as follows

$$u = u_w(x) = ax \;\; at\; v = 0, \quad -k\frac{\partial T}{\partial y} = h_f(T_f - T), \quad D_B\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right) = 0 \;\; at\; y = 0$$

$$u \to U_\infty = bx \;\; at\; v = 0, \quad T \to T_\infty, C \to C_\infty, as\; y \to \infty \quad (5)$$

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Here v and u represents the velocity components towards y- and x- axis respectively, $(\rho c)_p$ and $(\rho c)_f$ are the effective heat capacity $K(x)=\frac{k_r}{a(C_w-C_\infty)}$ of the Nano particles and base fluid, $\tau=\frac{(\rho c)_p}{(\rho c)_f}$ is the ratio of the Nano particle heat capacity and base fluid heat capacity, Chemical reaction parameter with rate constant k_r. We consider that the magnetic field $B(x)=B_0(x)$, where the constant magnetic field is B_0.

With similarity transformations

Solving equations (2) to (4)

$$\eta = y\sqrt{\frac{a}{\upsilon}},\ \ \psi = xf(\eta)\sqrt{a\upsilon} \tag{6}$$

Where $\psi(x,y)$ represents the Stream function

By using the transformations (6), the governing equations (2) to (4) reduced to

$$\left(1+\frac{1}{\beta}\right)f''' + ff'' - (f')^2 + A^2 + MA - (M+\lambda)f' = 0 \tag{7}$$

$$\theta'' + Prf\theta' + PrNb\theta'\phi' + PrNt\theta'^2 = 0 \tag{8}$$

$$\phi'' + Lef\phi' + \frac{Nt}{Nb}\theta'' - KLe\phi = 0 \tag{9}$$

By using (2.6) the transformed boundary conditions are

$f(0) = 0, f'(0) = 1, \theta'(0) = B_i(\theta - 1), Nb\phi' + Nt\,\theta' = 0$ as $y \to 0$

$f' = \frac{b}{a} = A,\ \theta \to 0, \phi \to 0$ as $\eta \to \infty$ (10)

The dimensionless parameters are defined as follows Velocity Ratio Parameter $A = \frac{b}{a}$, Magnetic field $M = -\left(\frac{\sigma B_0^2}{a\rho_f}\right)$, Porosity $\lambda = \frac{\upsilon}{ak_1}$, $\beta = \frac{\mu_B\sqrt{2\pi_T}}{P_y}$ Casson Parameter, $Pr = \frac{\upsilon}{\alpha}$, Nb=Brownian number$=\frac{C_\infty \tau D_B}{\upsilon}$, Nt=Thermophoresis parameter $= \tau\frac{D_T}{T_\infty \upsilon}(T_f - T_\infty)$, $Le = \frac{\upsilon}{D_B}$, Lewis number, $K(x)=\frac{k_r}{a(C_W-C_\infty)}$ The physical parameters of the skin-friction coefficient(Cf), Nusselt number Nu_x and shear hood number Sh_x are presented as follows

$$Cf = \frac{\tau_w}{\rho u_w^2} \Rightarrow Re_x^{-\frac{1}{2}} Cf = -f'(0)$$

Where $\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)$ $at\ y = 0$,

$$Nu_x = \frac{xq_\upsilon}{\kappa(T_f - T_\infty)}\ \ Where\ q_\upsilon = -\kappa\left(\frac{\partial T}{\partial y}\right)_{y=0} \Rightarrow Re_x^{-\frac{1}{2}}Nu_x = -\theta'(0),$$

$$Sh_x = \frac{q_m x}{D_B(C_w - C_\infty)}\ where\ q_m = -D_B\left(\frac{\partial C}{\partial y}\right)_{y=0} \Rightarrow Re_x^{-\frac{1}{2}}Sh_x = -\phi'(0)$$

Where $Re_x = \frac{ax^2}{\upsilon}$ be the Reynolds number

3. Methodology

To solve the ordinary differential equations (7) – (9) with their corresponding initial and boundary conditions we develop the most effective numerical technique in line with the fourth order Keller box method technique. The symbolic software MATLAB is used to obtain the numerical solution.

The Following steps are used.

- Convert the system of ordinary differential equations into a set of equations of the first order differential equations (7)–(9)

With the substitutions

$$f' = p\ ,\ p' = q,\ \phi' = g\ ,\ \theta' = t \tag{11}$$

$$\left(1+\frac{1}{\beta}\right)q' + fg - p^2 + A^2 + MA - (\lambda + M)p = 0 \tag{12}$$

$$t' + Prft + PrNbtg + PrNtt^2 = 0 \tag{13}$$

$$Nbg' + LeNbPrfg + Nt\,t' - KLe\,\emptyset = 0 \tag{14}$$

Boundary Conditions

$$f = o, p = 1, t = B_i(\theta - 1), Nbg + Ntt = 0\ as\ \eta \to 0$$
$$p = A, t \to 0, g \to 0\ \ as\ \ \eta \to \infty \tag{15}$$

- To solve ordinary differential equations, write the difference equations using the central differences.
- Using the Newton method, linearize the algebraic equations, and then write them down in matrix form.
- Use the block tridiagonal elimination method to solve the linear system.

Substitute the above values in equations (12) - (14) and write the first order ODEs into finite differences by using $\frac{f_j - f_{j-1}}{h_j} = \frac{p_j - p_{j-1}}{2}$ transformation and linearize The difference Equations.

4. Results and Discussion

The energy, momentum and concentration equation, as well as the magnetic field, velocity ratio, permeable material and chemical reaction plays a significant role in non-Newtonian Cassonnanofluid flow model that is presented in this study. We solve the system of nonlinear ordinary differential equations Eqs. (12) - (14) together with the boundary conditions (15) that expresses that problem using the Keller Box approach. The current results have been validated against earlier literature, according to Table 1. The outcomes are discovered to be in excellent agreement with Ch. Janaiah earlier published work ([32]). Table 2. Indicates variation in Skinfriction, Nusselt number and sheawood number for various parmeter values of velocity, temperature and concentration are all affected by the velocity ratio parameter (A) are shown in Fig.(1-3). Accordingly, if $A<1$ (i.e., $b=a$) there is constant flow in the velocity (i.e., there is no thickness in the boundary layer), as values of $A>1$ and further increment values of the velocity is high, and if $A<1$ the

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boundary layer of the flow is inverted. The temperature increases as there is a upsurge in the values of A and reverse results noticed in concentration profile.

Figures (4-6) show how the Casson parameter (β) affects the velocity, concentration and temperature. The fluid flow of the nanofluid decreases away from the sheet as a result, the boundary layer becomes thinner as the Casson parameter rises. Additionally it is noted that the fluid is close to Newtonian fluid for large values of β with much lower velocity than non-Newtonian fluid. However, both temperature and nanofluid concentration increase with increasing values of β. We have been observed from in Fig. 7 that there is surge in Biot number thermal diffusion increased within the fluid causing the boundary layer to become thicker and the fluid temperature rise.

The effect of the porous medium is studied through the permeability parameter (λ). Fig . (8-9) depicts the influence of λ, it is noticed that the increment values of K generates force called an obstruction force which opposes both the boundary layer thickness and velocity. A high porosity value according to physics increases the viscous forces between the layers of nanofluid increasing the thermal distribution of the fluid and decreasing the velocity of the fluid.

The impact of Magnetic field is studied on velocity through fig. (10). physically a resistive force develops in the flow of the nanofluid when a magnetic field is present. Velocity of the fluid is slow down due to this force.

Fig . (11) Shows various values of the Brownian motion parameter (Nb) to illustrate the contrast between nanoparticle concentration and temperature. It is significant to note that the concentration distribution is markedly slowed down by the existence of a Brownian motion mechanism for nanoparticles, whereas the temperature field exhibits the opposite trend. Physically, an increase in Nb values may cause the motion of nanofluid molecules to increase, resulting in an increase in their kinetic energy and the heat they produce in the boundary layer region.

According to the definition of Thermophoresis parameter Nt Fig. (12-13) shows that a higher value of Nt represents greater shear rate and temperature gradient. As a result, the nanofluid temperature and concentration raises through the boundary layer as Nt values are increases. Fig. 14 shows that as Prandtl number $\Pr$ increases, temperature profiles decrease due to a reduction in the thickness of thermal boundary layers. Fig.15 demonstrates the influence of Lewis number (Le) on concentration profile. Ratio of species diffusivity to thermal diffusivity is denoted by the Lewis number Le. As the species diffusivity larger than thermal diffusivity the Le increase, as a result concentration profile increases.

Fig.16 reveals that as chemical reaction parameter (K) raises the conversion of the molecules increases, as a result concentration of the nanofluiddrops.

The effects of various values M and λ on skin-friction coefficientis compared with Previous results in Table 1

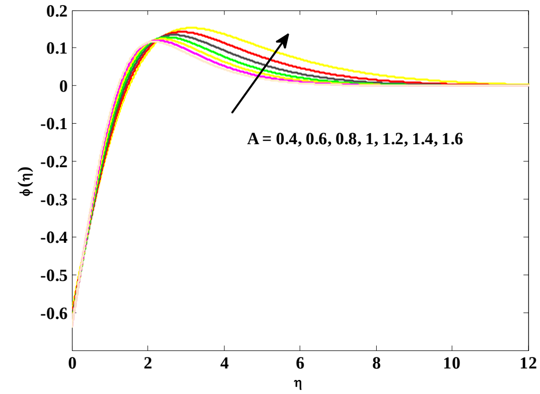

Figure 1: $A's$ impact on concentration

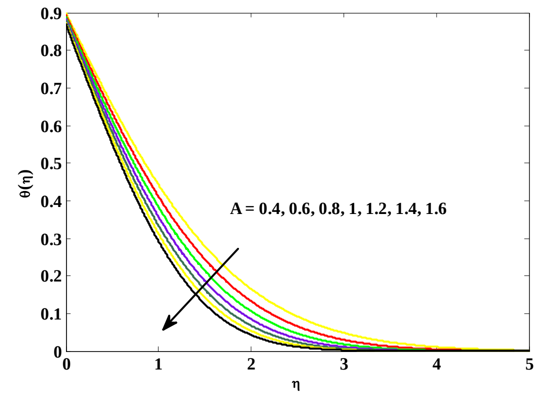

Figure 2: $A's$ impact on Temperature

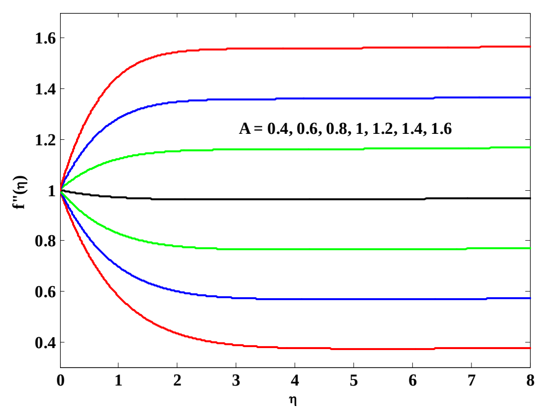

Figure 3: $A's$ impact on velocity

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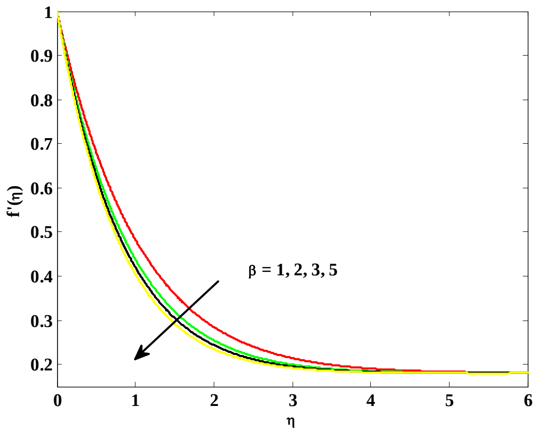

Figure 4: $\beta's$ impact on Velocity

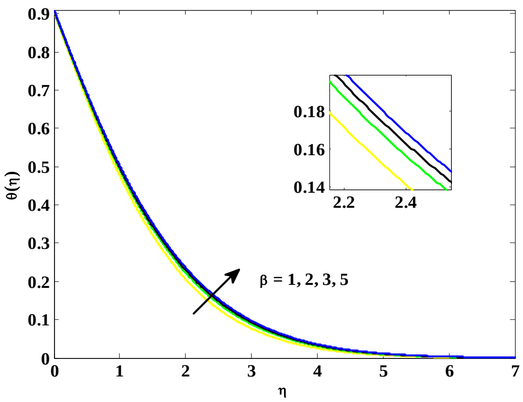

Figure 5: β's impact on Temperature

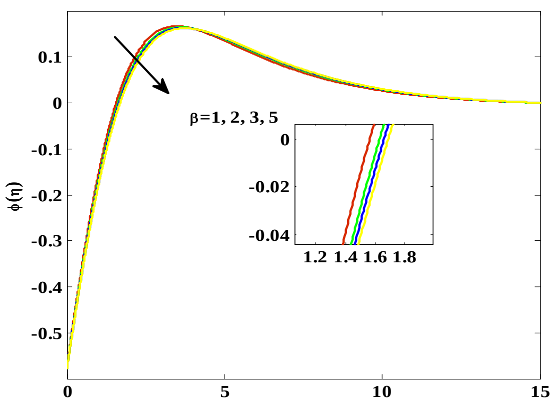

Figure 6: β's on impact on Concentration

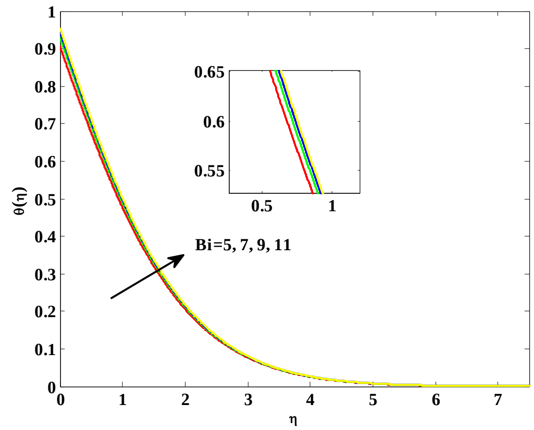

Figure 7: $Bi's$ on impact on Temperature

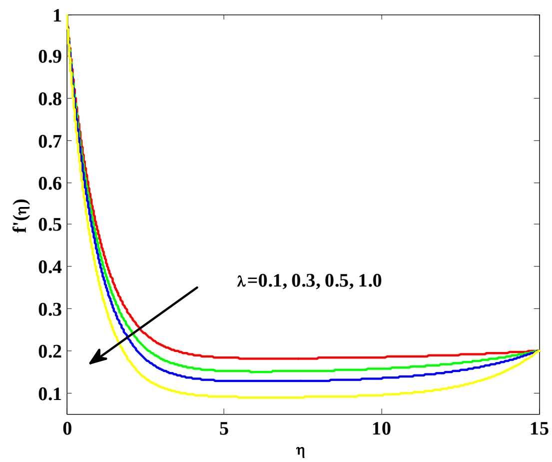

Figure 8: $\lambda's$ impact on Velocity

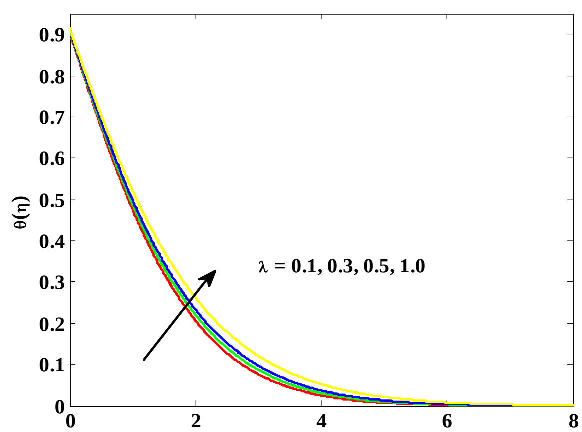

Figure 9: λ's impact on Temperature

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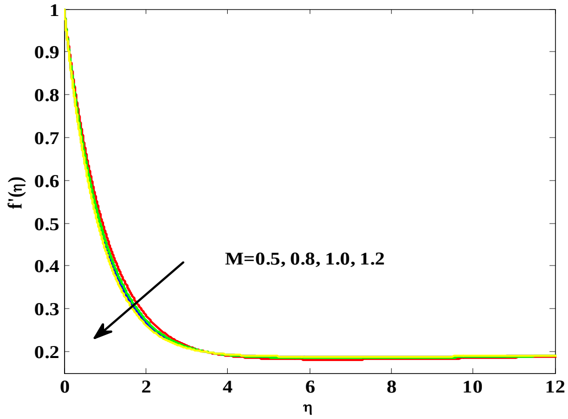

Figure 10: $M's$ impact on Velocity

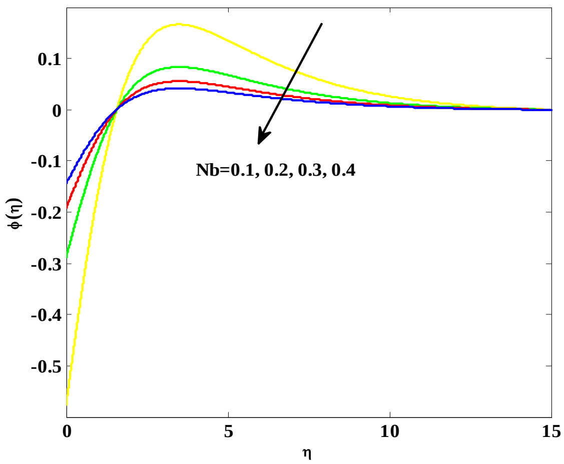

Figure 11: Nb's impact on Concentration

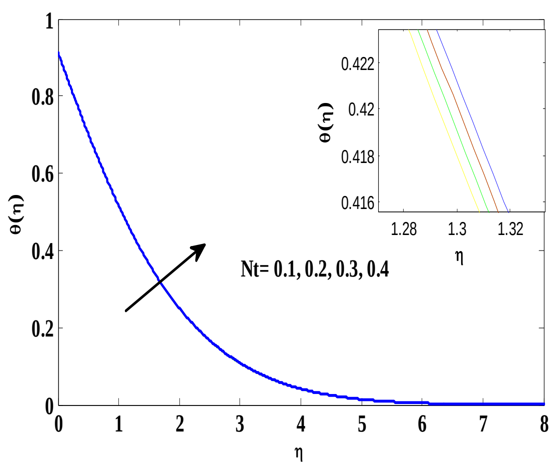

Figure 12: Nt's impact on Temperature

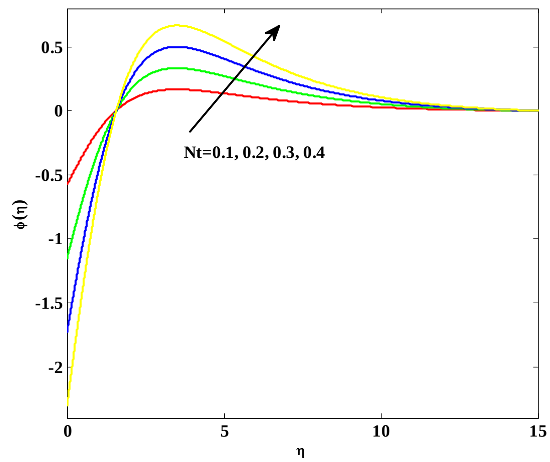

Figure 13: $Nt's$ impact on Concentration

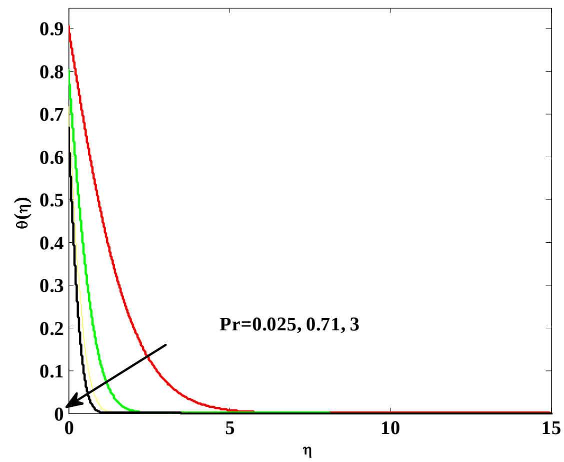

Figure 14: $Pr's$ impact on Temperature

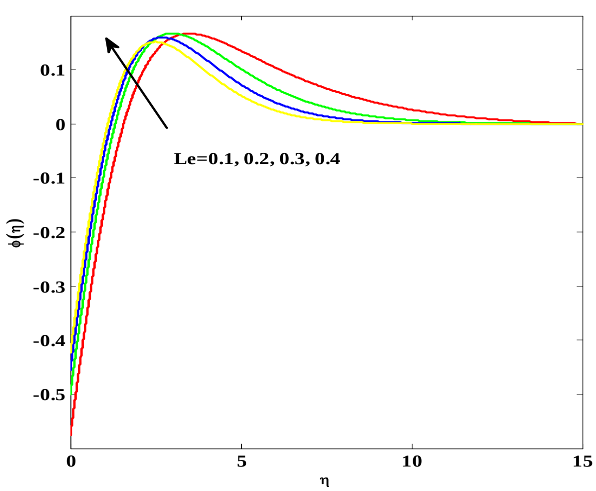

Figure 15: $Le's$ impact on Concentration

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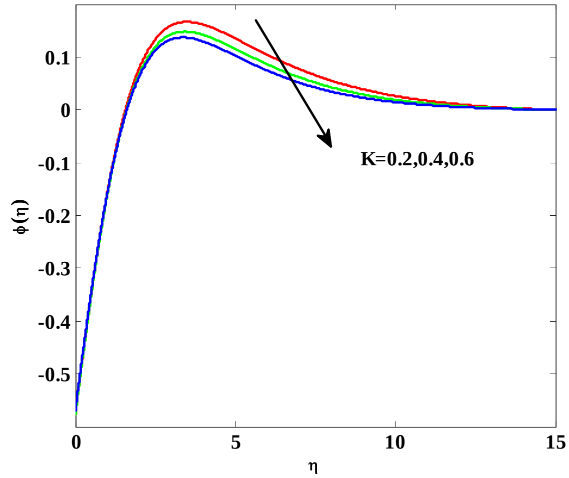

Figure 16: $K's$ impact on Concentration

Table 1: Comparison of skin-friction coefficient results [32] for different values of M, λ.

M	Previous Values	Present Values	λ	Previous Values	Present Values
0.5	1.124723	1.124723	0.0	1.076823	1.076823
0.8	1.205664	1.205664	0.3	1.214038	1.214038
1.0	1.257002	1.257002	0.5	1.296371	1.296371

Table 2: Numerical values of skin-friction coefficient, rate of heat and mass transfer coefficient for variation of $\beta, M, A, \lambda, Pr, Nt, Nb, Le, Bi, K$ λ, Cf, Nu_x, Sh_x.

β	M	A	λ	Pr	Nt	Nb	Le	Bi	K	$-Cf$	$-Nu_x$	Sh_x
1										0.795247	0.472085	0.472085
2										0.918306	0.457845	0.457845
3										0.974021	0.451858	0.451858
	0.5									0.795247	0.472085	0.472085
	0.8									0.852519	0.466250	0.466250
	1.0									0.888828	0.462647	0.462647
		0.2								0.795247	0.472085	0.472085
		0.4								0.655965	0.504183	0.504183
		0.6								0.482588	0.533762	0.533762
			0.1							0.795247	0.472085	0.472085
			0.3							0.858389	0.461200	0.461200
			0.5							0.916629	0.451293	0.451293
				0.71						0.795247	0.472085	0.472085
				3.0						0.795247	0.978283	0.978283
				7.0						0.795247	1.398627	1.398627
					0.1					0.795247	0.472085	0.472085
					0.2					0.795247	0.471200	0.942400
					0.3					0.795247	0.476314	1.410942
						0.1				0.795247	0.472085	0.472085
						0.2				0.795247	0.472085	0.236042
						0.3				0.795247	0.472085	0.157362
							0.1			0.795247	0.472085	0.472085
							0.2			0.795247	0.471430	0.471430
							0.3			0.795247	0.470890	0.470890
								5.0		0.795247	0.472085	0.472085
								7.0		0.795247	0.492720	0.492720
								9.0		0.795247	0.497664	0.497664
									0.2	0.795247	0.472085	0.472085
									0.4	0.795247	0.471885	0.471885
									0.6	0.795247	0.471695	0.471695

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5. Conclusions

In the present paper mainly concentrated on the influence of Casson parameter, porous medium, and velocity ratio and convective heating parameters on steady of incompressible nanofluid flow through a linear stretching sheet. Using Keller - box numerical technique technique, the flow governing equations are solved. The numerical outcomes for the concentration, temperature and velocity profiles for the various parameters are plotted graphically and thoroughly discussed. The primary conclusions of these investigations are

- The velocity profiles are declines by the increasing Casson parameter whereas the temperature is upsurges.
- Increasing values of the Prandtl number it is noticed that results a decrease in temperature profiles.
- For increasing Casson parameter and permeablity parameter values the magnitude of the skin friction parameter increases while the rates of heat and mass transfer decrease.
- Higher values of Le cause concentration profile to upsurges, while chemical reaction parameter causes it to diminish.

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