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MHD Boundary Layer Nanofluid flow of Heat Transfer over a Nonlinear Stretching Sheet Presence of Thermal Radiation and Partial Slip with Suction

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Abstract

This paper presents numerical method of solution to steady two-dimensional hydromagnetic flow of a viscous incompressible, electrically conducting fluid over a nonlinear stretching sheet with slip effect and Chemical radiate parameters. The basic partial differential equations are reduced to ordinary differential equations which are solved numerically using Keller-Box Method. This study reveals that the governing parameters, namely, the Chemical Reaction, the radiation parameters and Velocity Slip have major effects on the flow field, Velocity, Temperature, Concentration, skin friction coefficient, the heat transfer rate and mass transfer rate. Comparison between the obtained results and previous works are well in agreement.

Keywords: Heat transfer, Nanofluid, Chemical Reaction, Thermal Radiation, Velocity Slip B.C.

1. INTRODUCTION

The flow over a stretching surface is an important role in many engineering processes with applications in industries such as extrusion, melt-spinning, the hot rolling, wire drawing, glass fiber production, manufacture of plastic and rubber sheets, cooling of a large metallic plate in a bath, which may be an electrolyte, etc. Sakiadis [1] analyzed boundary-layer behavior on continuous solid surface. Hayat [2] conducted convection flow over a non-linearly stretching sheet of a micro polar fluid using Homotopy analysis method. Cortell [3] was investigated similarity solutions for flow and heat transfer of a quiescent fluid over a non-linearly stretching surface. Vajravelu[4] studied flow and heat transfer in a viscous fluid over a nonlinear stretching sheet without viscous dissipation. The study of magnetic field effects has important applications in physics, chemistry and engineering. Industrial equipment, such as magneto hydrodynamic (MHD) generators, pumps, bearings and boundary layer control are affected by the interaction between the electrically conducting fluid and a magnetic field. The work of many investigators has been studied in relation to these applications. Prasad et al. [5] analyzed the fluid properties on the MHD flow and heat transfer over a stretching surface by using Keller-box method.

The nano particles can be found in metals such as (Cu, Ag), oxides (Al2O3), carbides (SiC), nitrides (AlN, SiN) or nonmetals (graphite, carbon nanotubes). Nanofluids have novel properties that make them potentially useful in many applications in heat transfer including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines. Nanoparticles provide a bridge between bulk materials and molecular structure. The nanofluid term was first used by Choi[6]. Boundary layer flow of a nanofluid over a non-linearly stretching sheet with boundary conditions of convective was investigated by Makinde and Aziz[7]. Sheikholeslami et.al [8] investigated Effect of electric field on hydrothermal behavior of nanofluid in a complex geometry. Hamad [9] investigated the magnetic field effects on free convection flow of past a vertical semi-infinite flat plate of a nanofluid. Sheikholeslamiand Rashidi [10] ,Sheikholeslami and Ganji [11] investigates on nanofluids and heat transfer effects of magnetic fields. Boundary layer stagnation-point flow toward a stretching/shrinking sheet in a nanofluid was studied by Bachoket.al[12].

Chemical reactions are classified as either homogeneous or heterogeneous. Combined heat and mass transfer problems with chemical reactions are important in many processes of interest in Engineering and have received significant attention in recent years. These processes include drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler. The diffusion of species with chemical reaction in the boundary layer flow has enormous applications in pollution studies, fibrous insulation, oxidation and synthesis materials for instance. Awang [13] investigated the series solution of flow over a nonlinearly stretching sheet with the chemical reaction and magnetic field. Chemical reaction and uniform heat generation effects on stagnation point flow of a nanofluid on MHD over a porous sheet was investigated by Imran Anwar et al [14].

The radiation heat transfer is very important for its uses in different engineering areas such as gas cooled nuclear reactors, nuclear power plants, hypersonic fights, gas turbines and space vehicles etc. Zhang et al. [15] studied the effects chemical reaction and thermal radiation on nanofluids of heat transfer through the porous medium. Several authors are examined the combination of chemical reaction and thermal radiation on nanofluids of heat transfer over a stretching sheet. Ramya et.al[16] invstigated on influence of Chemical Reaction on MHD boundary Layer Flow of nanofluids over a nonlinear stretching Sheet with Thermal Radiation.

M.H. Yazdi et.al [17]were studied by Slip MHD liquid flow and heat transfer over non-linear permeable stretching surface with chemical reaction using the Dormand–Prince pair and shooting method. S. Das et.al [18] was investigated on MHD Boundary Layer Slip Flow and Heat Transfer of Nano fluid Past a Vertical Stretching Sheet with heat generation/absorption. Ramya et.al[19] studied Boundary layer Viscous Flow of Nanofluids and Heat Transfer Over a Nonlinearly Isothermal Stretching Sheet in the Presence of Heat Generation/Absorption and Slip Boundary Conditions.

In view of above mentioned applications and development of research in nanofluids, our main aim to study in the present work we have MHD Boundary layer flow of nanofluids over a nonlinear stretching sheet the presence of thermal radiation, chemical reaction, velocity slip and suction/injection. The governing boundary layer equations are transformed to nonlinear ordinary differential equations using similarity transformation which are then solved numerically. The influence of non-dimensional governing parameters on the flow field and heat transfer characteristics are discussed and presented through graphs and tables.

2. FORMULATION OF THE PROBLEM:

Consider a two dimensional, incompressible viscous and steady fluid flow of a water-based nanofluid flow past a nonlinear stretching surface. The sheet is extended with velocity $u_W = ax^n$ with fixed origin location, where n is a nonlinear stretching parameter, a is a constant, and x is the coordinate measured along with the stretching surface. The nanofluid flows at $y \geq 0$, where y is the coordinate normal to the surface. The fluid is electrical conducting due to an applied magnetic field $B(x)$ normal to the stretching sheet. The magnetic Reynolds number is assumed small and so, the induced magnetic field can be considered negligible. The wall temperature T_W and the nano particle fraction C_W are assumed constant at the stretching surface. When y tends to infinity, the ambient values of temperature and nano particle fraction are denoted by T_∞ and C_∞, respectively. The governing equations of momentum, thermal energy and nanoparticles equations (Mabood et al. [21])can be written as

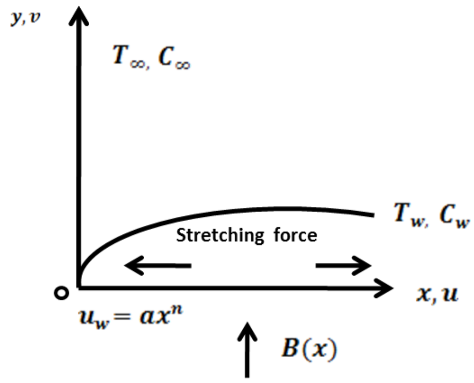

Fig.1. Physical model and coordinate system

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2(x)}{\rho_f}u \ , \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\tau\left\{D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\times(\frac{\partial T}{\partial y})^2\right\}-\frac{1}{(\rho c p)_f}\frac{\partial q_r}{\partial y}+\frac{\upsilon}{c_p}(\frac{\partial u}{\partial y})^2, \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\left(\frac{D_T}{T_\infty}\right)\frac{\partial^2 T}{\partial y^2}-K_r(C-C_\infty) \tag{4}$$

The boundary conditions (Mabood et al.[14]) are given by

$$y=0: \quad u=u_W+K_1\frac{\partial u}{\partial y}, \ v=0, \ T=T_W, C=C_W$$

$$y=\infty: \quad u=0, \quad v=0, \quad T=T_\infty, C=C_\infty \tag{5}$$

$\alpha=\dfrac{K}{(\rho c)_f}$ is the thermal diffusivity. $\tau=\dfrac{(\rho c)_p}{(\rho c)_f}$ is the ratio between the effective heat capacity of the nanoparticle material and the heat capacity of the ordinary fluid. Where $u_W=ax^n$, K_1 is the velocity slip parameter, V_w is the variable velocity components in vertical direction at the stretching surface in which $V_w<0$ represents to the suction cases and $V_w>0$ represents to the injection ones.We assume that the variable magnetic field $B(x)=B_0 x^{n-1/2}$, where B_0 is constant.

Using Rosseland approximation for radiation, we can write

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

where k^* is the absorption coefficient, σ^* is the Stefan-Boltzman constant, Assuming the temperature difference within the flow is such that T^4 may be expanded in a Taylor series about$T_\infty$and neglecting higher orders we get $T^4 \approx 4T_\infty^3 T - 3T_\infty^4$.

Hence Eq. (7), becomes

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3(\rho_{cp})_f k^*}\frac{\partial^2 T}{\partial y^2} \tag{7}$$

The dimensionless variable can be taken as

$$\eta = y\sqrt{\frac{a(n+1)}{2\upsilon}}x^{\frac{n-1}{2}},\ u = ax^n f'(\eta),\ \ v = -\sqrt{\frac{a\upsilon(n+1)}{2}}x^{\frac{n-1}{2}}\left(f(\eta) + \frac{n-1}{n+1}\eta f'(\eta)\right),$$

$$\theta(\eta) = \frac{T-T_\infty}{T_W-T_\infty},\ \phi(\eta) = \frac{C-C_\infty}{C_W-C_\infty} \tag{8}$$

Where ψ represent the stream function and is defined as $u = \frac{\partial\psi}{\partial y}, v = -\frac{\partial\psi}{\partial x}$.

Substituting Eq. (8) into Eqs. (1) - (4), we obtain the ordinary differential equations as follows:

$$f''' + ff'' - \frac{2n}{n+1}f'^2 - Mf' = 0 \tag{9}$$

$$\frac{1}{Pr}(1 + \frac{4}{3}R)\theta'' + f\theta' + Nb\phi'\theta' + Nt\theta'^2 + Ecf''^2 = 0 \tag{10}$$

$$\phi'' + \mathrm{Le}\, f\phi' + \frac{\mathrm{Nt}}{\mathrm{Nb}}\theta'' - \gamma Le\phi = 0 \tag{11}$$

The transformed boundary conditions

$$f(0) = S, f'(0) = 1 + \lambda f''(0), \theta(0) = 1,\ \ \phi(0) = 1,$$

$$f'(\infty) = 0,\ \ \theta(\infty) = 0,\ \ \phi(\infty) = 0 \tag{12}$$

Where the prime denotes differentiation with respect to η.

$$M = \frac{2\sigma B_0^2}{a\rho_f(n+1)},\ Pr = \frac{\upsilon}{\alpha},\ Ec = \frac{u_W^2}{c_p(T_W-T_\infty)},\ Nb = \frac{(\rho c)_p D_B(C_W-C_\infty)}{(\rho c)_f \upsilon},\ Le = \frac{\upsilon}{D_B},$$

$$Nt = \frac{(\rho c)_p D_T(T_W-T_\infty)}{(\rho c)_f T_\infty \upsilon}, \gamma = \frac{2k_1}{a(n+1)(C_W-C_\infty)}x^{(n-1)/2}, \lambda = K_1\sqrt{\frac{a\upsilon(n+1)}{2}}x^{n-\frac{1}{2}},$$

$$S = -V_W\sqrt{\frac{a\upsilon(n+1)}{2}}x^{n-1/2} \tag{13}$$

Here $M, Pr, Ec, Nb, Le, Nt, \gamma, \lambda, R$ and S are denote the Magnetic parameter, Prandtl number, Eckert number , the Brownian motion parameter, the Lewis number, the thermophoresis parameter, Chemical reaction parameter, Velocity slip parameter, Thermal radiation and Suction parameter parameters respectively.

The special interests and importance of the present problem of nano fluid, in this study, the local skin-friction, Nusselt number and Sherwood number are defined as

$$C_{fx} = \frac{\mu_f}{\rho u_w^2}\left[\frac{\partial u}{\partial y}\right]_{y=0}, \quad Nu_x = \frac{x q_w}{k(T_w - T_\infty)}, \quad Sh_x = \frac{x q_m}{D_B(C_w - C_\infty)} \tag{14}$$

Where k is the thermal conductivity of the nano fluid and q_w, q_m are the heat and mass fluxes at the surface, given by

$$q_w = -\left[\frac{\partial T}{\partial y}\right]_{y=0}, \quad q_m = -D_B\left[\frac{\partial C}{\partial y}\right]_{y=0} \tag{15}$$

Substituting Eq. (6) into Eqs. (15)-(16), we obtain

$$\mathrm{Re}_x^{1/2}\, Cf_x = \sqrt{\frac{n+1}{2}} f''(0), \quad \mathrm{Re}_x^{-1/2}\, Nu_x = -\sqrt{\frac{n+1}{2}}\theta'(0), \quad \mathrm{Re}_x^{1/2}\, Sh_x = -\sqrt{\frac{n+1}{2}}\phi'(0) \tag{16}$$

Where $\mathrm{Re}_x = u_w x / \nu$ is the local Reynolds number.

3. RESULTS AND DISCUSSION

As Eqs.(9)-(11) are nonlinear, it is impossible to get the closed form solutions. Consequently, the equations with the boundary conditions (12) are solved numerically by means of a finite-difference scheme known as the Keller-box method. In this section we present a comprehensive numerical parametric study is conducted and the results are reported graphically and in tabular form. Numerical simulations were carried out to obtain approximate numerical values of the quantities of engineering interest. The quantities are the skin-friction $f''(0)$, heat transfer rate $\theta'(0)$ and mass transfer rate $\phi'(0)$.

Table-1: Comparison of Skin- friction coefficient, Nusselt and Sherwood numbers for various values of *Ec* and *M* when $Pr = 6.2$, $Le = 5$, $Nb = Nt = 0.1$ $n = 2$, $R = 0$ and $\gamma = 0$

Ec	**M**	**Mabood et.al**			**Present work**		
		$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.0	0	1.10102	1.06719	1.07719	1.10142	1.06713	1.07684
0.1			0.88199	1.22345		0.88888	1.22329
0.2			0.70998	1.37078		0.70941	1.37081
0.3			0.52953	1.51919		0.52869	1.51941
0.5			0.16484	1.81933		0.16344	1.81995
0.0	0.5	1.30989	1.04365	1.01090	1.30991	1.04365	1.01090
0.1			0.81055	1.20605		0.81053	1.20603
0.2			0.57564	1.40279		0.57562	1.40279
0.3			0.33889	1.60115		0.33883	1.60116
0.5			0.14022	2.00282		0.14033	2.00287

Table-2: Calculation of Skin- friction coefficient, Nusselt and Sherwood numbers for various values of *R and* γ *when* $Pr = 6.2$, $Le = 5$, $Nb = Nt = 0.1$ $n = 2$, $S = 0.1 = \lambda$

R	γ	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.0	0.1	1.30991	0.7954	1.2528
0.5			0.7338	1.2623
0.9			0.6739	1.2824
1.0			0.6739	1.2876
0.1	0.2	1.30991	0.6588	1.3323
	0.5		0.6566	1.3323
	0.7		0.6536	1.5377
	0.9		0.6510	1.6491

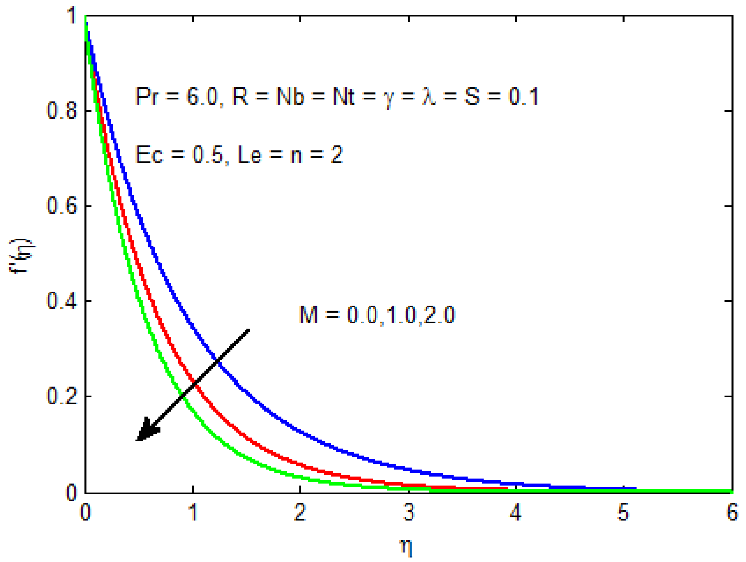

Fig 2: Effect of Magnetic parameter (M) on Velocity profile.

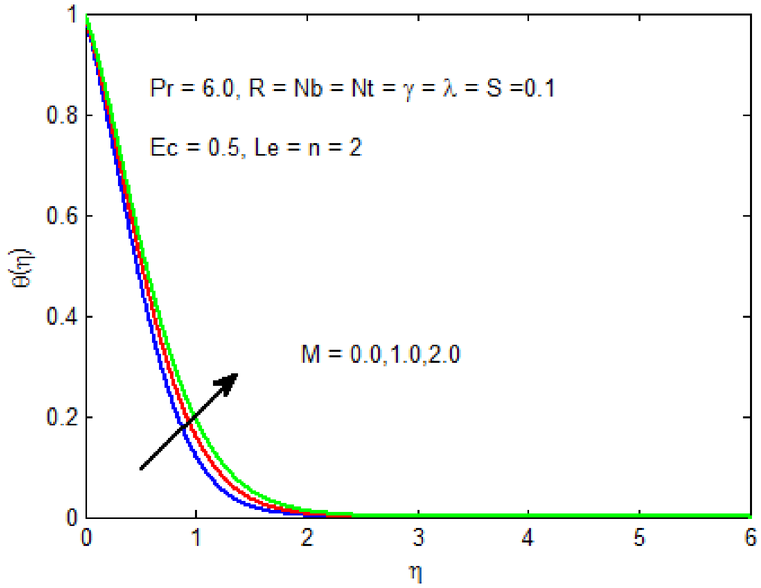

Fig 3: Effect of Magnetic parameter (M) on Temperature profile.

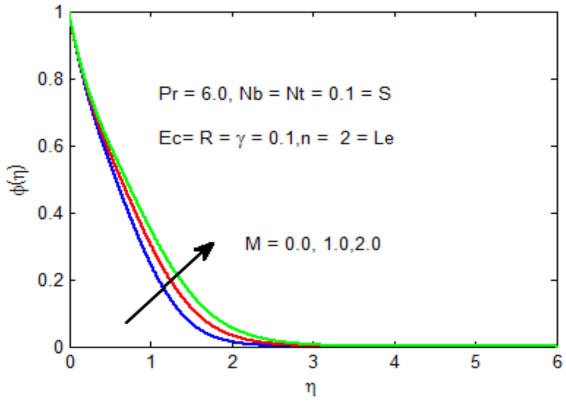

Fig 4: Effect of Magnetic parameter (M) on Concentration profile.

Fig.2 displays the effect of magnetic field *(M)* on the velocity profile. It is observed that the velocity reduces with the increase of magnetic parameter. This is due to the fact that magnetic field introduces a retarding body force which acts transverse to the direction of the applied magnetic field. This body force, known as the Lorentz force, decelerates the boundary layer flow and thickens the momentum boundary layer, and hence induces an increase in the absolute value of the velocity gradient at the surface.Fig.3 and 4 displays the effect of magnetic field *(M)* on temperature and concentration profiles. From these figures we observed that both the temperature and the concentration profiles demonstrated an increasing behavior for increasing values of M. In an electrically conducting fluid if magnetic field is applied a resistive force like a drag force is produced, which is called Lorentz force. The nature of Lorentz force retards the force on the velocity field and therefore the magnetic field effects decelerate the velocity profiles. The Lorentz force has the tendency to slow down the fluid motion and the resistance offered to the flow. Therefore, it is possible for the increase in the temperature; hence the thermal boundary layer thickness increases.

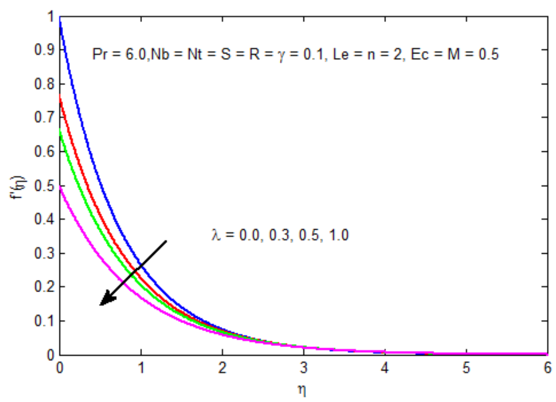

Fig 5: Effect of slip parameter (λ) on Velocity profile.

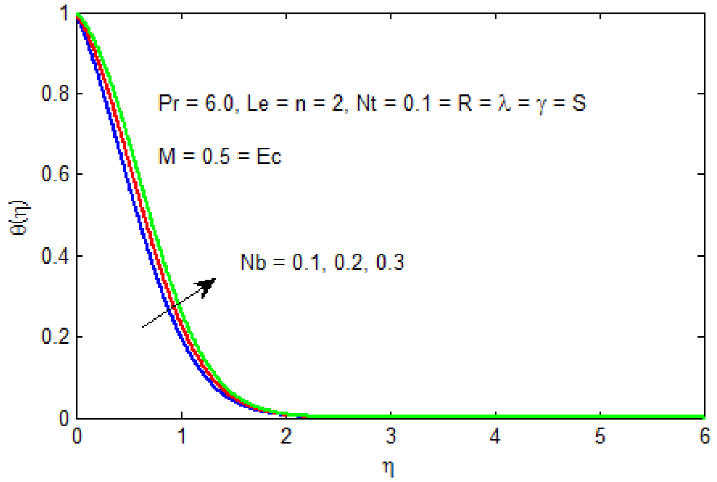

Fig.6. Effect of Brownian motion parameter (Nb) on temperature profile.

Fig.5 displays the effect of slip parameter on velocity profile.The velocity curves show that the rate of transport decreases with the increasing distance of the sheet. In all cases the velocity vanishes at some large distance from the sheet .With the increasing λ, the horizontal velocity is found to decrease.When slip occurs, the flow velocity near the sheet is no longer equal to the stretching velocity of the sheet.With the increase in, such slip velocity increases and consequently fluid velocity decreases because under the slip condition, the pulling of the stretching sheet can be only partly transmitted to the fluid. Fig 6 illustrates the effects of Brownian motion parameter Nb on temperature profile. When Nb increases, random motion of nanoparticles increases. Therefore collision of particles increases and kinetic energy converted to heat energy. Hence temperature profile increases for an increase in Nb.Figs.7 and 8 present typical profiles for temperature and concentration for various values of thermophoretic parameter (Nt). It is observed that an increase in the thermophoretic parameter (Nt) leads to increase in both fluid temperature and nanoparticle concentration. Thermophoresis serves to warm the boundary layer for low values of Prandtlnumber (Pr) and Lewis number (Le). So, we can interpret that the rate of heat transfer and mass transfer decrease with increase in Nt.

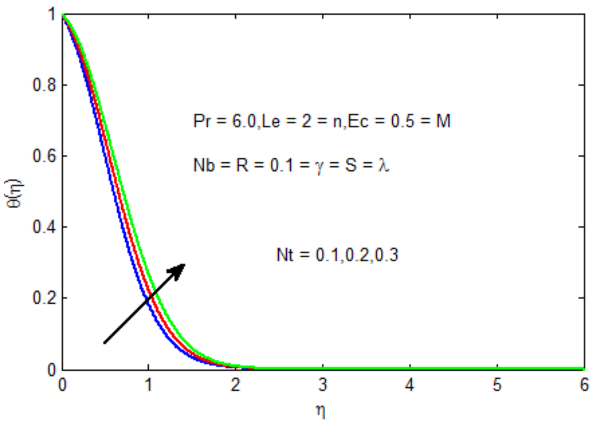

Fig.7. Effect of Thermophoresis parameter (Nt) on temperature profile.

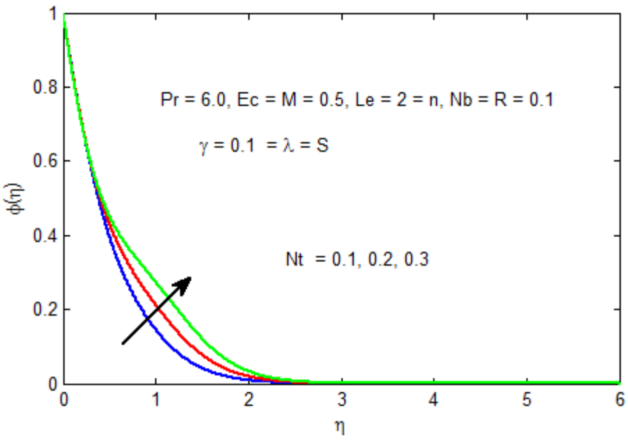

Fig.8. Effect of Thermophoresis parameter (Nt) on Concentration profile.

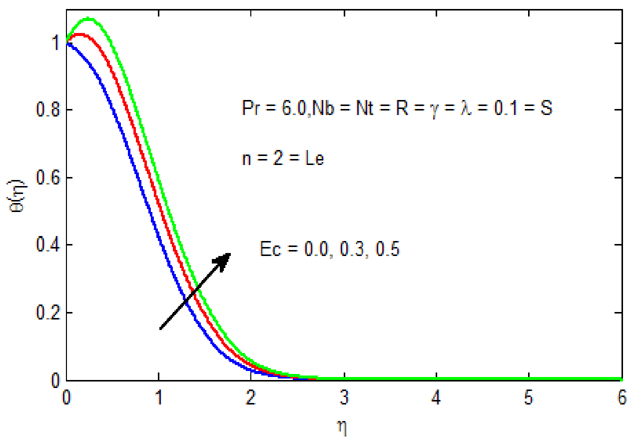

Fig.9. Effect of Viscous dissipation parameter (Ec) on temperature profile.

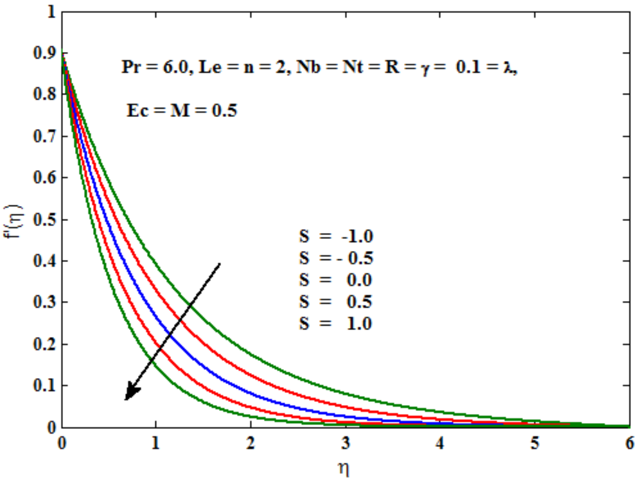

Fig.10. Effect of Suction parameter (S) on velocity profile.

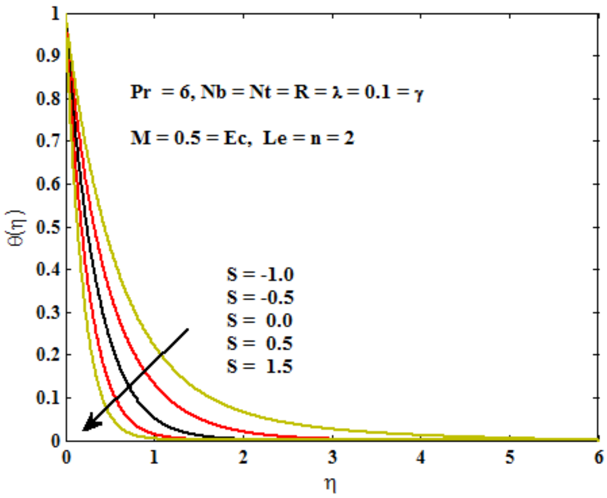

Fig.11. Effect of Suction parameter (S) on temperature profile.

Fig 9 shows that the effect of viscous dissipation (E*c*) on temperature profile.it is seen that the temperature gradient increases initially with an increase in the Eckert number. Fig.10 shows that the effect of Suction blowing parameter S on velocity profile in presence of slip boundary conditions for non-linear stretching sheet. It is observed that the increasing suction parameter S, where as fluid velocity is found to be increase with blowing in fig.10. It is found that, when the wall suction($S > 0$) is considered, this causes a decrease in the boundary layer thickness and the dimensionless velocity field is reduced. *S* = 0 represents the case of non-porous stretching sheet. From Fig. 11, it is seen that temperature decreases with increasing suction parameter whereas it increases due to blowing. Temperature wave-off is noted for suction blowing (*S*< 0). This feature prevails up to certain heights and then the process is decelerates and at a far distance from the wall temperature vanishes.

4. CONCLUSIONS

The boundary layer viscous flow and heat transfer of a nanofluid over a nonlinearly stretching sheet with the effect of velocity slip, thermal radiation and chemical reaction have been studied numerically. The influence of the governing parameters: magnetic parameter M, velocity slip parameter λ, Eckert number Ec, Brownian motion parameter Nb, thermophoresis parameter Nt on the velocity, temperature& concentration profiles. It is observed that the present results are equalized with the previous work done by Mabood et.al[20]. The results are as follows:

1. When the magnetic parameter M increases, then it reduces the velocity profile, and enhances the temperature and concentration profiles due to the effect of Lorentz force.
2. When the magnetic parameter M and the velocity slip parameter are increased individually, then the velocity profile decreases while the temperature and concentration profiles increase.
3. As the value of Ec increases, the temperature profile increases.
4. By increasing the Browinian motion parameter Nb, the temperature increases.
5. By increasing the values of the thermophoresis Parameter Nt, the temperature and concentration increase. This is due to the fact that thermophoretic is produced by the temperature gradient. In this case the fluid is more heated and passes away from the stretching sheet.

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