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Unsteady Heat Transfer Flow of Nanofluid over a Permeable Shrinking Sheet with Viscous Dissipation and Convective Boundary Condition

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ABSTRACT:- *Forced convection in unsteady magneto hydrodynamic boundary layer flow of nanofluid over a permeable shrinking sheet in the presence of viscous dissipation and convective boundary condition is studied. The nanofluid model includes Brownian motion and thermophoresis effects. Similarity transformations are employed to transform the governing partial differential equations into ordinary differential equations. The transformed equations are then solved numerically by Bvp4cMatlab solver. The flow features and heat and mass transfer characteristics for different values of the governing parameters viz.thermophorosis parameter, Brownian motion parameter, Prandtl number, unsteadiness parameter, wall mass suction parameter, Biot number, Lewis number and Eckert numberare analyzed and discussed in detail.*

Keywords:- *nanofluid, Convective Heat Transfer, viscous dissipation, wall mass suction.*

I. INTRODUCTION

The heat transfer phenomenon in boundary layer flow over a stretching/shrinking sheet is very important for its day by day increasing industrial applications. The quality of final industrial products strongly depends on the heat transfer characteristics. The flow due to a linearly stretching plate was first studied by Crane [1]. Bhattacharyya et al. [2] investigated the heat transfer in boundary layer flow of Maxwell fluid over a porous shrinking sheet with wall mass transfer and concluded that the viscous boundary layer thickness decreases with Deborah number.

The boundary layer flow of an electrically conducting fluid in the presence of magnetic field has wide applications in many engineering problems such as MHD generator, plasma studies, nuclear reactors, geothermal energy extraction, and oil exploration. Vajravelu et al. [3] studied the MHD flow and heat transfer of an Ostwald-de Waele fluid over an unsteady stretching surface. Gorla and Kumari [4] investigated the mixed convection in an axisymmetric flow of a non-Newtonian nanofluid on a vertical cylinder. BasiriParsa et al. [5] studied the laminar magnetohydrodynamic boundary-layer flow past a stretching surface with uniform free stream and internal heat generation or absorption in an electrically conducting fluid. Gorla and Khan [6] studied the natural convection past a vertical cylinder in a porous medium saturated with a nanofluid and concluded that as Nr, Nb, and Nt increase, the friction factor and heat transfer rate (Nusselt number) decrease and also the mass transfer rate (Sherwood number) increases with Le, Nb, and Nt.Hua and Su [7] investigated the unsteady magnetohydrodynamic (MHD) boundary layer flow and heat transfer on a permeable stretching sheet embedded in a moving incompressible viscous fluid. Salem et al.[8] investigated the unsteady boundary layer stagnation point flow of heat and mass transfer in a nanofluid with magnetic field and thermal radiation. Sameh et al. [9] discussed the magnetohydrodynamic mixed convection boundary-layer stagnation point flow of a nanofluid towards a stretching surface in the presence of both nanoparticles and gyrotactic microorganisms. Turkyilmazoglu [10] investigated the heat and mass transfer characteristics of the magnetohydrodynamicnanofluids flow over a permeable stretching/shrinking surface with thermal slip condition. Sheikholeslami et al. [11] discussed the nanofluid flow and heat transfer characteristics between two horizontal parallel plates in a rotating system. Nadeem and Haq [12] studied the magnetohydrodynamics (MHD) three dimensional flow past a porous shrinking sheet in the presence of thermal radiation. Nadeem et al. [13] investigated the MHD boundary layer flow of a Maxwell fluid past a stretching sheet in the presence of nanoparticles. Ali et al. [14] studied the unsteady flow and heat transfer past an axisymmetric permeable shrinking sheet with radiation effect. Nandy et al. [15] studied the unsteady MHD boundary-layer flow and heat transfer of nanofluid over a permeable shrinking sheet in the presence of thermal radiation. Gopi Chand and Jat [16] investigated the unsteady two-dimensional laminar flow of a viscous incompressible electrically conducting fluid past over a horizontal stretching sheet in the presence of uniform transverse magnetic field in the porous medium.Gangadhar and Bhaskar Reddy [17] investigated thelaminar free convection boundary layer flow of a continuously moving vertical porous plate in a chemically reactive and porous medium in the presence of a transverse magnetic field and concluded that the momentum boundary layer thickness decreases, while both thermal and concentration boundary layer thicknesses increase with an increase in the magnetic field intensity.Suneetha and Gangadhar [18] analyzed the effect of thermal radiation on a two-dimensional stagnation-point flow of an in-compressible magneto-hydrodynamic Carreau fluid toward a shrinking surface in the presence of convective boundary condition.

Dissipation is the process of converting mechanical energy of downward-flowing water into thermal and acoustical energy. Gangadhar [19] investigated the natural convection over a moving vertical plate with internal heat generation and viscous dissipation.Bharathi Devi and Gangadhar [20] studied theFlakner-Skan boundary layer flow over a stationary Wedge with momentum and thermal slip boundary conditions and the temperature dependent thermal conductivity in the presence of porous medium and viscous dissipation.

However, the interactions of forced convection in unsteady magnetohydrodynamic boundary layer flow of nanofluid over a permeable shrinking sheet in the presence of viscous dissipation and convective boundary condition is considered. The governing boundary layer equations have been transformed to a two-point boundary value problem in similarity variables and the resultant problem is solved numerically using bvp4c MATLAB solver. The effects of various governing parameters on the fluid velocity, temperature, concentration, the rate of heat and mass transfer are shown in figures and analyzed in detail.

II. MATHEMATICAL FORMULATION

Consider unsteady two-dimensional convective laminar boundary-layer flow of incompressible electrically conducting viscous nanofluid past a permeable shrinking sheet. Schematic diagram of the physical problem is shown in figure A.

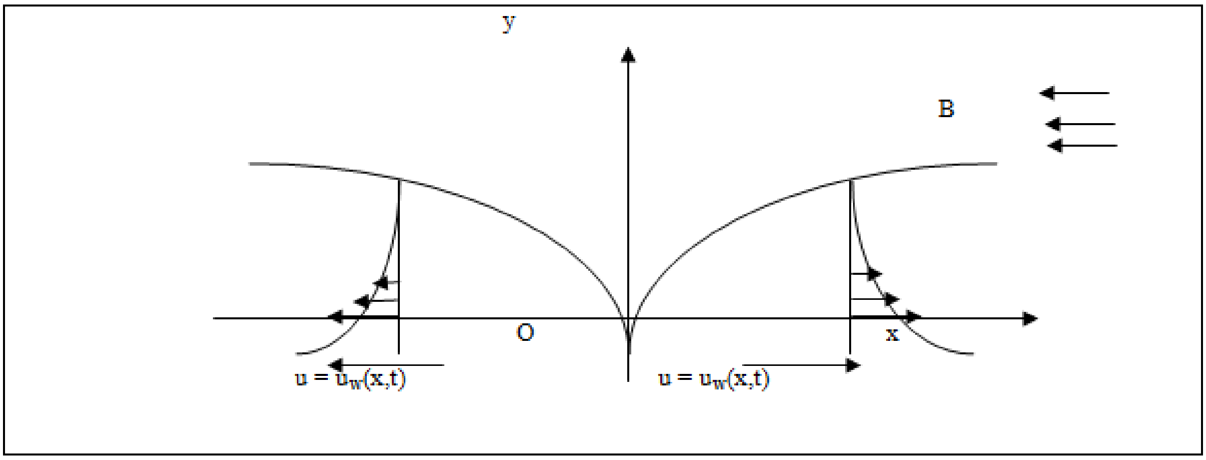


Fig. A: Schematic diagram of the physical problem.

The flow is subjected to a transverse magnetic field of strength *B* which is assumed to be applied in the positive y-direction, normal to the surface. It is assumed that the velocity of the shrinking sheet is $u_w(x,t)$ and the velocity of the mass transfer is $v_w(x,t)$, where x is the coordinate measured along the shrinking sheet and t is the time. It is also assumed that the constant surface temperature and concentration of the sheet are T_w and C_w, while the uniform temperature and concentration far from the sheet are T_∞ and C_∞, respectively.

The governing equations of motion, the energy and mass equation may be written in usual notation as
Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (2.1)$$

Momentum equation

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2}{\rho_f}u \qquad (2.2)$$

Energy equation

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_m\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho_f c_p}\frac{\partial q_r}{\partial y}+\tau\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]+\frac{\upsilon}{\rho_f c_p}\left(\frac{\partial u}{\partial y}\right)^2 \qquad (2.3)$$

Spices equation

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \qquad (2.4)$$

The boundary conditions are

$$u=u_w(x,t)=-\frac{cx}{1-\lambda t},v=v_w(x,t),k\frac{\partial T}{\partial y}=-h_f(T_w-T),C=C_w \text{ at } y=0$$
$$u\to 0,T\to T_\infty,C\to C_\infty \text{ as } y\to\infty \qquad (2.5)$$

where u and v are the velocity components in the x and y-directions respectively, υ is the kinematic viscosity, σ is the electrical conductivity (assumed constant), ρ_f is the density of the base fluid, am is the thermal diffusivity, D_B is the Brownian diffusion coefficient, D_T is the thermophoresis diffusion coefficient and c_p is the specific heat at constant pressure. Here τ is the ratio of the effective heat capacity of the nanoparticle material and the heat capacity of the ordinary fluid, T is the fluid temperature and C is the nanoparticle volume fraction.
The wall mass transfer velocity then becomes

$$v_w(x,t)=-\sqrt{\frac{c\upsilon}{1-\lambda t}}S \qquad (2.6)$$

where S is the constant wall mass transfer parameter with S> 0 for suction and S< 0 for injection, respectively. To attain the similarity solutions of the Eqs. (2.1)–(2.4) with the boundary conditions (2.5), we take the transverse unsteady magnetic field strength applied to the sheet is of the form

$$B=\frac{B_0}{\sqrt{1-\lambda t}} \qquad (2.7)$$

where B_0 is constant. This form of $B_0(t)$ has also been considered by Vajravelu et al. [3] while analyzing the MHD flow and heat transfer over an unsteady stretching sheet.

where the stream function ψ is defined in the usual way $u=\frac{\partial\psi}{\partial y}$ and $v=-\frac{\partial\psi}{\partial x}$.

The stream function and dimensionless variable can be taken as

$$\psi=\sqrt{\frac{c\upsilon}{1-\lambda t}}xf(x),\eta=y\sqrt{\frac{c}{\upsilon(1-\lambda t)}},\theta=\frac{T-T_\infty}{T_w-T_\infty},\phi=\frac{C-C_\infty}{C_w-C_\infty}$$
$$M=\frac{\sigma B_0^2}{\rho_f c},A=\frac{\lambda}{c},\Pr=\frac{\upsilon}{\alpha_m},\upsilon=\frac{\mu}{\rho_f},Nb=\frac{\tau D_B(C_w-C_\infty)}{\upsilon} \qquad (2.8)$$
$$Nt=\frac{\tau D_T(T_w-T_\infty)}{T_\infty\upsilon},Le=\frac{\upsilon}{D_B},Ec=\frac{u_w^2}{c_p(T_w-T_\infty)},Bi=\frac{h_f}{k}\sqrt{\frac{\upsilon(1-\lambda t)}{c}}$$

where $f(\eta)$ is the dimensionless stream function, $\theta(\eta)$ is the dimensionless temperature, $\phi(\eta)$ is the dimensionless concentration, η is the similarity variable, M is the magnetic parameter, A is the unsteadiness

parameter, Pr is the Prandtl number, Nb is the Brownian motion parameter, Nt is the thermophoresis parameter, Le is the Lewis number, Ec is the Eckert number and Bi is the Biot number.
Substituting (2.8) into Eqs. (2.1)–(2.4), we obtain the following ordinary differential equations

$$f'''+ff''-f'^2-A\left(f'+\frac{\eta}{2}f''\right)-Mf'=0 \quad (2.9)$$

$$\frac{1}{\Pr}\theta''+f\theta'-A\frac{\eta}{2}\theta'+Nb\theta'\phi'+Nt\theta'^2+Ecf''^2=0 \quad (2.10)$$

$$\phi''+Le\left(f-A\frac{\eta}{2}\right)\phi'+\frac{Nt}{Nb}\theta''=0 \quad (2.11)$$

The transformed boundary conditions can be written as

$$f(0)=S,\ f'(0)=-1,\theta'(0)=-Bi\left[1-\theta(0)\right],\phi(0)=1$$
$$f'\to 0,\theta\to 0,\phi\to 0 \text{ as } \eta\to\infty \quad (2.12)$$

where primes denote differentiation with respect to η

The physical quantities of interest are the wall skin friction coefficient C_{fx}, the local Nusselt number Nu_x and the local Shearwood number Sh_x which are defined as

$$C_{fx}=\frac{\tau_w}{\rho_f u_w^2},Nu_x=\frac{xq_w}{k\left(T_w-T_\infty\right)},Sh_x=\frac{xq_m}{D_B\left(C_w-C_\infty\right)} \quad (2.13)$$

where τ_{xy} is the shear stress at the stretching sheet, q_w and q_m is the heat and mass flux, respectively.

Thus, we get the wall skin friction coefficient C_{fx}, the local Nusselt number $Nu_x$and the local Shear wood number Sh_xas follows:

$$\mathrm{Re}_x^{1/2}C_f=f''(0)$$
$$\mathrm{Re}_x^{\frac{-1}{2}}Nu_x=-\theta'(0) \quad (2.14)$$
$$\mathrm{Re}_x^{\frac{-1}{2}}Sh_x=-\phi'(0)$$

Where $\mathrm{Re}_x=\frac{u_w(x,t)x}{\upsilon}$ is the local Reynolds number based on the stretching velocity $u_w\left(x,t\right)$.

III. SOLUTION OF THE PROBLEM

The above Eqs. (2.9) - (2.11) along with the boundary conditions are solved by converting them to an initial value problem. We set

$$f'=z,z'=p,p'=z^2+A\left(z+\frac{\eta}{2}p\right)+Mz-fp$$
$$\theta'=q$$
$$q'=\Pr\left(A\frac{\eta}{2}q-fq-Nbqr-Ntq^2-Ecp^2\right) \quad (3.1)$$
$$\phi'=r$$
$$r'=-Le\left(f-A\frac{\eta}{2}\right)-\frac{Nt}{Nb}q'$$

with the boundary conditions

$$f(0)=S,z(0)=-1,q(0)=-Bi(1-\theta(0)),\phi(0)=1$$

In order to integrate (3.1) as an initial value problem, one requires a value for p(0), that is, $f''(0)$ and q(0), that is, $\theta'(0)$, and r(0), that is, $\phi'(0)$ but no such values are given at the boundary. The suitable guess values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ are chosen and then integration is carried out. Comparing the calculated values for f',θ and ϕ at $\eta=10$= 10 (say) with the given boundary conditions $f'(10)=0,\theta(10)=0$ and

$\phi(10)=0$ and adjusting the estimated values, $f''(0), \theta'(0)$ and $\phi'(0)$, we apply the fourth order classical Runge–Kutta method with step-size h =0.01. The above procedure is repeated until we get the converged results within a tolerance limit of 10^{-6}.

IV. RESULTS AND DISCUSSION

The abovementioned numerical scheme is carried out for various values of physical parameters, namely, magnetic parameter (M),unsteadiness parameter (A), the Brownian motion parameter (Nb), the thermophoresis parameter (Nt), the Prandtl number (Pr), the Lewis number (Le), Biot number (Bi_1), suction parameter (S)and the Eckert number (Ec) to obtain the effects of those parameters on dimensionless velocity, temperature and concentration distributions. The obtained computational results are presented graphically in Figures 1-11.

The velocity, temperature and concentration distributions for suction parameter S are shown in Figs 1(a) -1(c). It is observed that the velocity, temperature and concentration decreases with raising the values of S.This results in a reduction in the momentum, thermal and concentration boundary layers thickness. Figs 2(a)-2(c) demonstrates the impact of the unsteadiness parameter A on the velocity, temperature and concentration distributions. It is noticed that the velocity of the fluid decreases whereas temperature and concentration of the fluid increases with the influence of unsteadiness.Figs. 3(a)-3(c) presents the changes in the velocity, temperature and concentration profiles with the effect of magnetic parameter M. The velocity profilesdecreasewith the raising of magnetic parameter M. This is due to magnetic field opposing the transport phenomena, since the variation of magnetic parameter Mcauses the variation of Lorentz forces. The Lorentz force is a drag like force that produces more resistance to transport phenomena and that causes reduction in the fluid velocity. The effect of magnetic field is more in shear-thinning fluids than shear thickening fluids. The effect of magnetic fields increases the temperature and concentration profiles.

Fig 4(a) and 4(b) shows that the effect of thermophoresis parameter Nt on temperature and concentration, respectively. It is observed that the temperature and concentration of the fluid increases with raising the values of Nt.Fig 5(a) and 5(b) shows that the effect of Brownian motion parameter Nb on temperature and concentration, respectively. It is observed that the temperature of the fluid increases whereas concentration of the fluid increases with raising the values of Nb.

The effect of Biot number Bi on temperature and concentration is shown in figs 6(a) and 6(b), respectively. It is observed that increases the fluid temperature and concentration effectively with increases Bi. It is further increases the thermal and concentration boundary layer thickness. Fig. 7(a) and 7(b) depicts the effect of Eckert number Ec on temperature and concentration profiles, respectively. It is observed that temperature as well as concentration of the fluid increases with the influence of viscous dissipation.The effect of Prandtl number Pr on temperature is shown in fig. 8 respectively. Physically, enhancing the Prandtl number Pr results in a reduction in thermal diffusivity. It can be seen that the temperature of the fluid decrease with an increase in the Prandtl number Pr. The effect of Lewis number Le on concentration is shown in fig. 9 respectively. It can be seen that the concentration of the fluid decrease with an increase in Le.

The effects of magnetic parameter M, the unsteadiness parameter $A < 0$ and the suction parameter S on skin-friction, local Nusselt number and local Sherwood number are shown in Figs 10(a) - 10(c), respectively. These figures indicate an increase in the values of skin friction coefficient with the increase in M or A or S (fig. 10(a)). The local Nusselt number decreases with an increases the values of M or A or S (fig.10(b)). Further, it can be seen that the effect of M or Sis to increase the local Sherwood number but the local Sherwood number decreases with a rising the values of A (fig. 10(c)). The effect of thermophoresis parameter Nt, Brownian motion parameter Nb and Biot number Bi on local Nusselt number and local Sherwood number are shown in Figs 11(a) and 11(b), respectively. These figures indicate an increase in the values of local Nusselt number with the increase Bi whereas decrease in the values of local Nusselt number with the increase Nt or Nb and an increase in the values of local Sherwood number with the increase Nb whereas decrease in the values of local Sherwood number with the increase Nt or Bi .

V. CONCLUSIONS

The two-dimensional forced convection in unsteady magnetohydrodynamic boundary layer flow of nanofluid over a permeable shrinking sheet in the presence of viscous dissipation and convective boundary condition is investigated. Using similarity transformations, the governing equations are transformed to self-similar ordinary differential equations which are then solved fourth order classical Runge–Kutta method. From the study, the following remarks can be summarized.

1. Velocity, temperature and concentration boundary layer thickness decreases with a rising the values of suction parameter.

2. Velocity decreases whereas temperature and concentration increases with increases the values of magnetic parameter/unsteadiness parameter.
3. Temperature and concentration increases with an increase thermophoresis parameter/Biot number/Eckert number.Temperature increases and concentration decreases with an increase Brownian motion parameter.
4. Skin-friction coefficient increases with an increases the values of magnetic parameter/suction parameter/unsteadiness parameter.
5. Local Nusselt number increases with increases the Biot number whereas local Nusselt number decreases with an increase the magnetic parameter/unsteadiness parameter/Brownian motion parameter/thermophoresis parameter.
6. Local Sherwood number increases with increases the unsteadiness parameter/Brownian motion parameter whereas local Sherwood number decreases with an increase the Biot number/thermophoresis parameter.

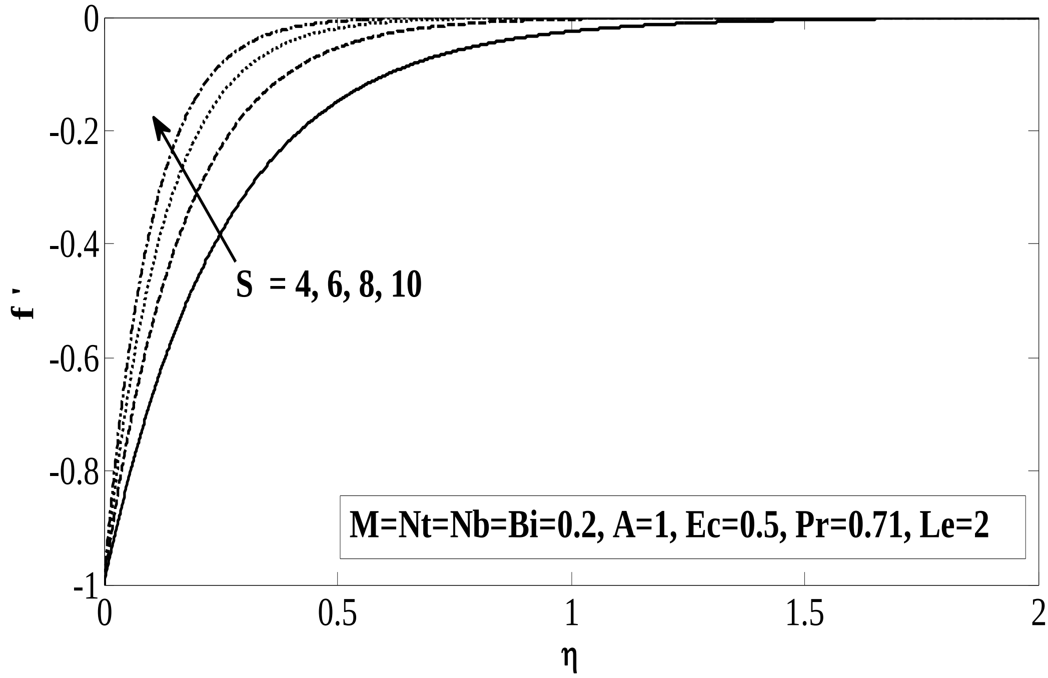


Fig.1 (a) Velocity for different *S*

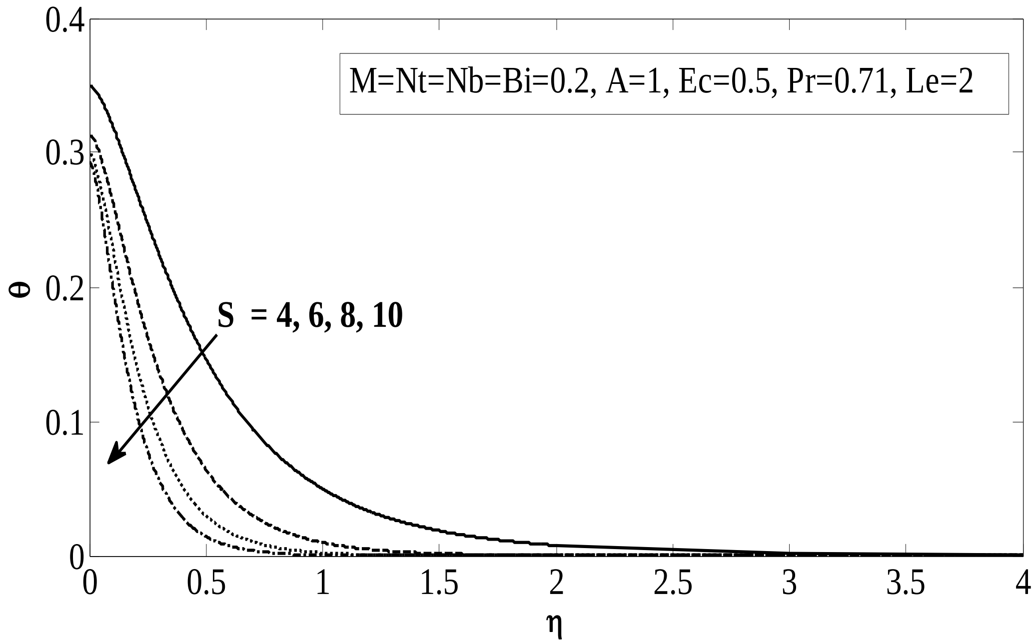


Fig. 1(b) Temperature for different *S*

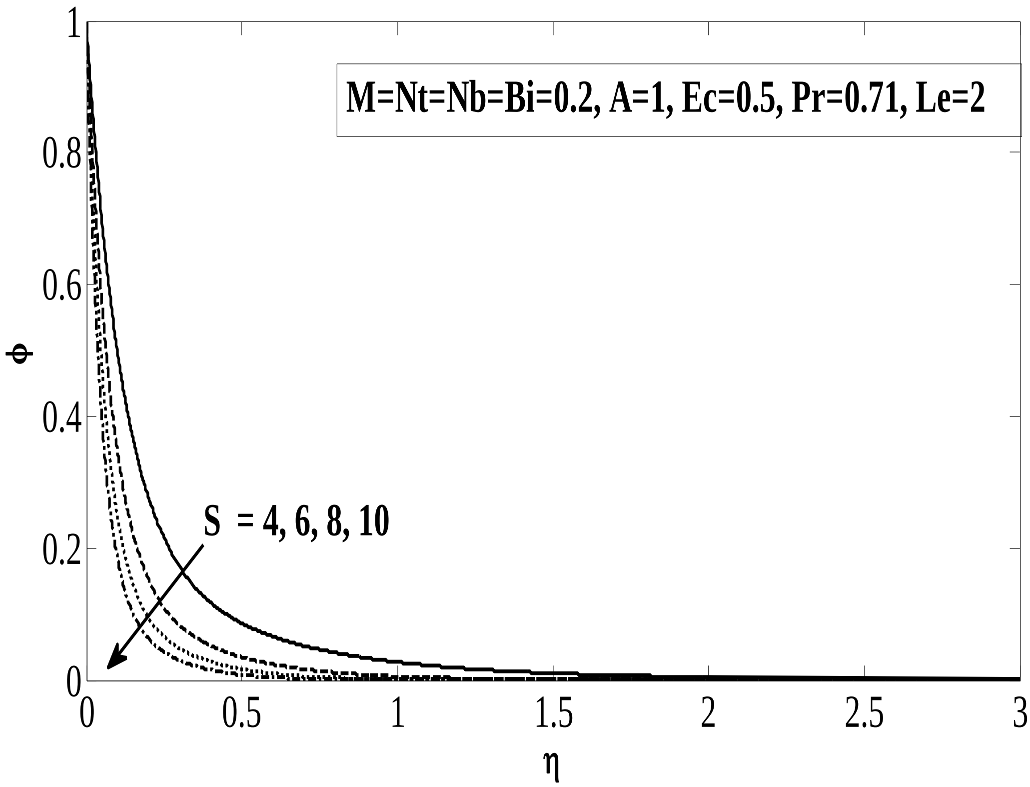


Fig. 1(c) Concentration for different *S*

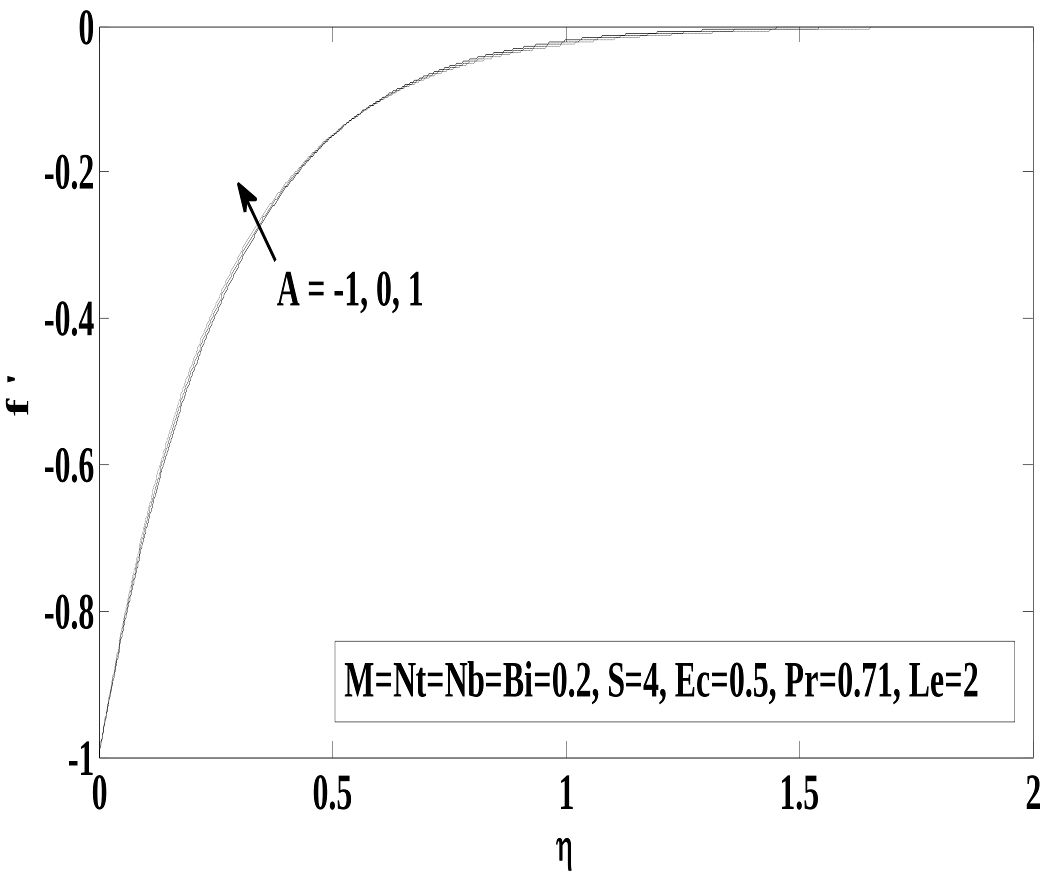


Fig. 2(a) Velocity for different *A*

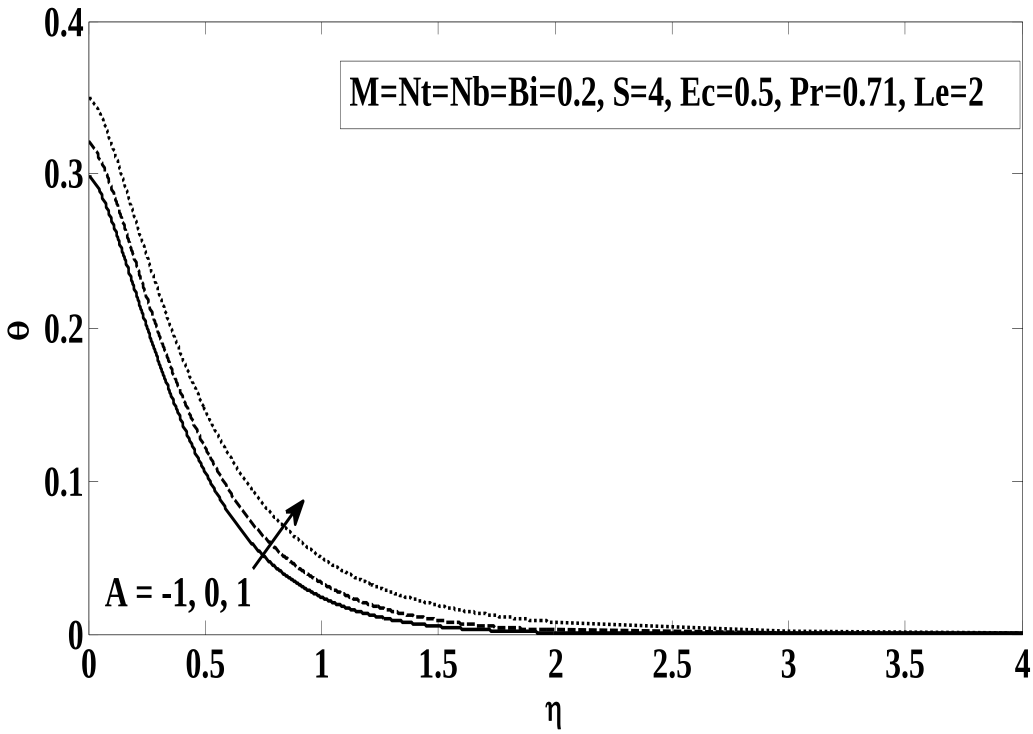


Fig.2 (a) Temperature for different *A*

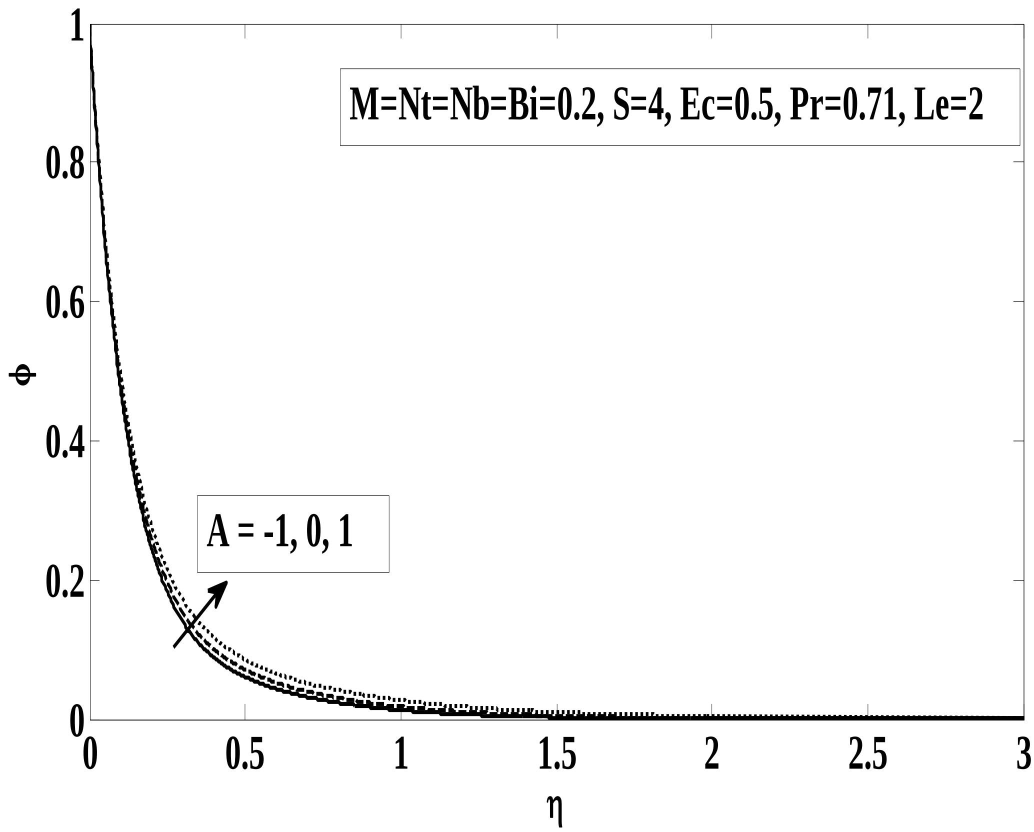


Fig.2(c) Concentration for different *A*

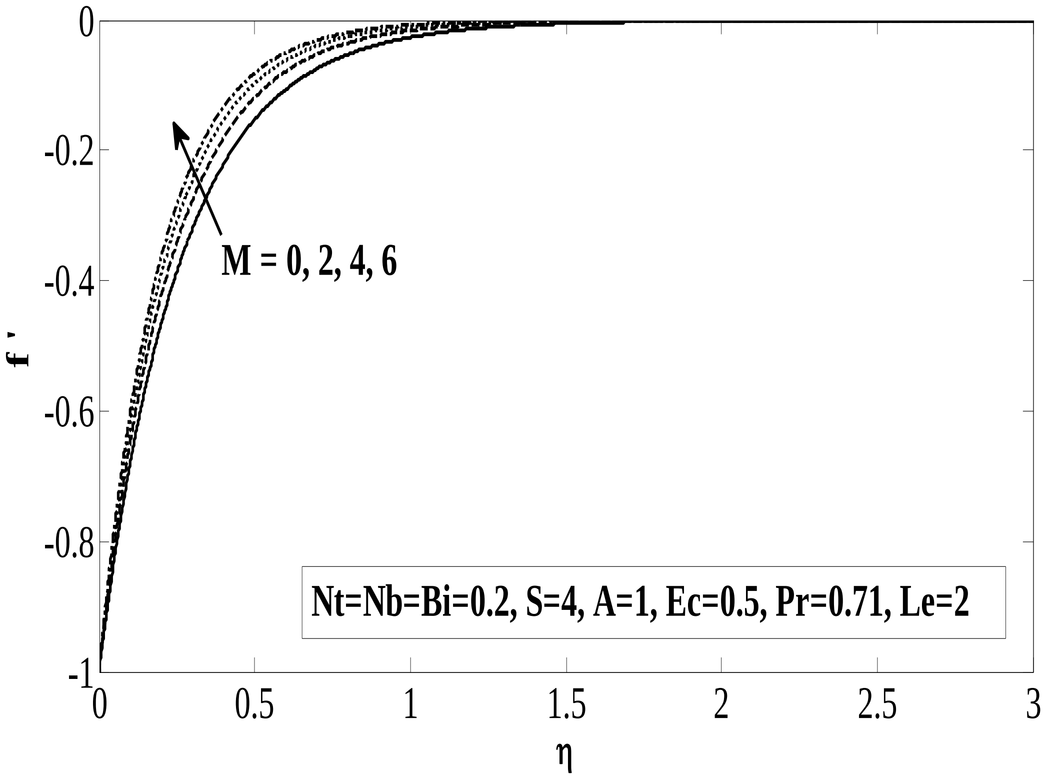


Fig.3 (a) Velocity for different *M*

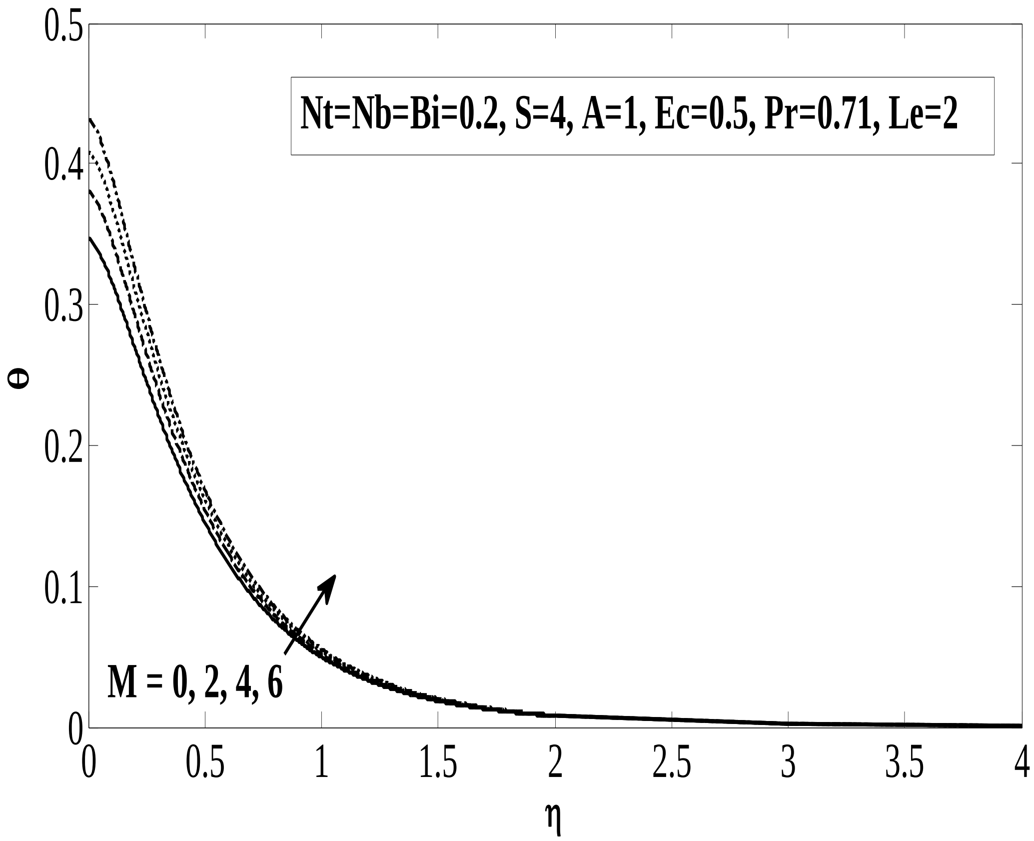


Fig.3 (b) Temperature for different *M*

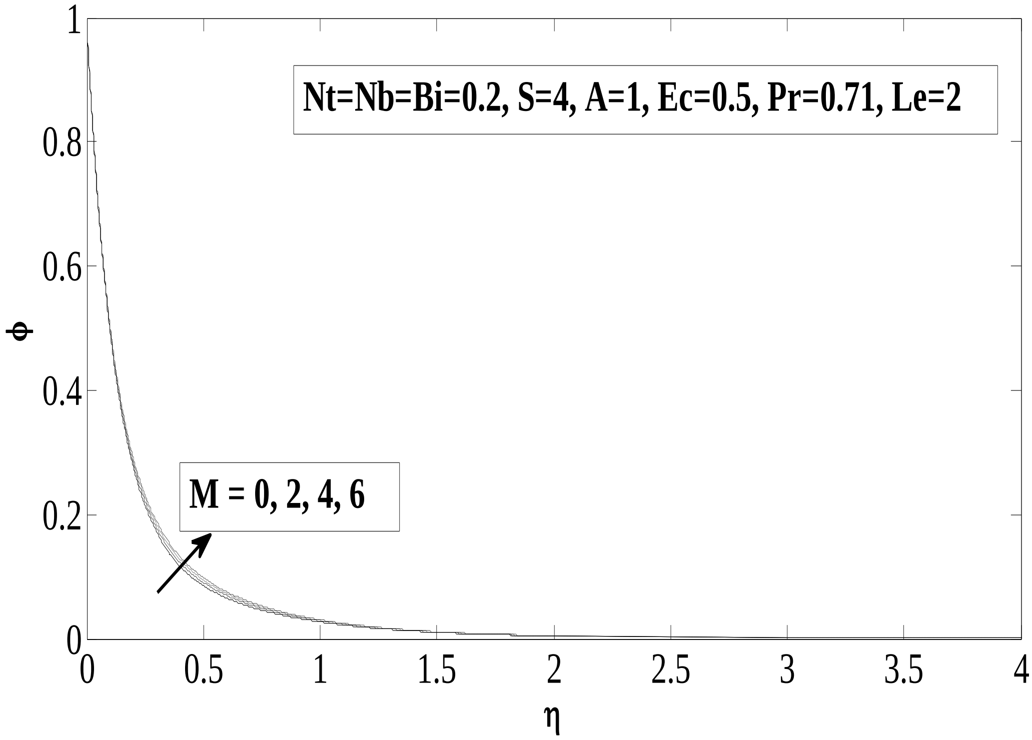


Fig.3(c) Concentration for different *M*

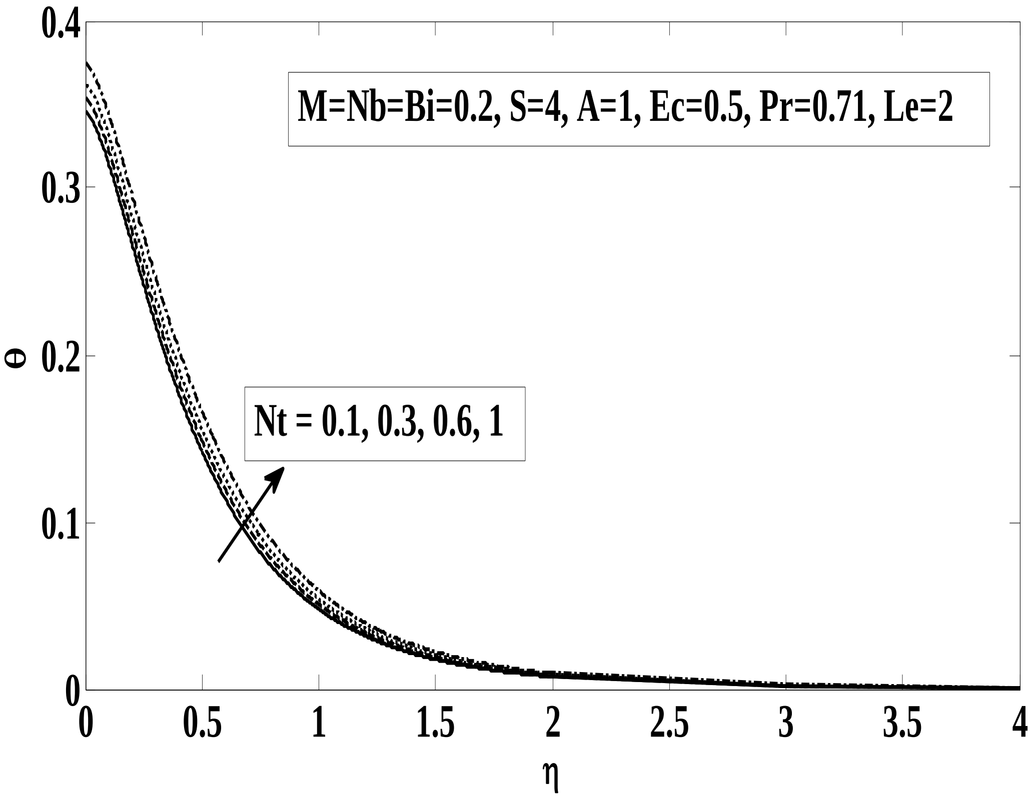


Fig.4 (a) Temperature for different *NT*

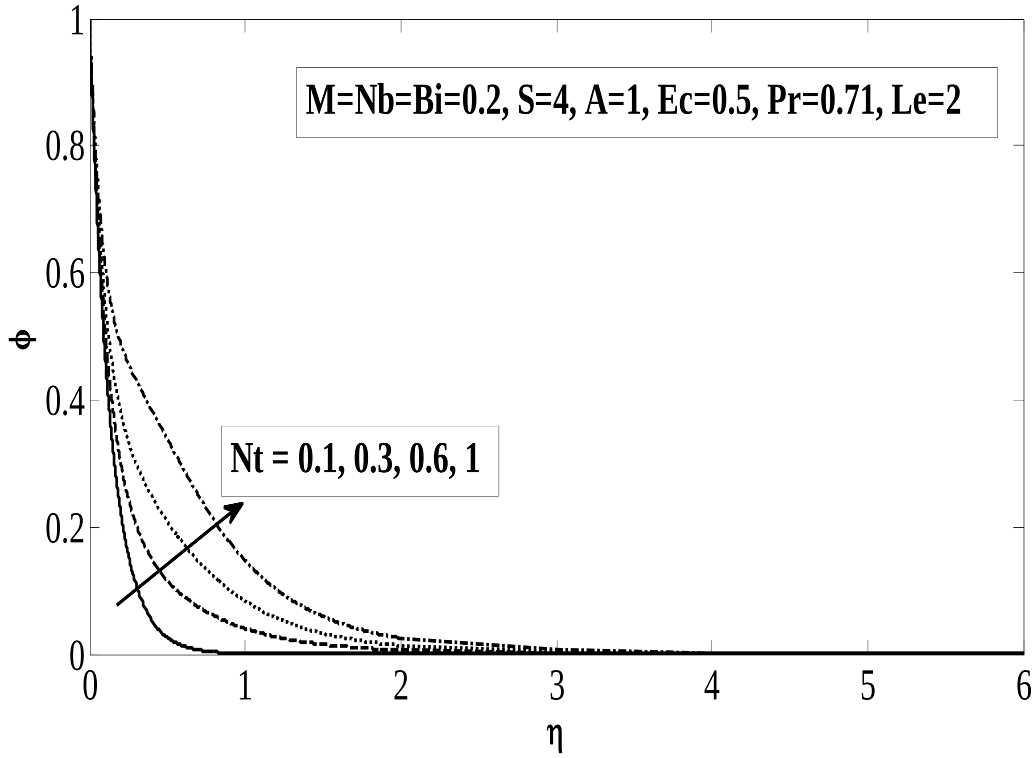


Fig.4 (b) Concentration for different *NT*

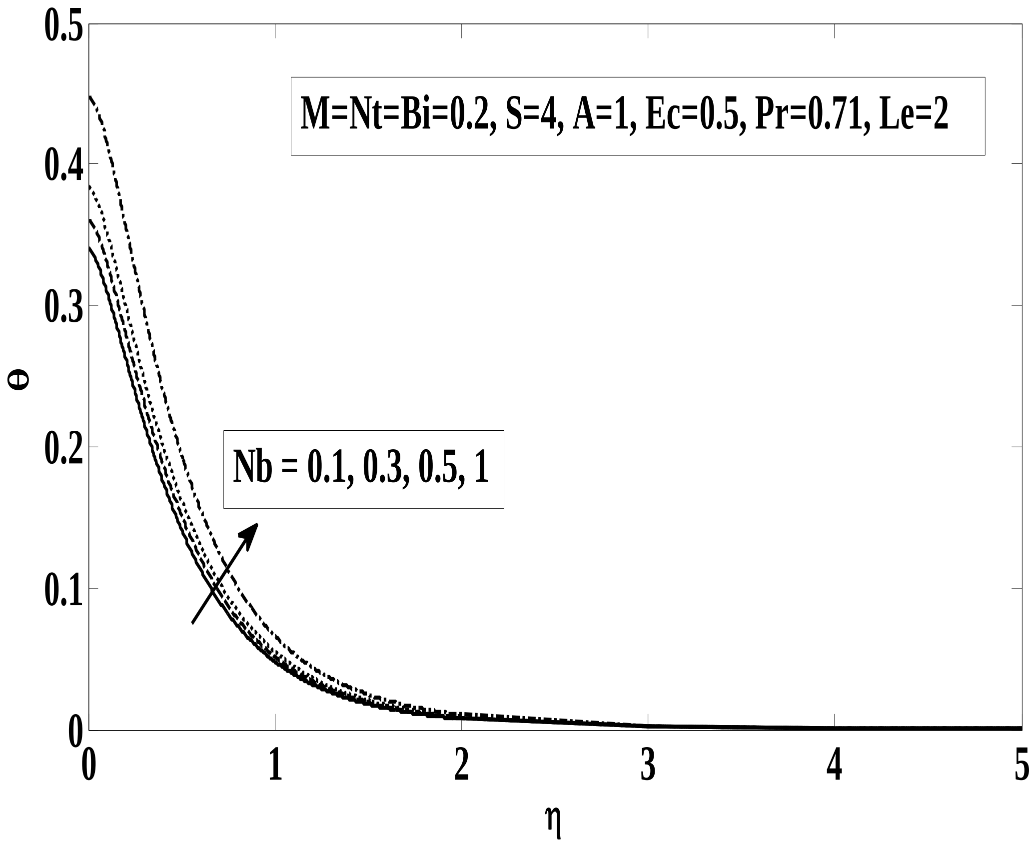


Fig.5 (a) Temperature for different *Nb*

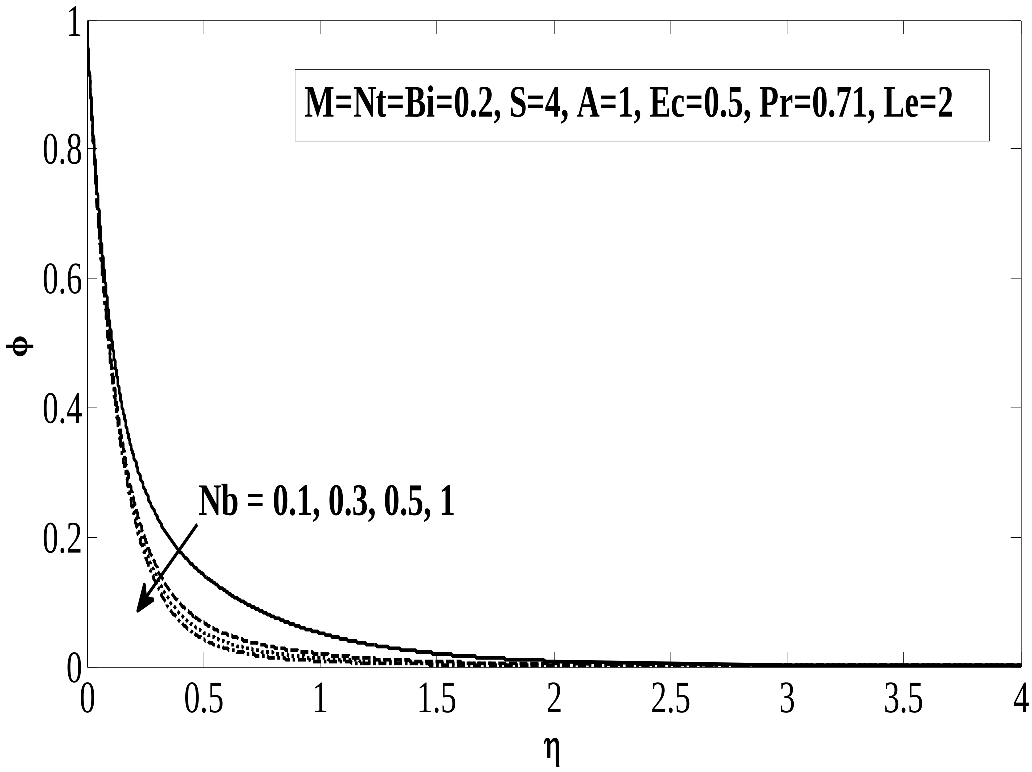


Fig.5 (b) Concentration for different *Nb*

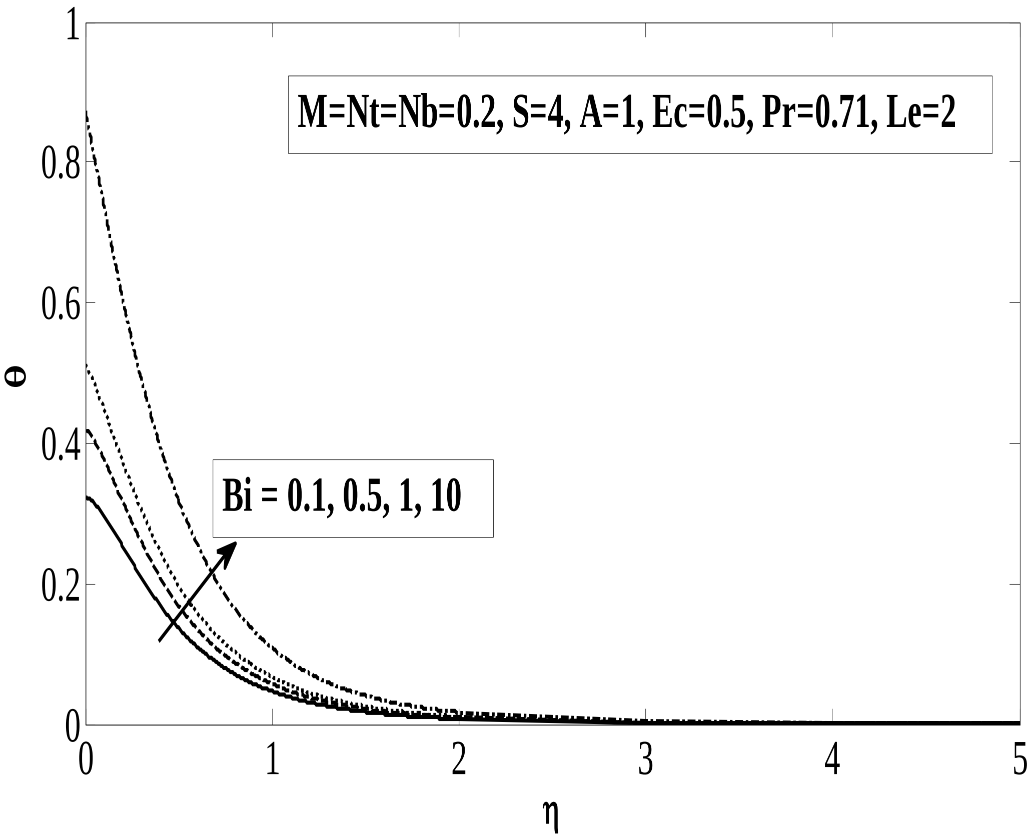


Fig.6 (a) Temperature for different *Bi*

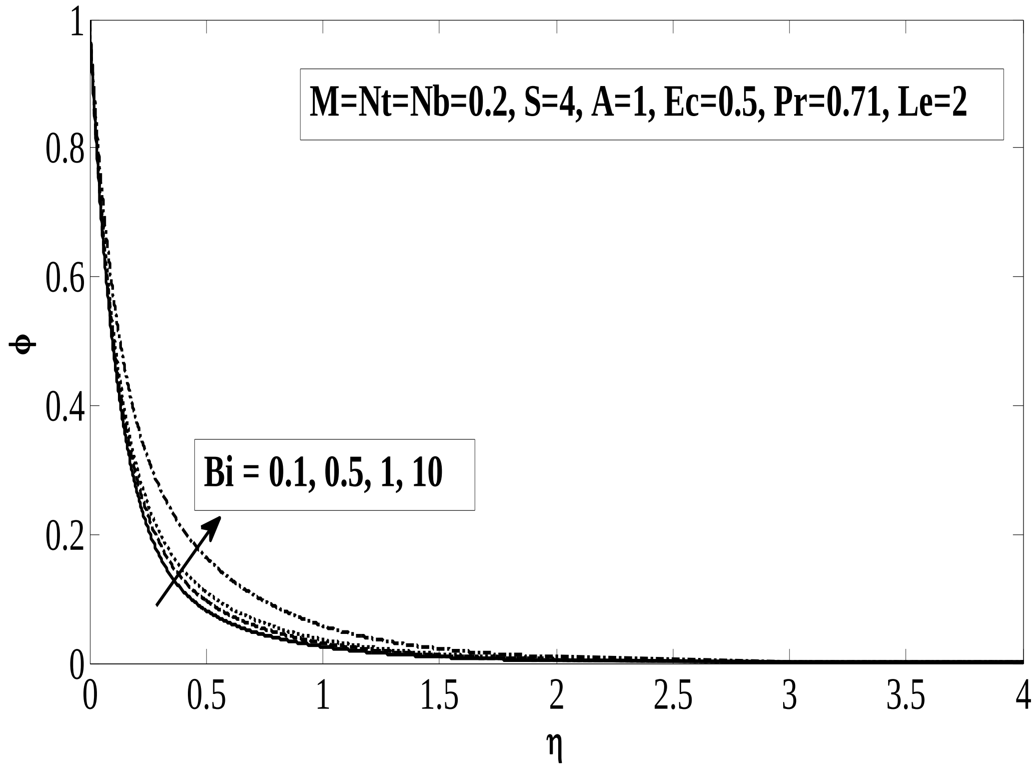


Fig.6 (b) Concentration for different *Bi*

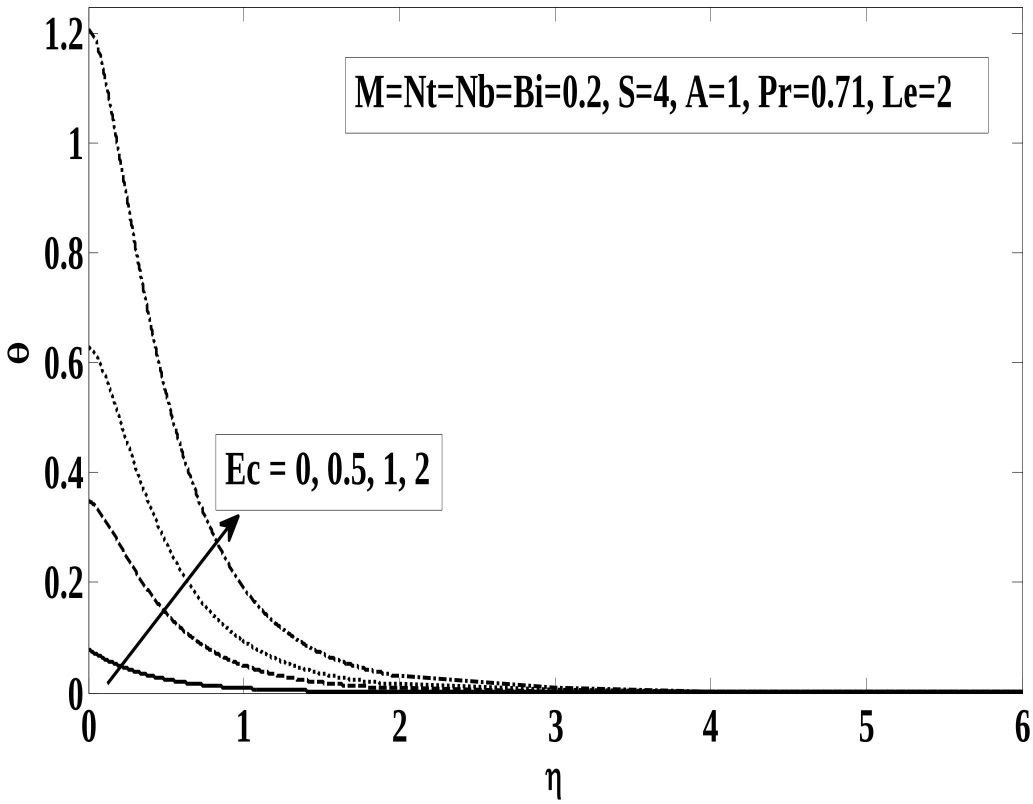


Fig.7 (a) Temperature for different *Ec*

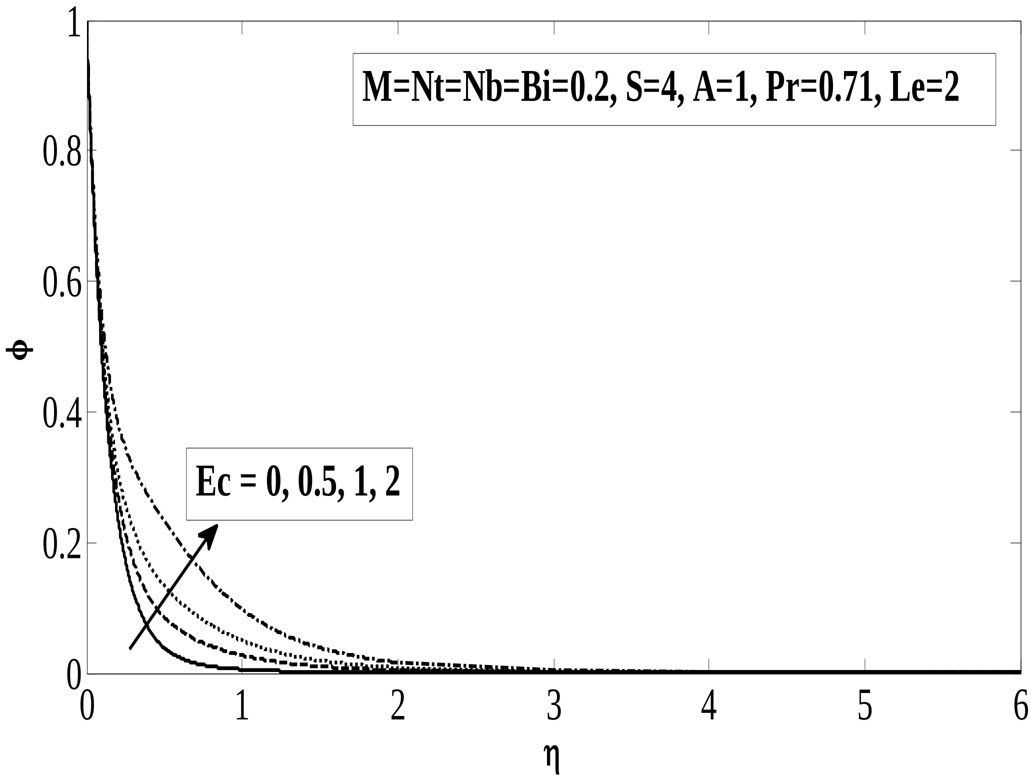


Fig.7 (b) Concentration for different *Ec*

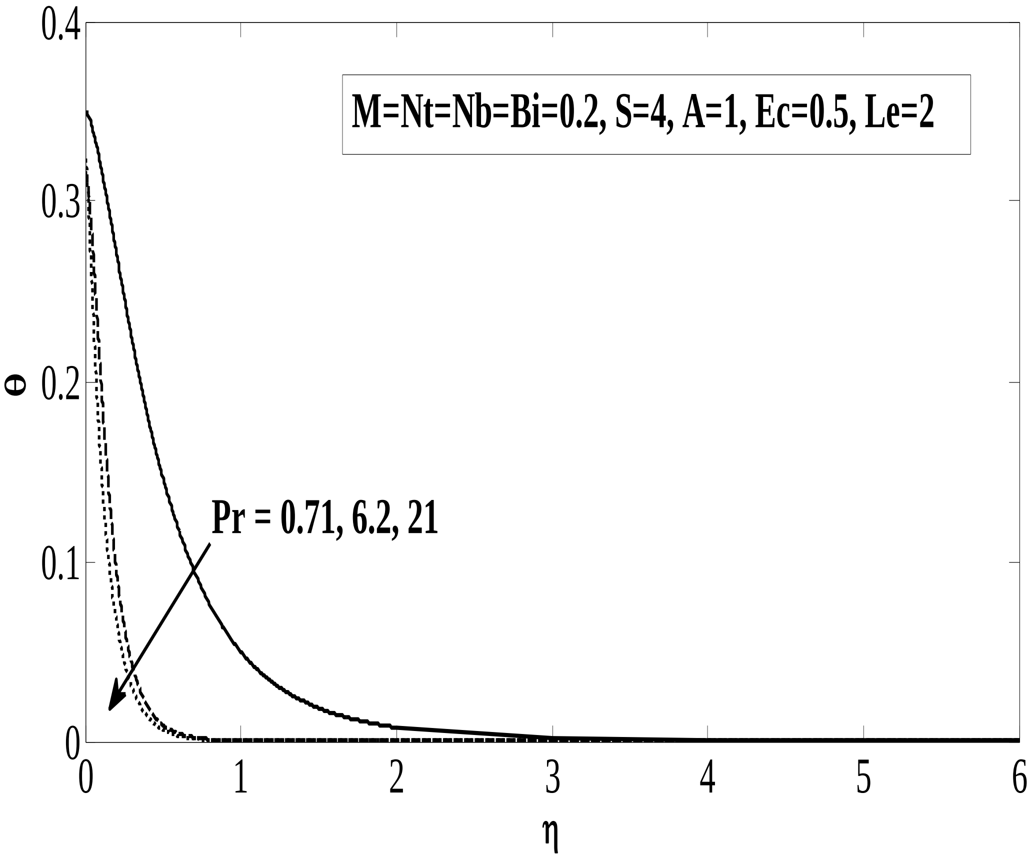


Fig.8 Temperature for different *Pr*

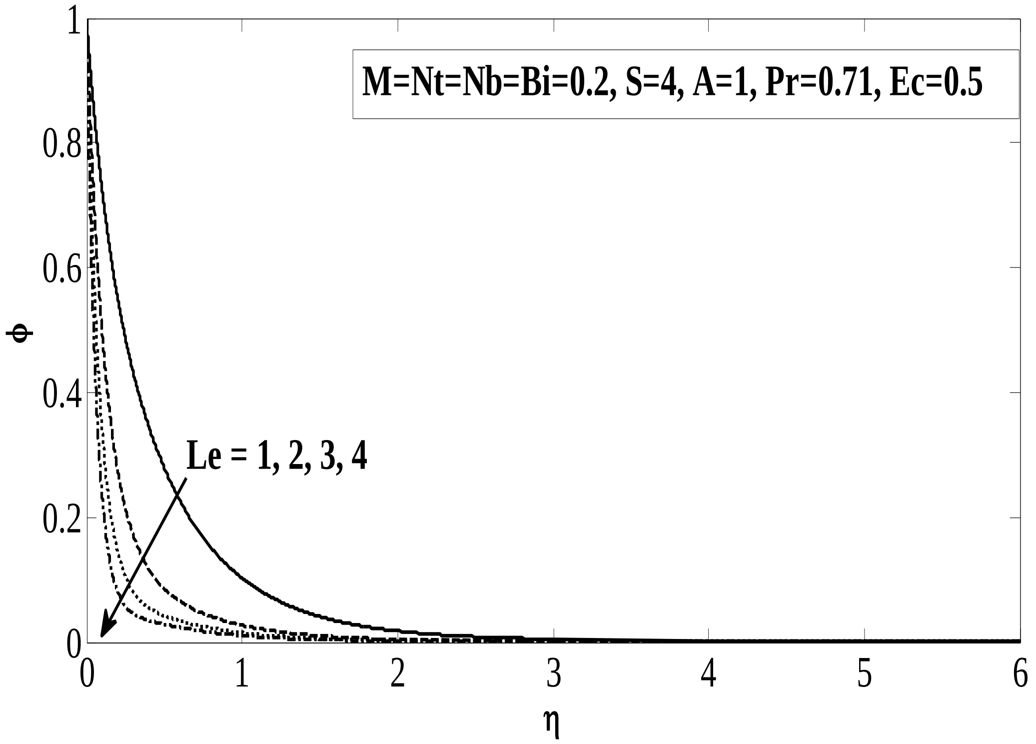
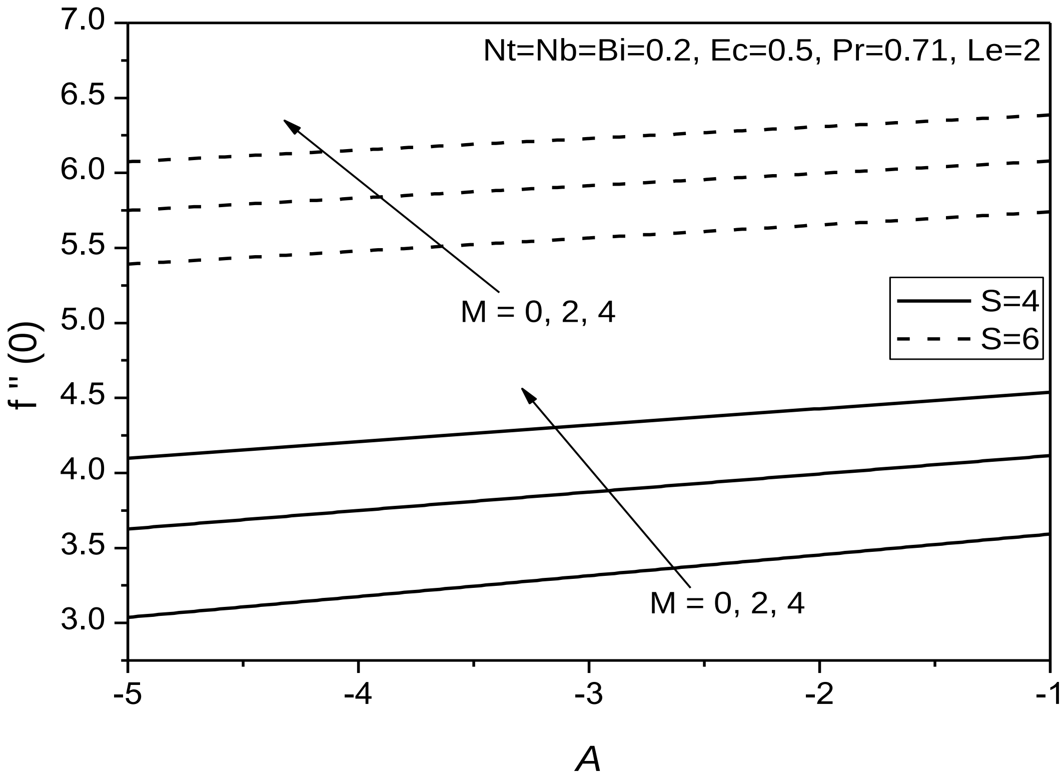
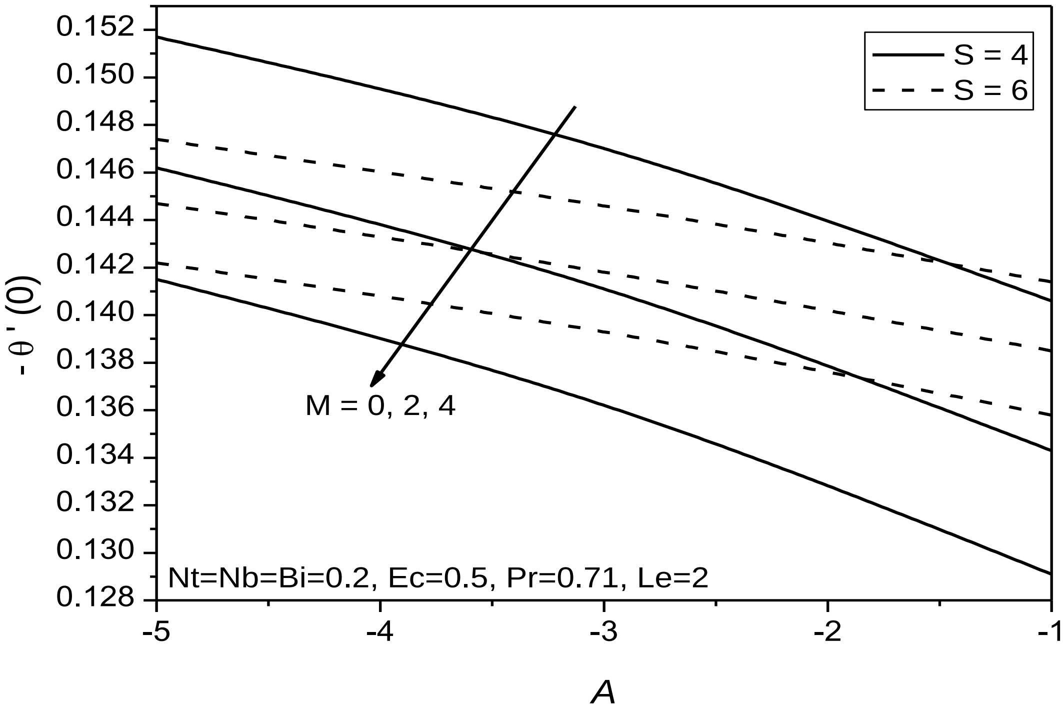


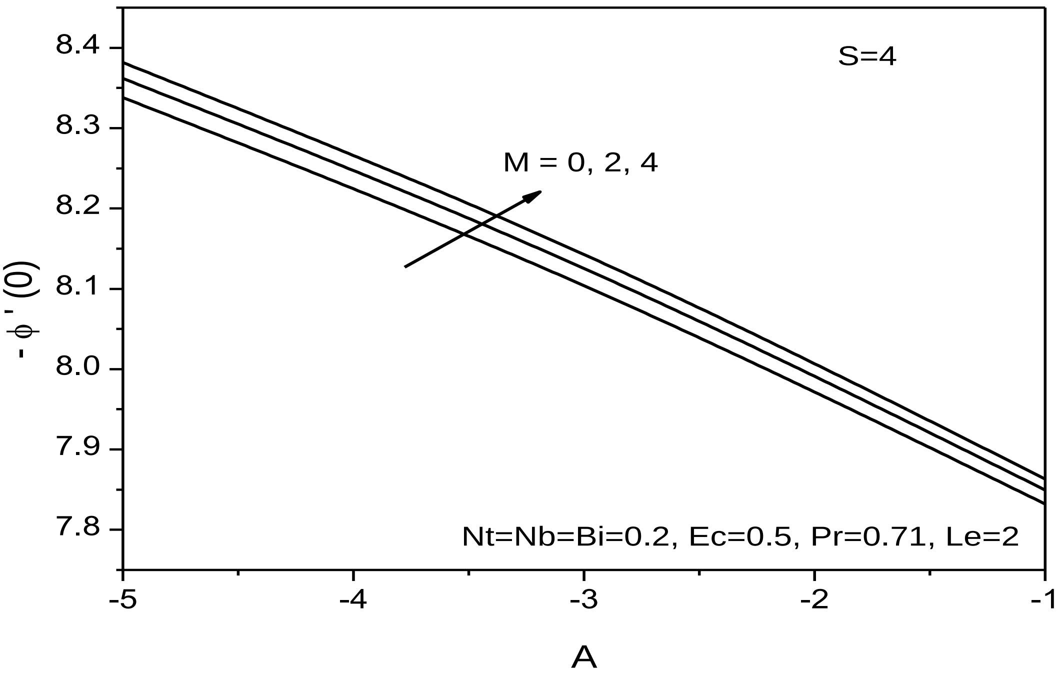
Fig.9 Concentration for different *Le*

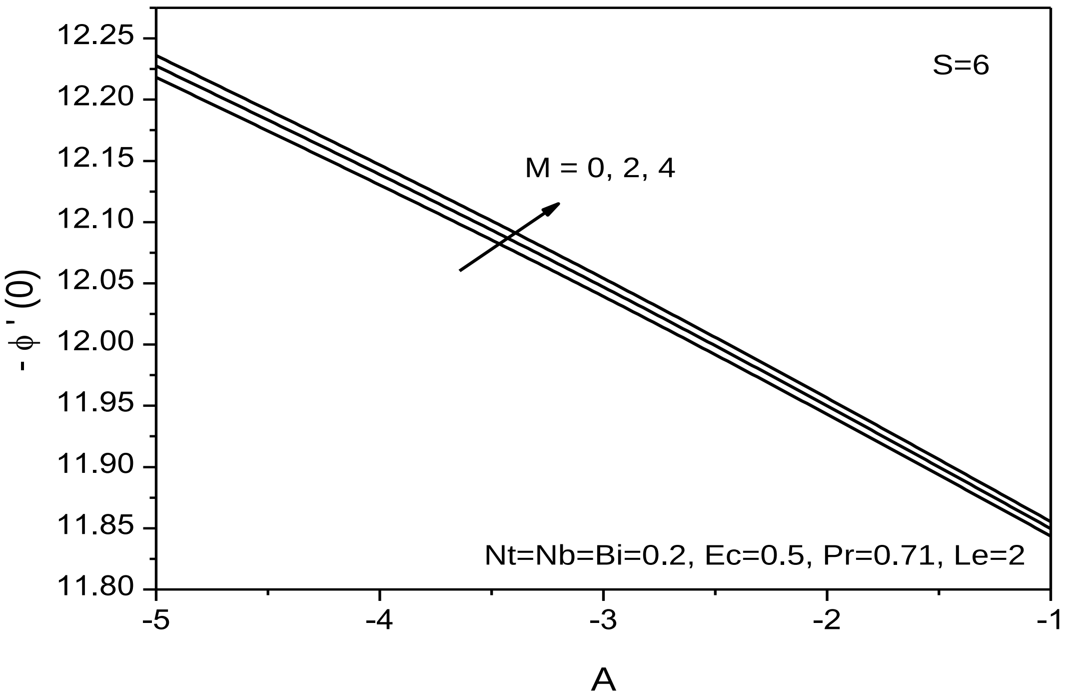


10(a) Local skin-friction for different values of M and S for A<0.



10(b) Local Nusselt number for different values of M and S for A<0.





10(c) Local Sherwood number for different values of M and S for A<0.

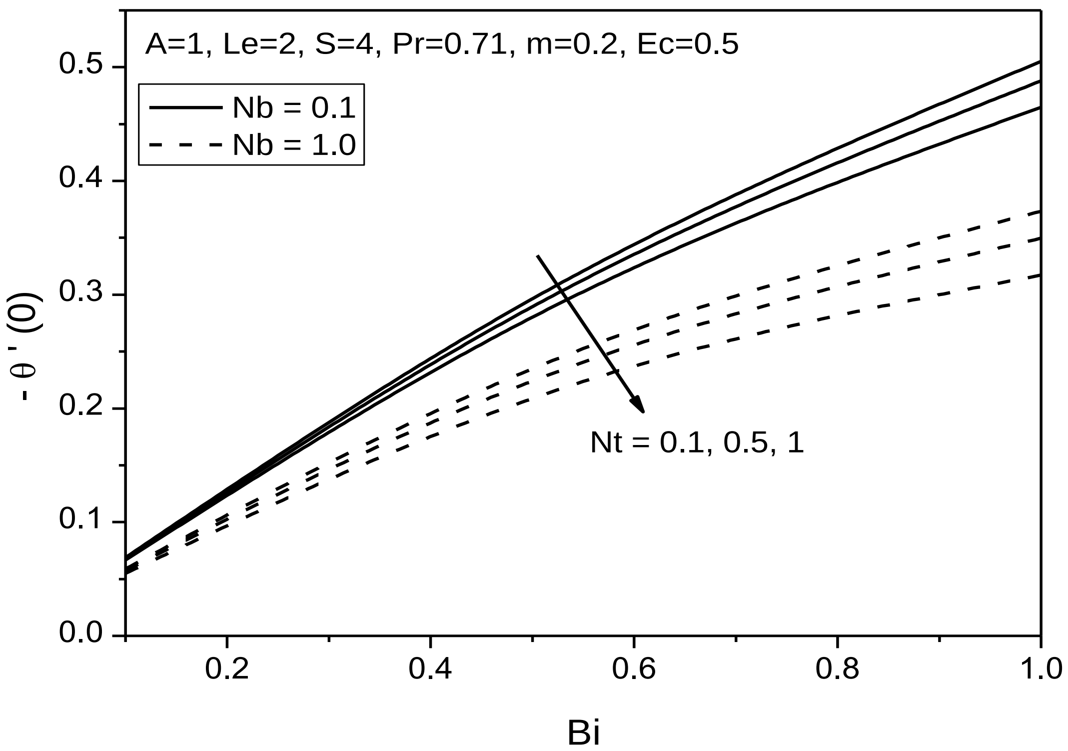


Fig.11 (a) Local Nusselt number for different *Nt, Nb*and *Bi*

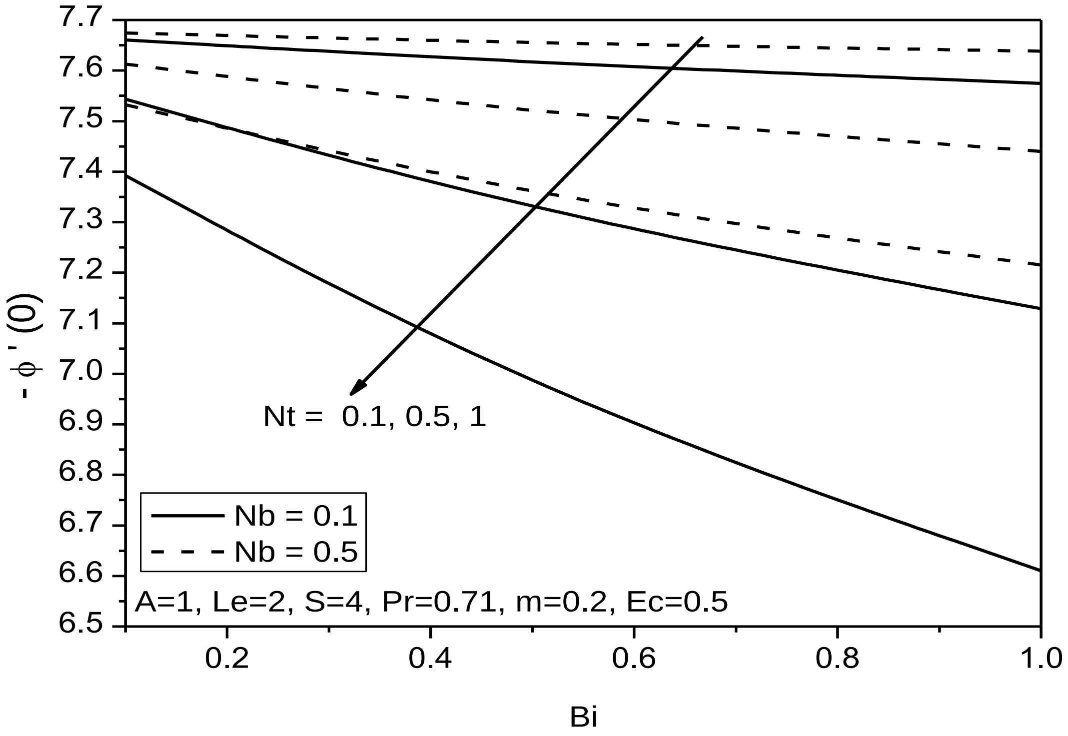


Fig.11 (b) Local Sherwood number for different *Nt, Nb* and Bi

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