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EFFECT OF VISCOUS DISSIPATION OVER A RIGA-PLATE IN A NANOFLUID WITH HEAT SOURCE/SINK: A NUMERICAL STUDY

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Abstract - This analysis is mainly related to the study of flow of a nanofluid past a vertical convective heated Riga-plate with viscous dissipation and heat source. A riga plate is an electromagnetic mechanism made up of magnets which are stable and a span wise arrangement of electrodes alternatively set on a plane face. This sketch instigates Lorentz force which is in the direction of the arrangement and degenerates exponentially. Nanoparticle wall mass flux becomes zero at the surface. Traditional transformations provide to the similarity equations which are numerically evaluated by using shooting method. MATLAB bvp4c solver is applied for initiating the numerical results.

Keywords - Mixed convection, Nanofluid, Lorentz force, heat generation/absorption, Viscous Dissipation, Riga-plate

I. INTRODUCTION

Flow over a riga plate unlock a new research era. Gallites and Lilausis [1] introduced the concept of producing wall-parallel Lorentz force. Electromagnetic field is applied externally for attaining Lorentz force by an arranging electrodes and magnets on a flat surface having alternating polarity and magnetisation. Riga plate is very useful device which avoids the separation of the boundary layer and also diminishes the turbulence effects. It generates crossed magnetic and electric fields which are fixed on a plane surface. It is also useful to minimise the friction and pressure drag of submarines. Nanoparticle flux at the surface diminishes. Pantokratoras and Magyari [2] studied the MHD free-convection flow over a Riga-plat. Pantokratoras [3] investigated the Sakiadis flow along a vertical Riga-plate.

Nano fluids are the suspensions of solid nanoparticles in a base fluid with length 1-100 nm. The presence of nano particles enhances the heat transmission of base fluid and also the convective heat transfer coefficient. This technique was first introduced by Choi [4]. Generally the conventional base fluids are Water, glycol, ethylene and kerosene oil etc., the nanoparticles are made of copper, Carbon nanotubes, and gold etc. Bala Anki Reddy et al., [5] discussed the MHD Boundary Layer Slip Flow of a Maxwell Nanofluid over an exponentially stretching surface with convective boundary condition. Ahmad et al., [6] fed light on the effect of Lorentz force over a Riga plate and concluded that skin friction can be raised using the flow supported by Lorentz force and a decrement is observed for opposing Lorentz force.

In cooling processes, heat generation or absorption effect is very significant. Ahmed et al. [7] investigated how the heat generation/absorption effects the flow on the boundary layer of single phase nanofluid over an expanded tube. Very recently, Akilu and Narahari [8] studied the influence of heat source/sink over an inclined plate in a nanofluid.

In all the afore said literature, viscous mechanical dissipation is ignored. But such effects are vital in geophysical flows, industrial purpose and are generally regarded by the Eckert number. The natural convective flows with viscous dissipation effect are reported by Mahajan and Gebhart [9], and describes the heat transfer rates are lowered by rising the dissipation parameter. Various contributions on viscous dissipation Ahmed et al., [10] discussed the impact of radiation and viscous dissipation among the Riga Plates with carbon nanotubes. The flow of viscous fluid in the direction of a Riga plate with variable thickness was explored by Farooq et al., [11]. Also dissipation and chemical reactions are considered. Reddy et al., [12] investigated the Magnetohydro Dynamic Flow of Blood in a Permeable Inclined Stretching Viscous Dissipation, Non-Uniform Heat Source/Sink and Chemical Reaction.

In this study, our main objective is to analyze the nanofluid flow over a vertical Riga-plate with viscous dissipation and heat generation. Mixed convection is also considered. By using transformations, the similarity equations are formulated and the numerical solutions are obtained by MATLAB bvp4c. The impact of related physical parameters on the flow fields is interpreted through graphs.

II. MATHEMATICAL FORMULATION

Consider a vertical Riga-plate having infinite length through which a nanofluid is flowing. The velocity component along x axis is *u and* along y axis is *v*. The riga plate is taken in the directioin of x axis and y axis normal to it. Because of the electromagnetic field a Lorentz force is induced over the riga plate.

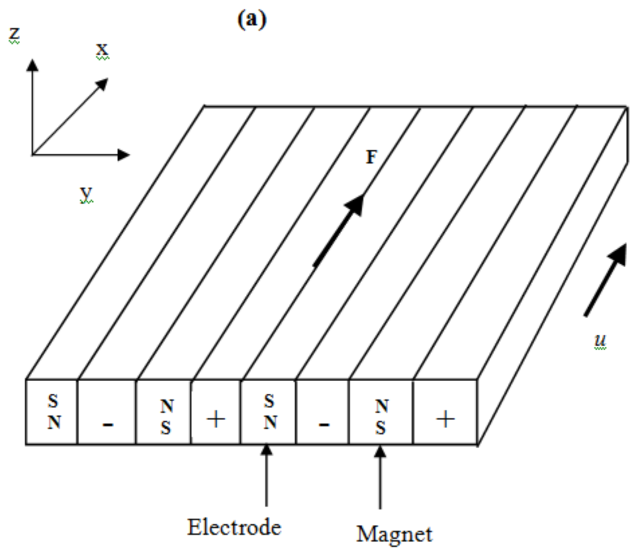

Fig.1 (a) Geometry of Riga-plate.

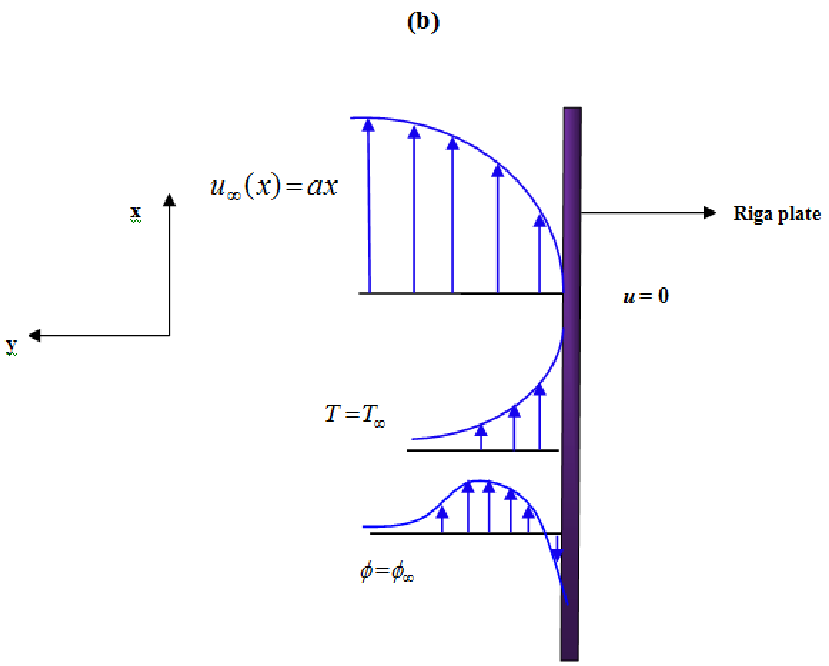

Fig.1 (b) Physical flow model of the problem.

An exponentially decrement in Lorentz force is observed as we move away from the plate normally. The velocity of the fluid faraway from the plate is represented as $u_\infty(x) = ax$.

Therefore, this force either assists or opposes the external flow along x-axis in positive or negative directions. T_f and h_f are temperature and heat transfer coefficients of the right direction of the plate surface which make contact with other fluid. (See Fig.1).

The concentration of the nanoparticle maintains zero normal flux at the plate. Let the temperature and nanoparticle concentration for the ambient flow is T_∞ and ϕ_∞. An Oberbeck-Boussinesq approximation is applied for the physical situation and are given by (see references [13] and [14]):

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=a^2x+\nu_f\frac{\partial^2 u}{\partial y^2}+\frac{1}{\rho_f}\left[\rho_{f\infty}\beta_T(1-\phi_\infty)(T-T_\infty)-(\phi-\phi_\infty)\left(\rho_p-\rho_{f\infty}\right)\right]g+\frac{\pi j_0 M_0}{8\rho_f}e^{-\frac{\pi}{p}y} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_f\frac{\partial^2 T}{\partial y^2}+\tau\left[D_B\frac{\partial T}{\partial y}\frac{\partial \phi}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]+\frac{\upsilon_f}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2+\frac{Q_0}{\rho C_p}(T-T_\infty) \tag{3}$$

$$u\frac{\partial \phi}{\partial x}+v\frac{\partial \phi}{\partial y}=D_B\frac{\partial^2 \phi}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \tag{4}$$

Here, T is the nanofluid temperature, β - the thermal expansion coefficient, ϕ - concentration of the nanoparticles,

D_T - the thermo diffusion coefficient, M_0 - the magnetization of permanent magnets , D_B - the Brownian diffusion coefficient, p is the thickness of magnets and electrodes, ρ_f the base fluid density, ρ_p the nanoparticle density, ν_f the base fluid kinematic viscosity , and j_0 the current density. With the subsequent conditions [11]:

$$\begin{gathered}u=0, v=0, -k_f\frac{\partial T}{\partial y}=h_f(T_f-T),\ \ D_B\frac{\partial \phi}{\partial y}+\frac{D_T}{T_\infty}\frac{\partial T}{\partial y}=0 \quad at\ y = 0\\ u\to u_\infty(x)=ax\ , T\to T_\infty\ ,\phi\to\phi_\infty \quad at\ y\to\infty\end{gathered} \tag{5}$$

in which h_f the heat transfer coefficient and k_f the thermal conductivity of conventional base fluid.

For solving the problem the first step is to introduce the similarity transformations:

$$\begin{gathered}\eta=y\left(\frac{a}{v_f}\right)^{\frac{1}{2}},\ u=axs'(\eta),\ v=-\left(av_f s(\eta)\right)^{\frac{1}{2}},\ \ T=\left(T_f-T_\infty\right)\theta(\eta)+T_\infty,\\ \phi=\phi_\infty+\phi_\infty f(\eta)\end{gathered} \tag{6}$$

here the dimensionless parameters, η the perpendicular distance, $s(\eta)$ the stream function, $\theta(\eta)$ the temperature and $f(\eta)$ the nanoparticle concentration. The continuity equation (1) is satisfies the transformations. Whereas Eqs. (2) – (5) are converted into ordinary differential equations as follows:

$$s'''+ss''-s'^2+\lambda\left(\theta-Nrf\right)+Ze^{-d\eta}+1=0 \tag{7}$$

$$\theta''+Nbf'\theta'\,pr+Nt\theta'^2\,pr+s\theta'\,pr+Ec\,pr\left(s''\right)^2+pr\,Q\theta=0 \tag{8}$$

$$f''+scf's+\frac{Nt}{Nb}\theta''=0 \tag{9}$$

$$s=0,\ s'=0,\ \theta'=-Bi\left[1-\theta\right],\ f'+\frac{Nt}{Nb}\theta'=0\ when\ \ \eta=0 \tag{10}$$

$$s' \to 1,\ \theta \to 0,\ f \to 0\ \ as\ \ \eta \to \infty$$

here prime denotes derivative with respect to η, $\lambda = \dfrac{g\beta(1-\phi_\infty)\left(T_f - T_\infty\right)}{a^2 x}\dfrac{\rho_f}{\rho_\infty} \equiv \dfrac{Gr_x}{\mathrm{Re}_x^2}$ is the Richardson number, where $Gr_x = \dfrac{g\beta(1-\phi_\infty)x^3}{v_f^2}\dfrac{\rho_f\left(T_f - T_\infty\right)}{\rho f_\infty}$ is the Grashof number and $\mathrm{Re}_x = \dfrac{ax^2}{v_f}$ is the Reynolds number. The nanofluid cools the hot plate when λ> 0 and λ< 0 indicates nano fluid cooling. $Z = \dfrac{\pi j_0 M_0}{8\rho_f a^2 x}$ denotes the modified Hartman number. For positive values Hartman number, Lorentz force is parallel to positive x-axis, for negative values of Hartman number, it is parallel to negative x-axis. The remaining physical quantities in non-dimensional form are referred as:

$$d = \frac{\pi}{p}\left(\frac{v_f}{a}\right)^{1/2},\ Nt = \frac{\tau D_T}{v_f T_\infty}\left(T_f - T_\infty\right),\ Nb = \frac{\tau D_B \phi_\infty}{v_f},\ Bi = \frac{h_f}{k_f}\left(\frac{v_f}{a}\right)^{1/2},\ Nr = \frac{\left(\rho_p - \rho_{f\infty}\right)\phi_\infty}{\rho_f \beta(1-\phi_\infty)\left(T_f - T_\infty\right)},$$

$\mathrm{Pr} = \dfrac{v_f}{\alpha_f},\ Sc = \dfrac{v_f}{D_B},\ Q = \dfrac{Q_0 x}{u_\infty\left(\rho c_p\right)},\ Ec = \dfrac{u_\infty^2}{a\rho c_p\left(T_f - T_\infty\right)}$, here d is the thickness of magnets and electrodes, thermophoresis parameter as Nt, the Brownian motion parameter as Nb, Biot number as Bi, Buoyancy ratio parameter as Nr , Prandtl number as Pr , Schmidt number as Sc, heat source or sink as Q and Eckert number as Ec. C_f the shear stress at surface is calculated as follows:

$C_f = \dfrac{\tau_w(x)}{\rho u_\infty^2(x)} = \dfrac{\mu_f \frac{\partial u}{\partial y}\big|_{y=0}}{\rho_f (ax)^2} = \mathrm{Re}_x^{-\frac{1}{2}} s''(0),$ where $\mathrm{Re}_x = {xu_\infty(x)}/{v_f}$ denotes the local Reynolds number. By the usual Fourier law, we can find the rate of heat transfer at the wall, as

$$Nu_x = \frac{xq_w}{k_f\left(T_f - T\infty\right)} = -\frac{\frac{\partial T}{\partial y}}{\left(T_f - T_\infty\right)} = -\mathrm{Re}_x^{1/2}\,\theta'(0).$$

The wall heat flux q_w contains terms having Nb and Nt (see Buongiorno [15] for details).We have assumed zero wall mass flux i.e., q_w= 0. The Sherwood number computes zero mass flux at the wall.

III. RESULTS AND DISCUSSION

Fig. 2 depict the effect of varying modified Hartman number Z on velocity. It is evident that rising values of Z leads to rise the fluid flow. An overshoot is observed in the velocity profiles for larger values of Z which express the velocity of the fluid near the plate is more than the velocity of free stream .Temperature profiles for various Biot number are shown in Fig 3 When Bi is more a strong convective heating is observed at the plate, so that temperature risies. isoflux wall situation case is noted when Bi=0, Bi→∞ represents isothermal wall situation. A minor decrease in temperature is observed as d increases. Fig. 4 elucidates the influence of thermophoresis, Nt on temperature. As Nt values increases from 0 to 1.5 an increasing trend is observed in temperature. The effect of Nt on nano particle concentration is presented in fig.5. The function f increases as Nt increases. An increase in Nt shows the thermophoretic force become stronger and further tends to stronger diffusion of nanoparticles in the direction of the ambient. The maximum for all curves is sited around η = 1.5.Fig 6.Presents the nano particle concentration for different Schmidt number. D_B is minimum for large Sc. Hence for smaller values of Sc, the mass boundary layer develop slowly. Fig.7 is prepared to analyse the influence of Brownian motion parameter Nb on nano particle concentration. The function f enhances as Nb decreases. The results of temperature on Ec is shown in Fig. 8. As Ec increased the velocity and the temperature increases, since internal energy is increased. The variations in the temperature for varied values of heat source/sink are represented in Fig. 9. It is noted that the temperature rises with an increase in heat source.

Table 1 illustrate the comparison of local skin friction coefficient for various values of Z and λ with the results R. Ahmad et al. [16], and are found in excellent agreement. It is also observed from this table that a growth is noted in local skin friction as Z and λ increases.

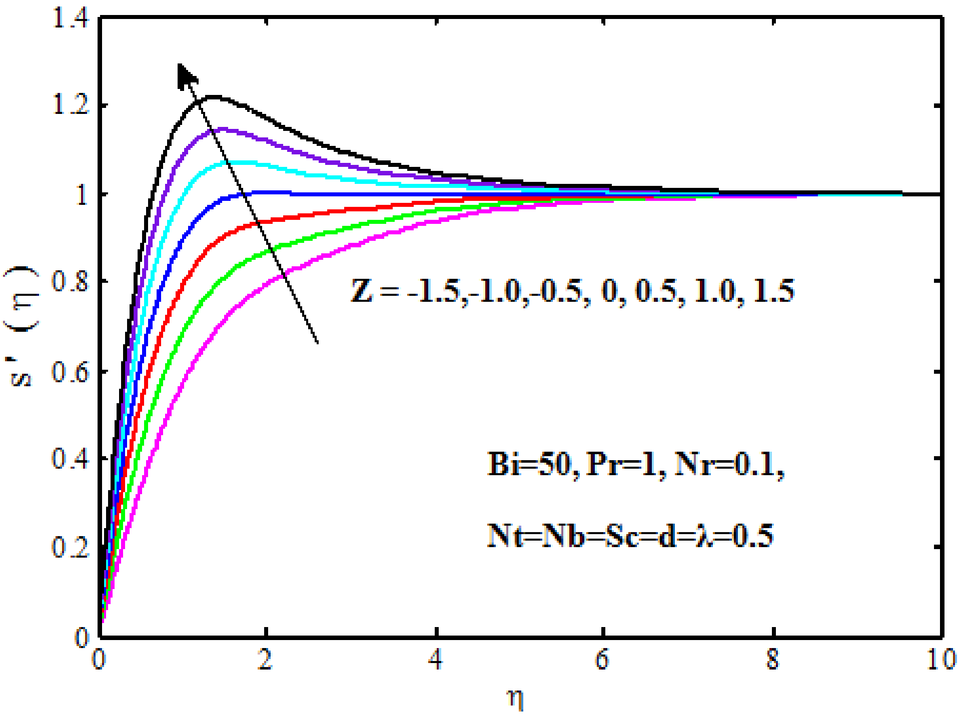

Fig.2 velocity profiles for different Z

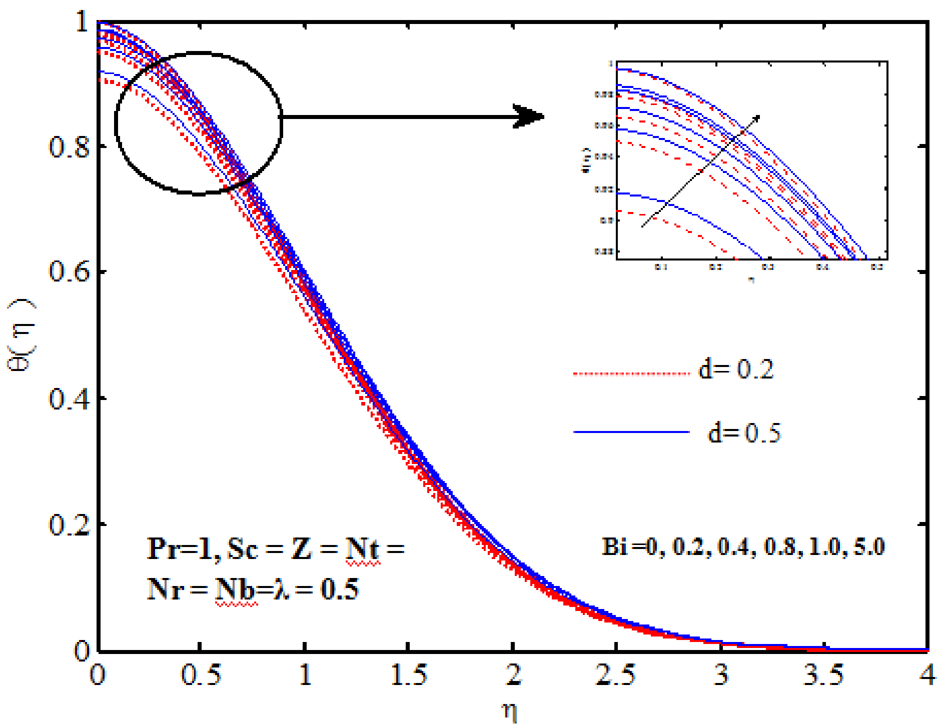

Fig.3 temperature profiles θ for different Bi

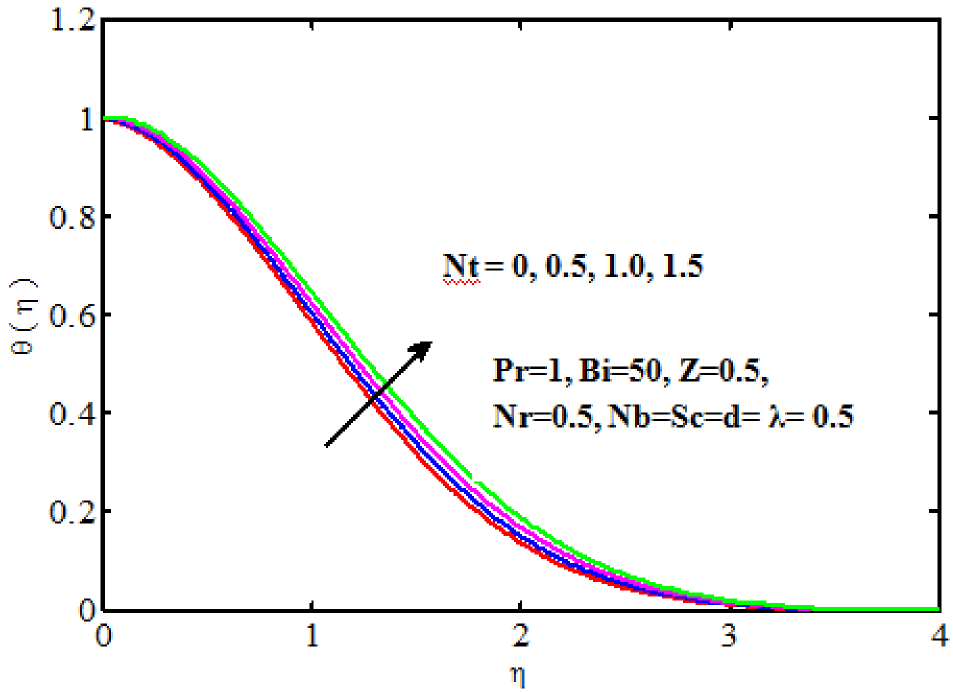

Fig.4 temperature profiles θ for different Nt

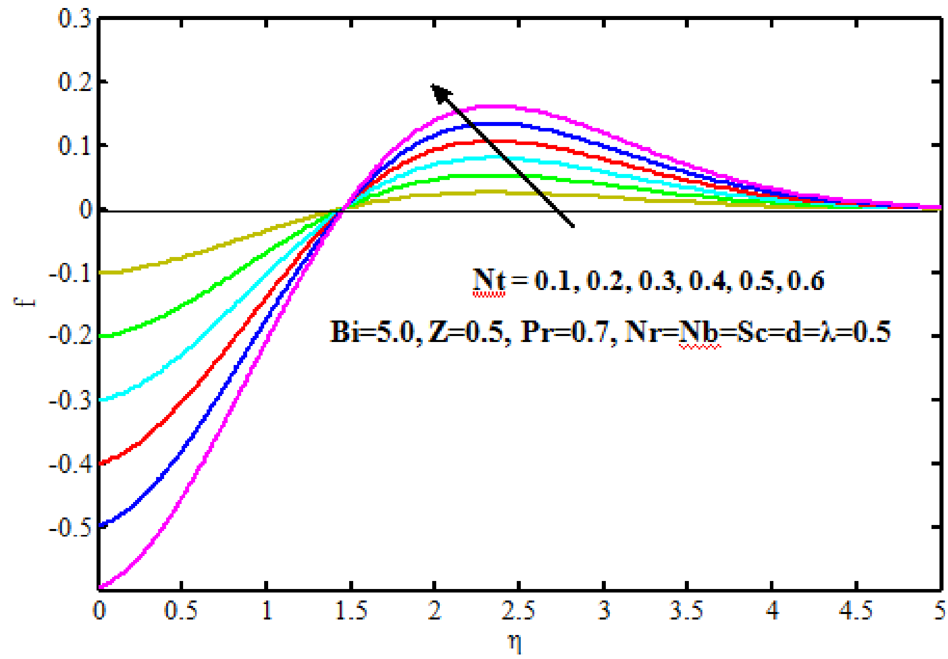

Fig.5 nanoparticle concentration profiles f for different Nt.

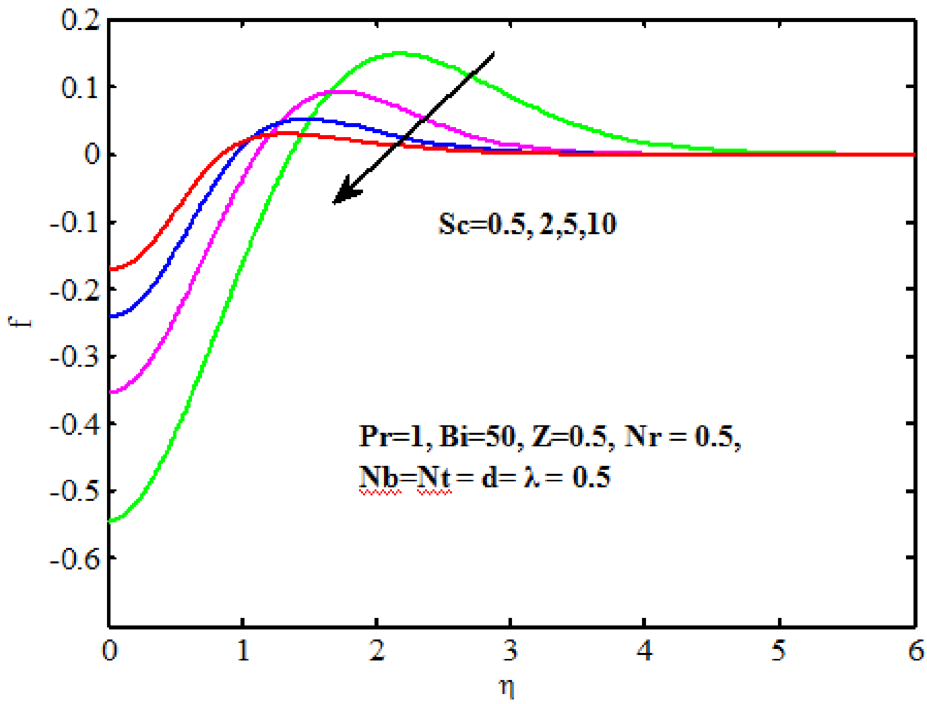

Fig.6 nanoparticle concentration profile f for different Sc.

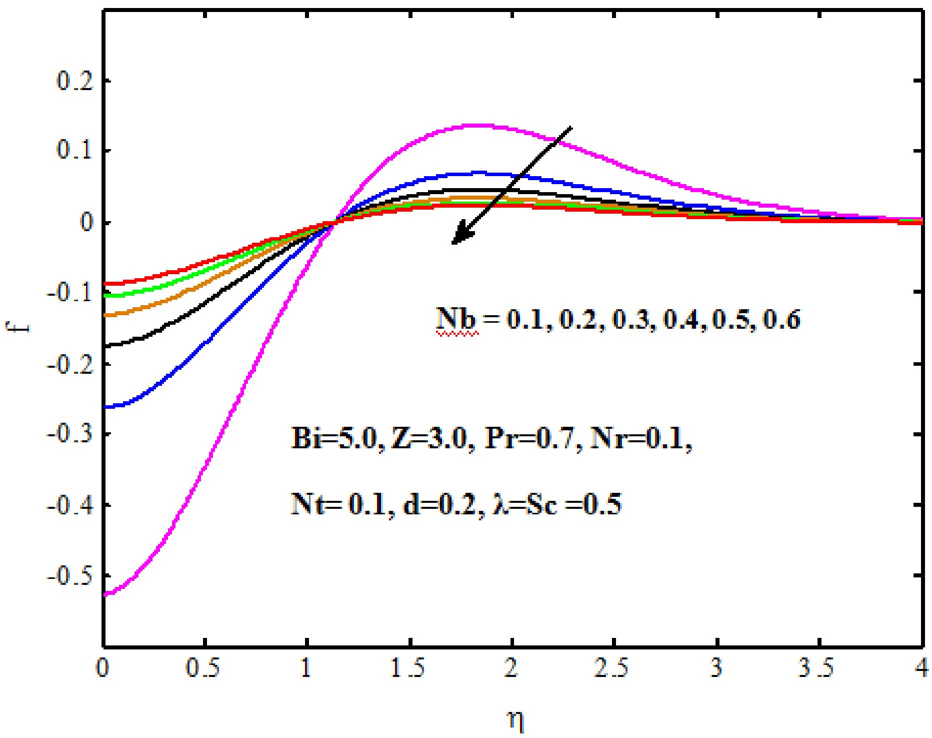

Fig.7 nanoparticle concentration profiles f for different Nb

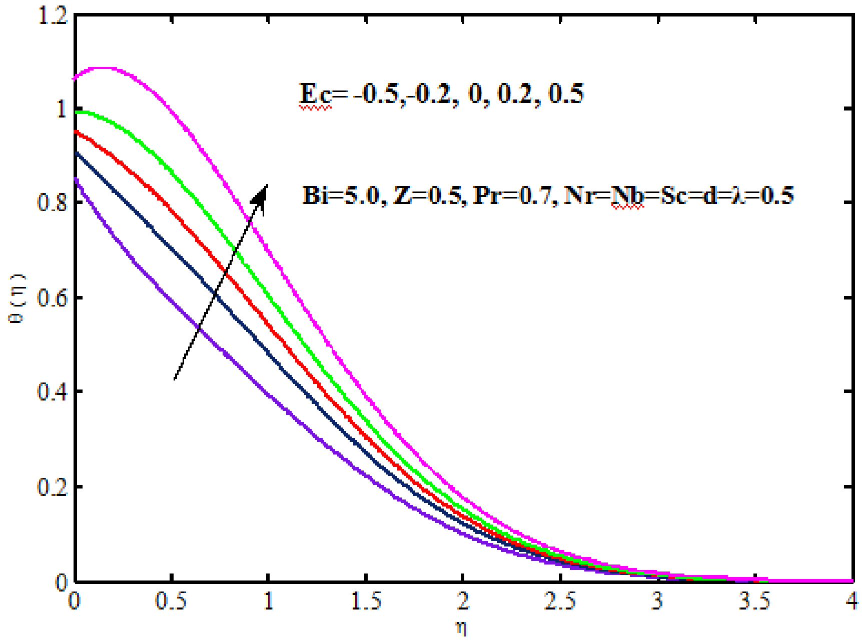

Fig.8 temperature profiles θ for different Ec.

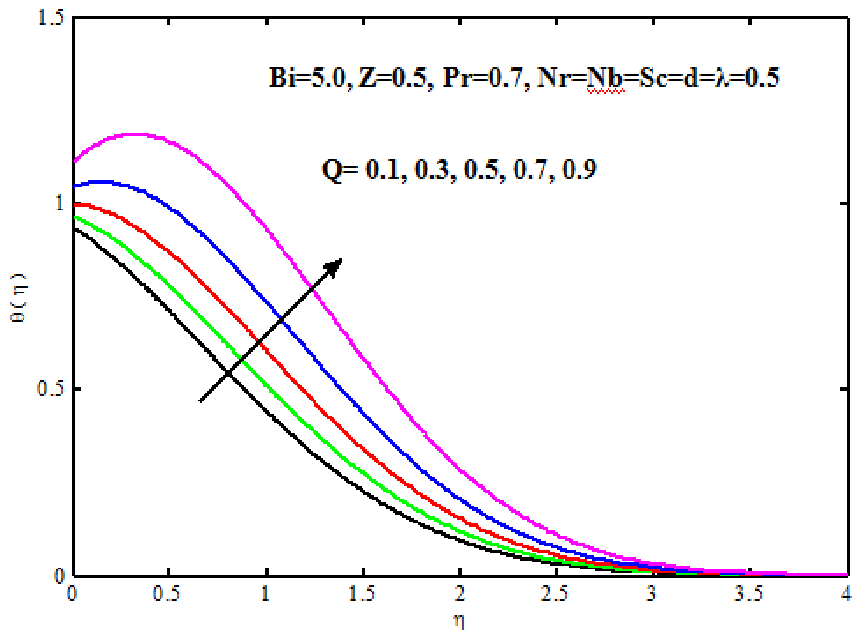

Fig.9 temperature profiles θ for different Q.

TABLE 1: Numerical results of S''(0) for various values of Z and λ with Pr = 5; d = 0.5; Nr = 0.1; Sc =0.5; Bi =5.0; Nt = 0.5; Nb= 0.5.

Z	λ	S''(0)	
		R.Ahmad et al. [14]	Present results
0	0.5	1.4294	1.4294
0.5	0.5	1.7244	1.7242
1	0.5	2.0099	2.0097
1.5	0.5	2.2874	2.2876
0.5	0	1.5394	1.5395
0.5	1	1.9023	1.9025
0.5	2	2.2416	2.2414
0.5	3	2.5631	2.5634

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