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ELECTRO-MHD FLOW AROUND BOUNDARY OVER AN IRREGULAR PENETRABLE STRETCHING SHEET IN A CASSON NANOFLUID THROUGH BOUNDARY CONDITIONS DUE TO HEAT CONVECTION AND SLIP

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ABSTRACT

This investigation involves predicament of 2D Casson liquid motion, close to boundary layer by collective cause of convective heating condition, in addition to Brownian motion as well as the rophoresis, over a nonlinear stretching sheet. A precise mathematical elucidation to boundary value problem involving nonlinear PDE's, for flow, heat and Nanoparticle concentration, variables are obtained from Runge- kutta -Fehlberg 4^{th}-5^{th} order technique. The impact of a range of various parametric quantities on Nanoparticle concentration, heat, and flow, variables are probed besides exploring by method of plots.

Key Words: Nonlinear stretching sheet; Casson liquid; Thermopheresis variable Nt; Brownian motion variable Nb, Prandtl number Pr; slip parametric quantity δ; Convective heat and mass transfer variables, $Bi1$ and Bi2 , Electric parameter E_1.

Introduction

Up to date nanotechnology perceives fresh possibilities to procedure and fabricate materials with regular crystalline range below 50 nm. Flow contiguous to boundary stratum with hotness and solutal transport are driving force of up-to-date research. Ensuing to the innovatory research by Ref [1], a colossal quantity of invented story is to hand on flow contiguous to frontier, of viscous and viscoelastic liquid flow over rectilinear and irregular sprawling surfaces. Assorted researchers have expansively well thought-out to a diversity of tribulations of flow contagious to frontier, hotness transport over rectilinear and irregular sprawling façade. (Ref [2-10]).

Ref [11-25] debated in relative to Casson nanofluid, convey over diverse geometries, and an assortment of other facets, such as stagnation point liquid motion, slip state, porous media, chemical reaction, convective state at the boundary, thermic conductivity etc.

Ref [26-35] inspected, liquid conveying excess of vertical façade with various facets, Viz, thermal radiation, natural convection, magnetic force, convective condition adjacent to boundary, porous media etc. The above-mentioned points perceived that no such research has been delineated, thus far. Hence in view of this facet, one is justified in deciding to solve this problem, enclosed. EMHD has many potential applications in radiation, viscous dissipation under heat transfer processes. It is applicable in radio transmission, astronomy, geophysics, solar and stellar structures. Saiqa Sagheer et al [36] examined study of movement of EMHD Nanofluid over a stretching sheet with impact of radiation, electric parameter along with variable heat flux and shown that, as electric field strength progresses, velocity profile does as well. Electro magneto hydro dynamic (EMHD) is study where, how electrically conducting fluid transports when subjected to magnetic and electric fields. Rashid et al [37] concentrated on the implications of EMHD on crumpled walls of microchannels in presence of porous media. Areekera et al [38], while considering the study of EMHD nanofluids investigated the significance of nonlinearly stretching sheet using the model of Casson nanofluid.

EMHD Darcy-Forchheimer flow is a subject of ongoing studies with various aspects of its consequences for dissimilar nanofluid flows. Amalgamation of MHD and electric effects finds interest to know flow characteristics in porous mediums when electromagnetic influences are present. Buttetal [39] considers investigating electromagnetic impacts to Darcy-Forchheimer flow of viscous fluid in nonlinear form. Hussain et al [40] formulated radiative transportation of nanofluid with generation of entropy and investigated impact of electromagnetic flow and heat transfer.

2 Computational Study

Casson nanoliquid, 2D motion more than a nonlinear stretching sheet, in region of y≥0, Motion is produced owing to the expansion of a thin sheet, caused to move at a certain speed, $u_w = cx^n$,

where ‘c’ = stretching rate

n = stretching nonlinear variable

Here, it is generally believed that the process of the sheet being stretched begins with a force acting simultaneously in equal and opposing directions. The motion resulting from the stretched sheet will reach a temperature Tw at the sheet's wall, while nanoparticle concentration, denoted as C, will assume the value Cw. Similarly, at a considerable distance from the flow region, they will attain the values T∞ and C∞, respectively.

Tf =convective heating variable

h =heat transfer constant.

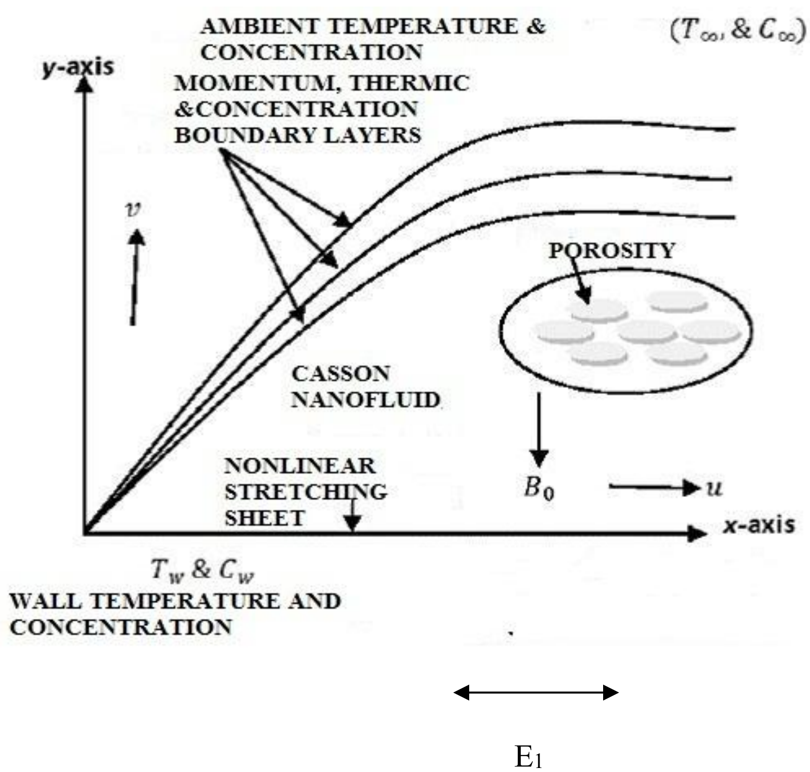

Fig A. Nano liquid motion above a nonlinear stretching sheet.

The fundamental steady motion equations concerning sheet boundaries are expressed in the context of Casson nanofluid.

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(\frac{1}{1+\beta}\right)\frac{\partial^2 u}{\partial y^2}-\frac{\sigma}{\rho}\left(B_0^2-EB_0\right)u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial y^2}\right)+\tau\left\{D_B\left(\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right)+\frac{D_T}{T_\infty}\left[\left(\frac{\partial T}{\partial y}\right)^2\right]\right\} \tag{3}$$

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

p =hydrostatic pressure

ρ_f =density

ν =kinematic viscosity

B=Casson fluid variable

α =thermal diffusivity

T =temperature

D_T =thermophoretic diffusion coefficient

E_1=Electric Parameter

D_B =Brownian diffusion coefficient

v and u = y and x components of velocity vectors

$\tau=(\rho c)_p/(\rho c)_f$ - relative amount of nanoparticle heat ability with base liquid heat capability

Circumstances at boundary, instigate slip are:

$$y=0, u=ax^{n}+N_{1}\nu\left(1+\frac{1}{\beta}\right)\frac{\partial u}{\partial y}, v==\pm v_{w}, -k\frac{\partial T}{\partial y}=h_{f}\left(T_{f}-T\right),\ D_{B}\frac{\partial C}{\partial y}=-h_{s}(C_{w}-C)\quad(5)$$

$$y\to\infty, u\to 0, \to T_{\infty}, C\to C_{\infty}, (6)$$

$$\eta=y\sqrt{\frac{a(n+1)}{2\upsilon}}x^{\frac{n-1}{2}},\ \varphi=\frac{C-C\infty}{C_{w}-C\infty},\quad u=ax^{n}f'(\eta),$$

$$v=\sqrt{\frac{a\upsilon(n+1)}{2}}x^{\frac{n-1}{2}}\left\{f=\frac{n-1}{n+1}\right\}\eta f'(\eta)\vartheta=\frac{\mathrm{T}-\mathrm{T}\infty}{\mathrm{T_f}-\mathrm{T}_{\infty}}, \mathrm{E}=ax^{\frac{n-1}{2}}, \mathrm{B}_{0}=cx^{\frac{n-1}{2}}$$

---(7)

Similarity transformations, in view of eq (7), below entered equations are obtained

$$\left(\frac{1}{1+\beta}\right)f'''+ff'-\left(\frac{2n}{n+1}\right)f'^{2}-M(f'-E_{1})=0,\ (8)$$

$$\theta''+Prf\theta'+PrNb\phi'\theta'+PrNt\theta'^{2}=0,\qquad(9)$$

$$\phi''+Lef\phi'+\frac{Nt}{Nb}\theta''=0,\ (10)$$

Conditions.at boundary are,

$$f(0)=1+\delta\left(1+\frac{1}{\beta}\right)f''(0),=1,\theta'(0)=-\left(\sqrt{\frac{1}{n+1}}\right)Bi1[1-\theta(0)],\varphi'(0)=-\left(\sqrt{\frac{1}{n+1}}\right)Bi2\left[1-\varphi(0)\right]$$

.... (11)

$$f'(\infty)=0,\theta(\infty)=0,\phi(\infty)=0,\quad ....(12)$$

here primes stand for derivative regarding η and parametric quantities appearing in Eqs. (8-12) are expounded as presented, are,

Where,

$$Pr = \frac{\upsilon}{a}, Le = \frac{\upsilon}{D_B}, Nb = \frac{(\rho c)pD_B(Cw - C\infty)}{(\rho c)_f \upsilon} \quad N_t = \frac{(\rho c)_p D_T(T_f - T\infty)}{(\rho c)_f \upsilon T_\infty},$$

$$B_i = \frac{h(\upsilon/a)^2}{k} \quad M = \frac{2\sigma c^2}{a\rho(n+1)}, f_w = -\frac{\nu_w}{(a\upsilon)^{\frac{1}{2}}}\left[\frac{2}{x^{n-1}(n+1)}\right)]^{\frac{1}{2}}, \delta = N_0(\frac{a}{2\upsilon})^{\frac{1}{2}},$$

$$B_{i1} = \frac{h_0}{k}(\frac{2\nu}{a})^{\frac{1}{2}}, B_{i2} = \frac{h_1}{D_B}(\frac{2\upsilon}{a})^{\frac{1}{2}} \quad E_{1=}\frac{a}{c^2 U_w}$$

…………………(13)

In Eq. (13), Nt, Pr, Le,M, Nb, f_w, β, δ, $Bi1$ and Bi2 stand for, the thermophoresis parametric quantity, Prandtl number, Lewis number, magnetic parametric quantity, Brownian motion parametric quantity, Suction/Injection Parametric quantity, Casson parametric quantity, slip parametric quantity, and the Biot numbers in that order

3. consequence and conversation

Eqs. (8-10) are under discussion for the conditions at the boundary, Eqs. (11) and (12), be deciphered computationally, through Runge- kutta -Fehlberg 4^{th}-5^{th} order approach

figs 1,2,3and 4,unveils the brunt of, Electric Parameter E_1 , slip parametric quantity δ, on velocity, thermic development, and solute transportation vectors, and here one observes that, velocity vector is rising with electric parameterE_1 , whereas it is diminishing with δ, while assolutal and thermal transfer vector are rising function of δ. Actually, this explains the fact that, speed, is contiguous to the sheet <speed, normal to stretching of sheet, because of slip condition. Enhancing δ ingresses additional liquid slipping in excess of the sheet and the liquid transportation slows down adjacent to the sheet.

Figures 5 and 6 lay bare the brunt of Bi1 and Bi2 on heat energy and nanoparticles, transfer vectors, when n=2, It is significance mentioning that the at hand effort reshapetoun vary ingexterior hotness, and mass transfer case, when Bi1 and Bi2, takes large values. Evidently, when Bi1 rises, dimensionless temperature rises as well.. Sheet convective heating is improved when Bi1 values increase, as can be seen in this image. As Bi2 is contrariwise correlated to Brownian diffusivity coefficient, even modest values of Bi1 rapidly rise temperature along with thickness of the related boundary layer. Consequently, momentum diffusivity increases, and thermal diffusivity decreases. Consequently, boundary layer turns thick as a result of enhancement in mass transfer.

The effect of the Caisson liquid parmetric quantity β on velocity variables is displayed in **Fig 7**. It is clear from this graph that velocity decreases as the Caisson liquid variable β increases. Reduction in velocity is also attributed to rise in liquid viscosity caused by acquiescence stress.

Figure 8 shows the available velocity vectors $f'(\eta)$ for varying the suction/injection parametric quantity f_w; as the parameter's cumulative values increase $(f_w \prec 0)$, the velocity $(f_w \prec 0)$ in boundary layer area declines; and as parameter's cumulative values rise (f_w>0), the vector $f'(\eta)$ experience upward movement.

Fig.9 displays the upshot of magnetic field parametric quantity, M on velocity variable $f'(\eta)$ plus it is percieved that velocity variable diminishes as M surges, this is since, Lorentz energy be prone tothwart the velocity of liquid motion, inside boundary layer, ensuing in boundary layer width thinning, which concurs over the outcome of an assortment of results in print hitherto.

It is pragmatic in view of **fig.10**, brunt of nonlinear stretching parametric quantity n, on velocity variable $f'(\eta)$ is to diminish in magnitude of velocity to some extent, with supplement of nonlinear stretching parametric quantity n.

We observed that the temperature allocation decreased as the Casson liquid parametric quantity β was increased in **Figure 11**, which depicts the control of this quantity on the heat transfer vector. The behavior of temperature vector quantity is similar to that of velocity vector for different values of β. This is because, as β decreases, velocity field in boundary layer also decreases, preventing the liquid particles from colliding too severely, leading to a reduction in temperature vector.

Figure 12 shows influences of Nb and Nt on, and increasing Nb and Nt causes the nanoparticles in the liquid to move more haphazardly, which focuses on the thermal boundary layer thickness esunveil enrichment then quickly reins in assonnano liquid's heat. Practically speaking, in thermophoresis, the hotter particles close to surface travel away from the hotter regions and in direction of colder area, increasing the total heat of the scheme. Because of the constant collision between the nanoparticles plus molecular motion of regular liquid, the random movement of nanoparticles within regular liquid is known as Brownian motion.

As shown in **Figure 13**, effect of Le, on temperature vector is most clear in an area immediately surrounding sheet surface, since curves in the plot are more likely to blend together at greater distances from surface. In boundary layer region, the Lewis number shows how the thermic dissemination pace compares to the species dissemination pace. Increasing Le will lead to a decline in thickness of thermal boundary layer and a corresponding decrease in thermal transport. As Le increases, the concentration vector values of nanoparticles will decrease, which will limit the spread of nanoparticle species. Concentration boundary layer thickness is observed to be significantly reduced as a result of a rise in Le, compared to thermic boundary layer thickness.

Fig. 14 exemplify the brunt of Biot number on thermic boundary layer. As predictable powerful convection outcome in high, temperature at the surface gives rise to the thermic upshot to go through extensive into the liquid which is at rest.

Fig. 15 unveil that as Prandtl number shoot up, depth of thermic boundary layer diminish in view of curve becoming more and more precipitous. As a repercussion, decreased Nusselt number, actuality comparative to initial slope, enhances. This prototype is evocative of natural convective boundary layer liquid motion inside regular liquid.

Fig 16 depicts the stimulus of M, on the temperature vector is perceptible only in an area in line to sheet surface, as curves incline to join at larger distances from surface of sheet. Enlarged values of M augments rate of heat transport and consequently temperature enhances within the boundary layer. Seemingly for greater M, Lorentz energy augments which supplements opposite forces to liquid particles ensuing in upsurge of hotness in thermic boundary layer area.

As seen in **Figure 17**, temperature vectors $\theta(\eta)$ in boundary layer decrease as sum of f_w increases, but as f_w quantity increases (f_w >0), the temperature vectors $\theta(\eta)$ exhibit an incremental trend.

The upshot of Nt along with Nb on Nanoparticle concentration vector $\varphi(\eta)$, is portrayed concurrently in **Figure 18, as well as Figure 19.** It is apparent by **Figure 18,** that greater values of Nb lessens the nanoparticle concentration. This happens because the nanoparticle concentration boundary layer gets hotter thanks to Brownian motion, which in turn increases particle dislocation away from liquid organization and results in degree of nanoparticle concentration vector to fall. As displayed in **Fig 19**, values of Nanoparticle concentration vector ($\theta(\eta)$) increase as Nt do.

Fig 20 shows result of on nanoparticle concentration vector ($\theta(\eta)$). The Nanoparticle concentration vector ($\theta(\eta)$), in contrast to the temperature vector, is only mildly pretentious when considering the intensity of thermophoresis along with Brownian motion. Upon comparing **Figures 13** and **20**, it becomes evident that the concentration spreading is significantly impacted by the Lewis number Le **(Fig. 20)**, while the hotness dissemination is not stimulated by it (Fig. 13). A smaller Brownian diffusion coefficient D_B **(refer to Eq.(19))** indicates a smaller penetration depth for concentration boundary layer in a regular liquid with a fixed kinematic viscosity ν , and a larger Lewis number (Le) suggests this.

It was detected in **Figure 21** that as heating due to convection of sheet is enriched i.e. *Bi* upsurges, then thermic diffusion deepness upsurges. Since concentration dissemination is determined by temperature vector field, and one antedates that a greater Biot number may endorse a deeper dispersion of concentration. This expectation is certainly comprehended in **Figure 21** that anticipates greater concentration, at greater Biot number values.

4.INFERENCE

The existing literature presents a 2DCassonnano liquid motion problem involving convection near the boundary layer and nonlinear stretching sheets as a collective cause of heat. Using the extremely well-structured Runge-Kutta Fehlberg algorithm, the solutions are numerically resolved and outcomes are illustrated by plots.

The most important results of our investigation are listed below.

In this case, we proved that Electric Parameter E1 increases as the velocity vector does, while β decreases as the velocity vector does. E1 also increases as the thermic and concentration transport vectors do.

Additionally It has long been recognized that δ boosts, thickness of momentum boundary layer. The Bi1 and Bi2 are enhancing functions of both thermic transport besides concentration transport vectors. On top of that, Nt is known to be an incremental function of the vectors representing thermal transport and concentration transport.

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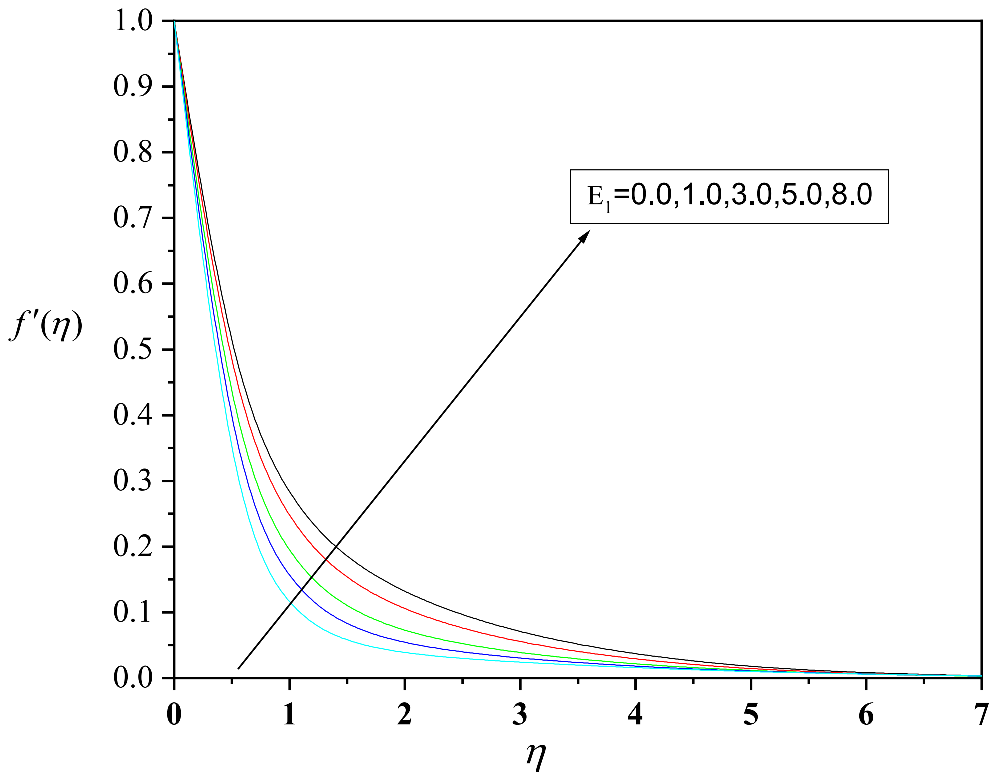


Fig 1 . Effect of Electric parameter E_1 on velocity profile, when M =1, n =2,

$Nt = Nb$ **=0.1,** $Le = Pr = 5,\ f_w = 0.5$. β=0.6, $Bi1 = 0.2$, Bi2=0.4

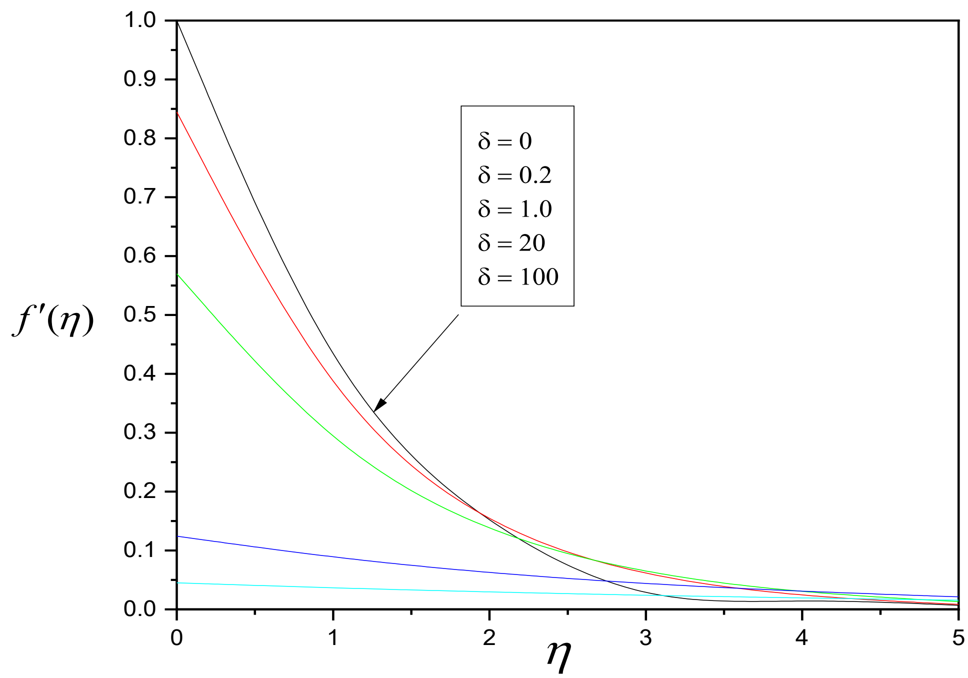


Fig 2 Effect of slip parameter δ on velocity profile, when, E_1=0.1, M ***=1,*** η ***=2,***

$Nt = Nb$ **=0.1,** $Le = Pr = 5$, $f_w = 0.5$ **.** β=0.6, $Bi1 = 0.2$, Bi2=0.4

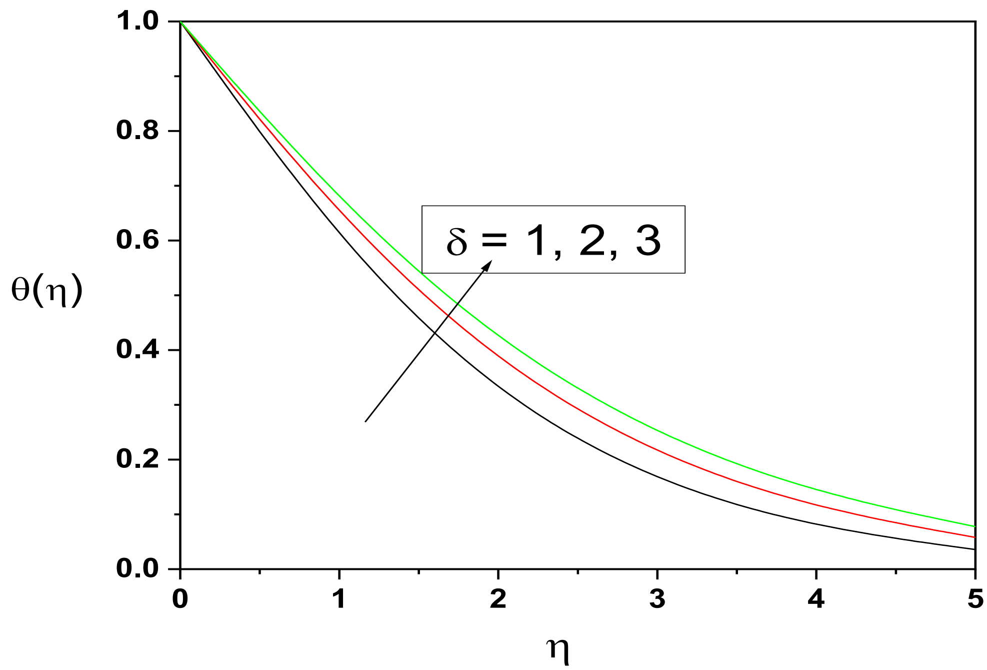
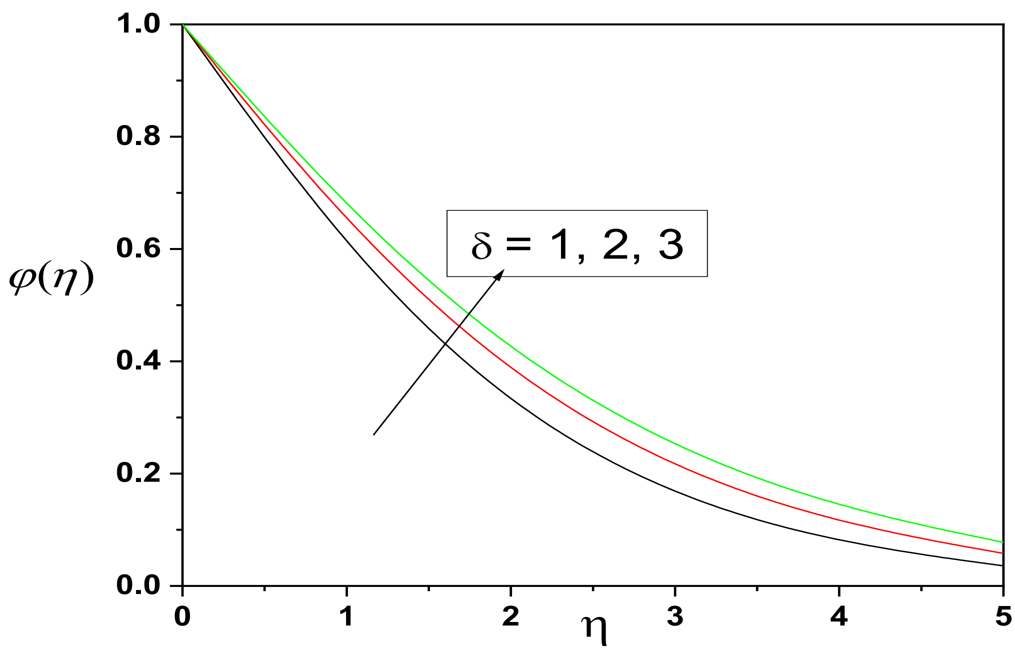


Fig.3. Effect of temperature profile θ(η) for different values of Navier slip parameter δ, When β=0.6, M ***=1,*** n ***=2,*** $Nt = Nb$ ***=0.1,*** $Le = Pr = 5$, $f_w = 0.5$ **,** $Bi1$ =0.2,Bi2=0.4.



1.0
0.8
0.6
0.4
0.2
0.0
$\varphi(\eta)$
δ = 1, 2, 3
0
1
2
3
4
5
η

Fig.4. Concentration profile φ(η) for different values of Navier slip parameter δ, when M ***=1,*** n ***=2,*** $Nt = Nb$ ***=0.1,*** $Le = Pr = 5$, $f_w = 0.5$ β=0.6, $Bi1 = 0.4$, $Bi2$=0.4.

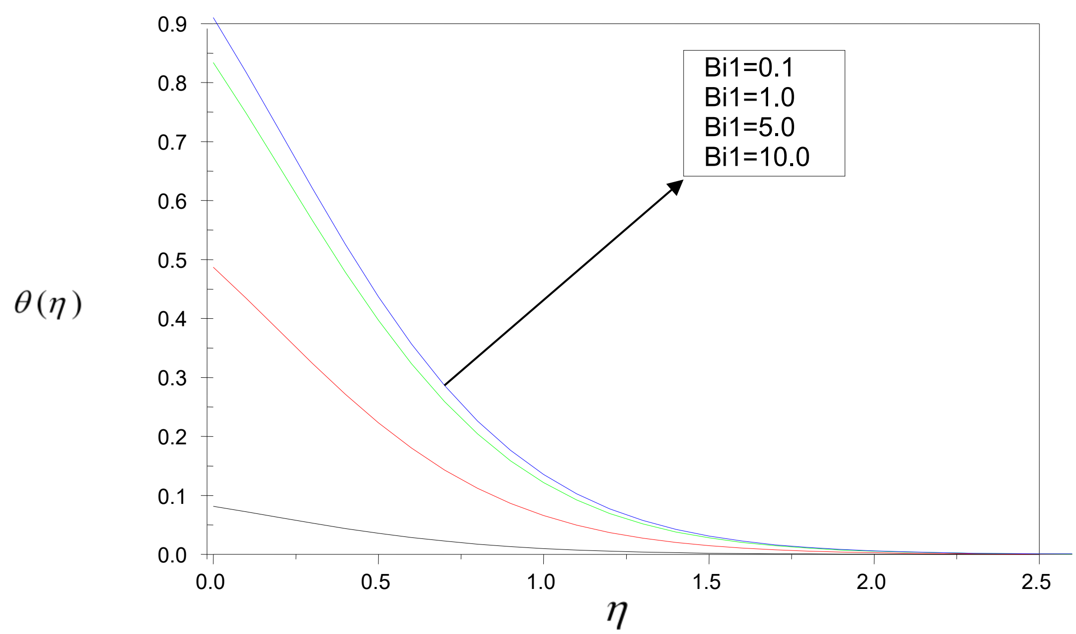


Fig.5. Temperature profile θ(η) for different values of convective heat transfer parameter* Bi1, *when M ***=1,*** n ***=2,*** $Nt = Nb = Bi2$ ***=0.1,*** $Le = Pr = 5$, $f_w = 0.5$**.**β=0.6,***δ=0.4.***

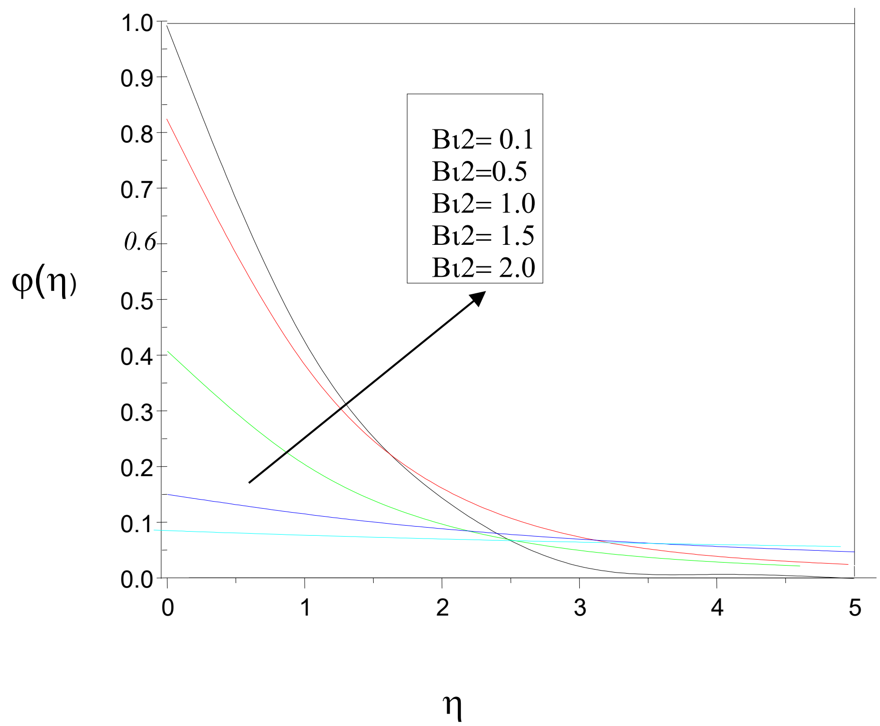


Fig.6 Concentration profile φ(η) for different values of Navier slip parameter δ,when, M ***=1,*** n ***=2,*** $Nt = Nb = Bi1$ ***=0.1,*** $Le = Pr = 5,$ $f_w = 0.5$ ***β=,δ=0.4.***

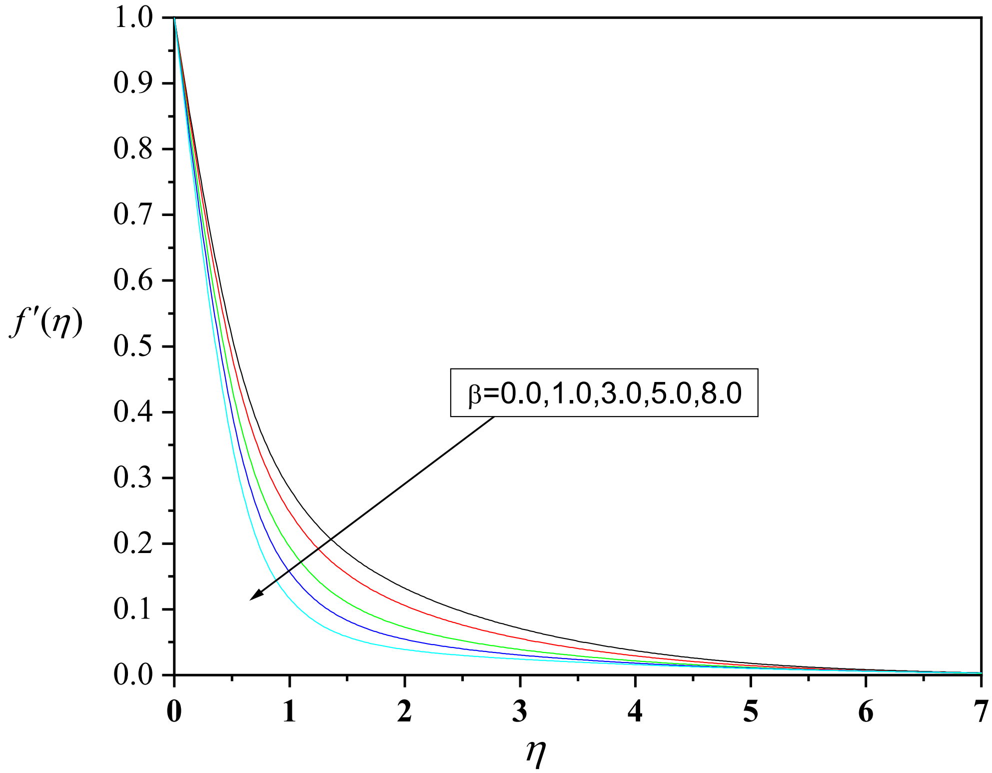


Fig 7. Effect of velocity profiles for different values of β, when E1=0.1, M ***=1,***

n=2, $Nt = Nb$ ***=0.1, β=0.6,*** $Le = Pr = 5$, $f_w = 0.5$ **.** δ=0.6, $Bi1 = 0.2$, Bi2=0.4.

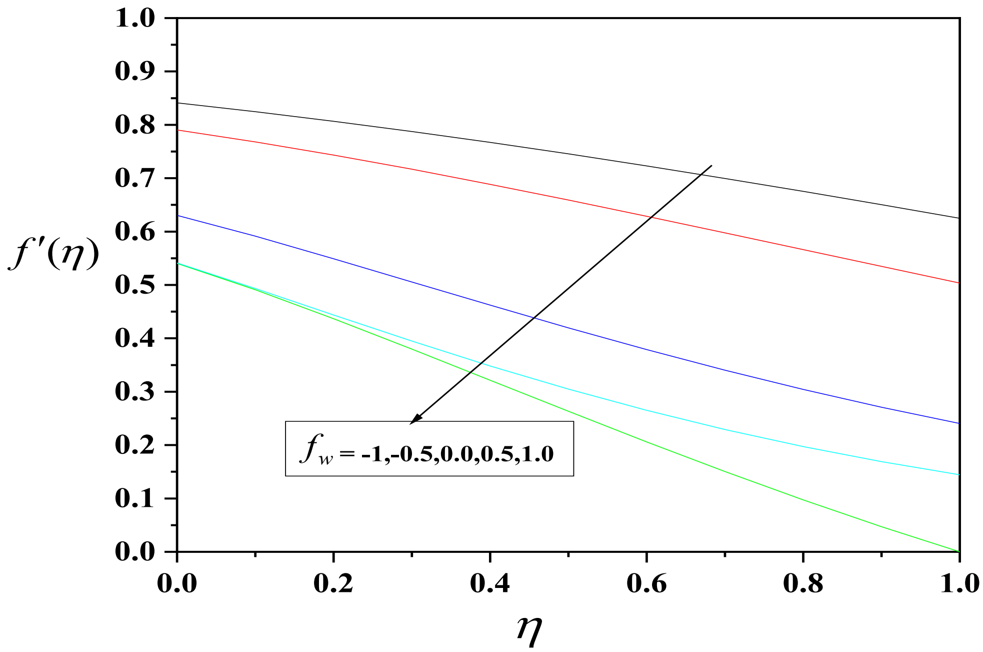


Fig. 8Effect of f_w on velocity profiles when M =1, E_1=0.1, η=2, δ=0.6,

$Nt = Nb$ ***=0.1,β=1.0.*** $Bi1 = 0.2$, $Bi2$=0.4.

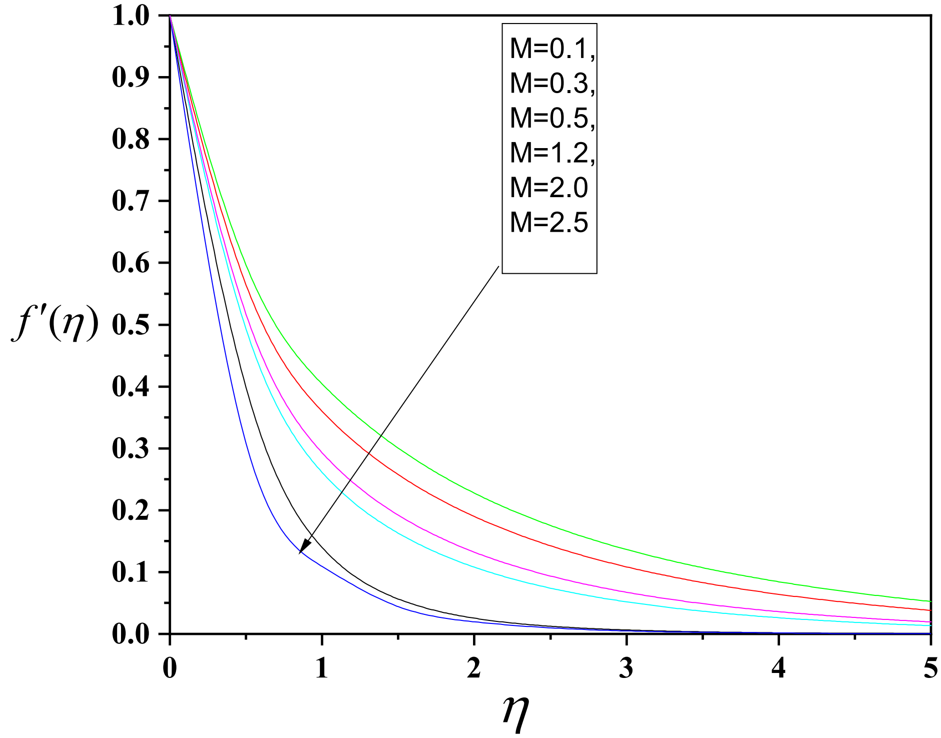


Fig 9Effect of M on velocity profiles $f'(\eta)$***,when,E_1=0.1,***

Nt=Nb=0.1,δ=0.6,Le=Pr=5,n=2, β=1.0, $f_w = 0.5$ ***,*** $Bi1 = 0.2$, $Bi2=0.4$.

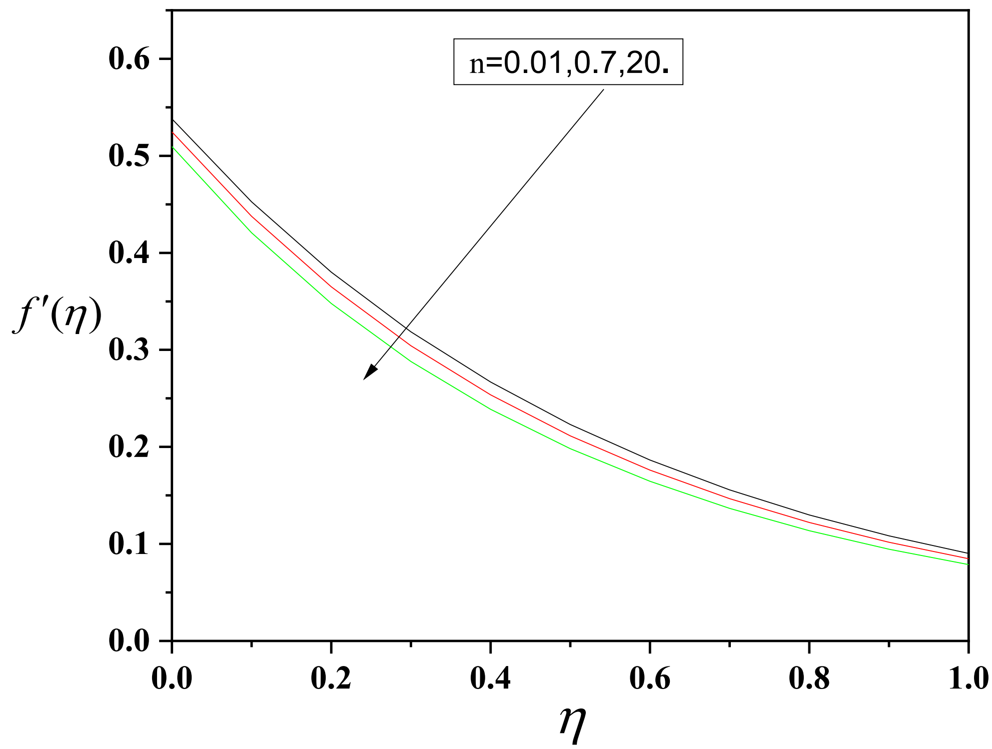


Fig.10. Effect of nonlinear stretching parameter n on velocity profile $f'(\eta)$ ***for various values of*** E_1***=0.1, δ=0.6,*** $Nt = Nb = 0.1, Le = Pr = 5., M = 2, \ \beta = 0.5.$ $f_w = 0.5,$ $Bi1 = 0.2, \ Bi2 = 0.4.$

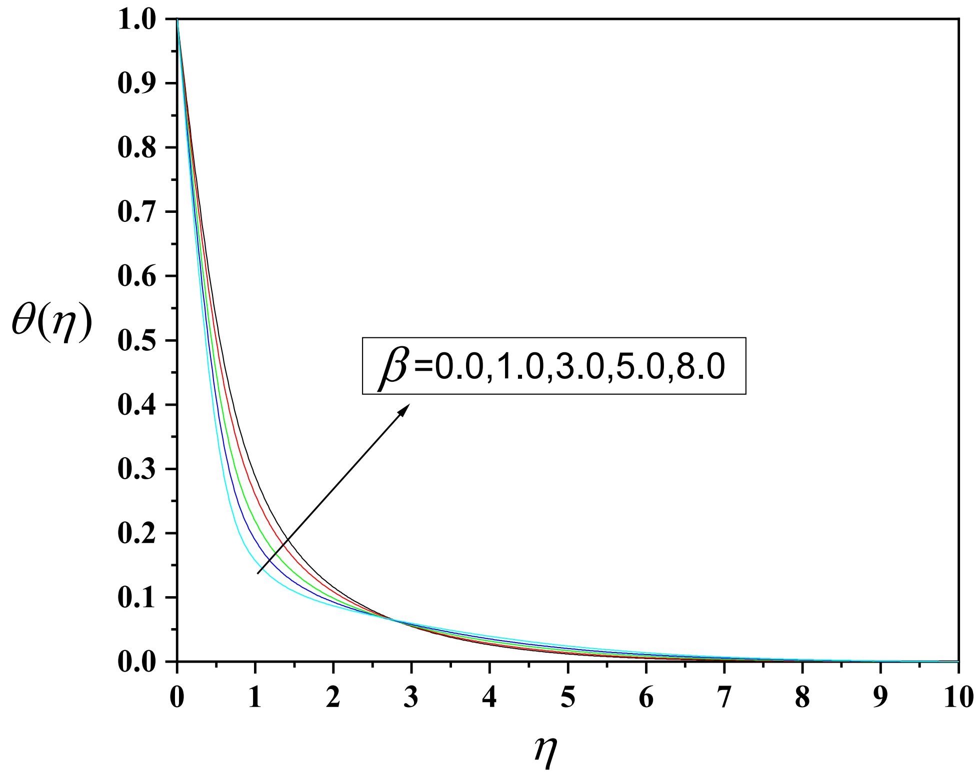


Fig11. Effect of Casson parameter β on temperature profile, for different values of $Nt = Nb = Bi = 0.1, Le = Pr = 5., M = 2.$ $n = 0.7, f_w = 0.5.$ $Bi1 = 0.2,$ $Bi2=0.4.$

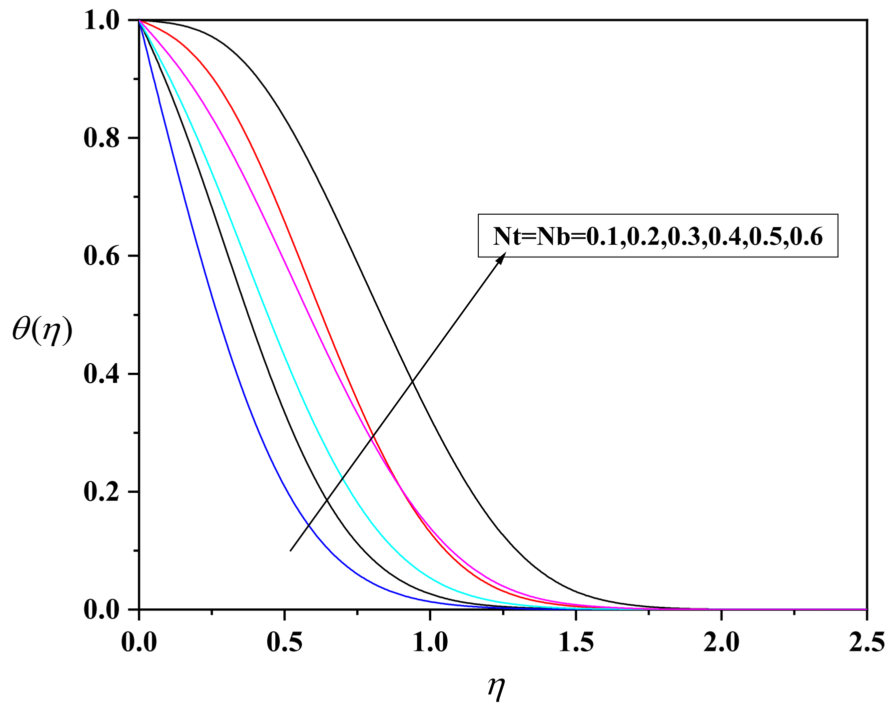


Fig 12. Effects of Nt and Nb on temperature profiles,for,δ=0.6, M=2, n=2,

$Le = 5, Pr = 5, f_w = 0.5, \beta = 5.0.\ Bi1 = 0.2,\ \ Bi2=0.4.$

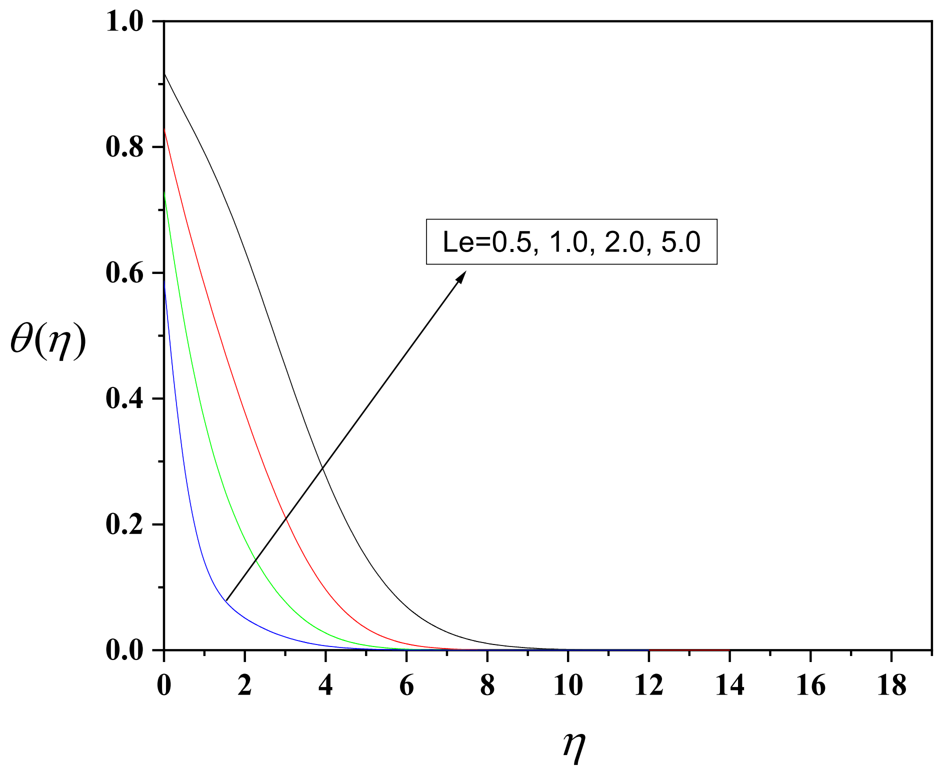


Fig.13 Effect of Le ***on temperature profiles*** $\theta(\eta)$ ***whenδ=0.6,***

$Bi1 = 0.2$, $Bi2=0.4$, ***M=2,*** $Nt = Nb = 0.1, Pr = 5,$ $\beta = 5.0, f_w = 0.5, n = 2.$

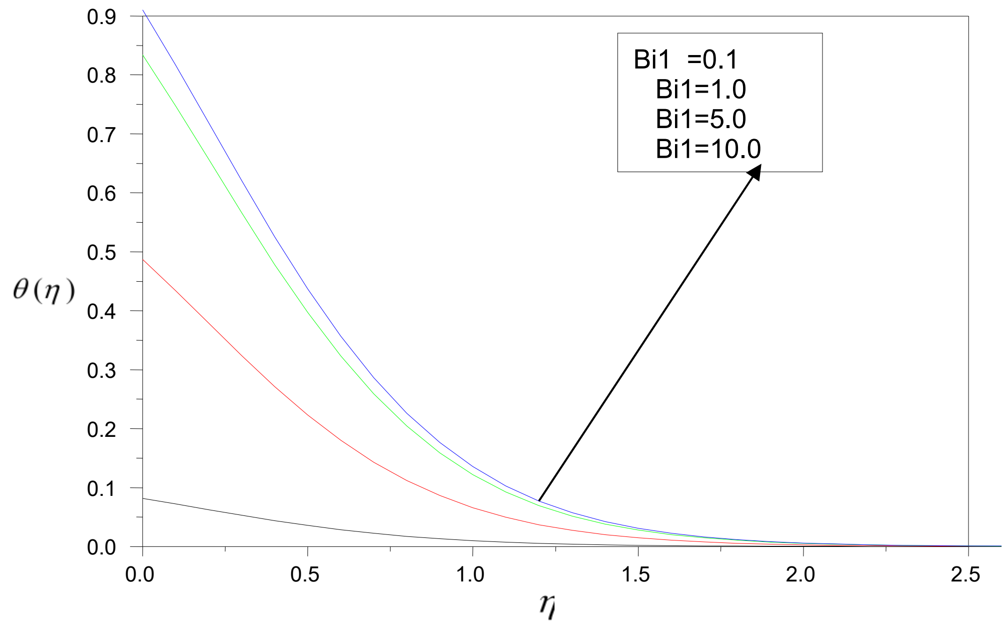


Fig. 14 Effect of Bi **on temperature profiles** $\theta(\eta)$ **when** $Bi2=0.4.$ **M=2,δ=0.6,**

$Nt = Nb = 0.1, Pr = Le = 5,\ \beta = 5.0, f_w = 0.5, n = 2.$

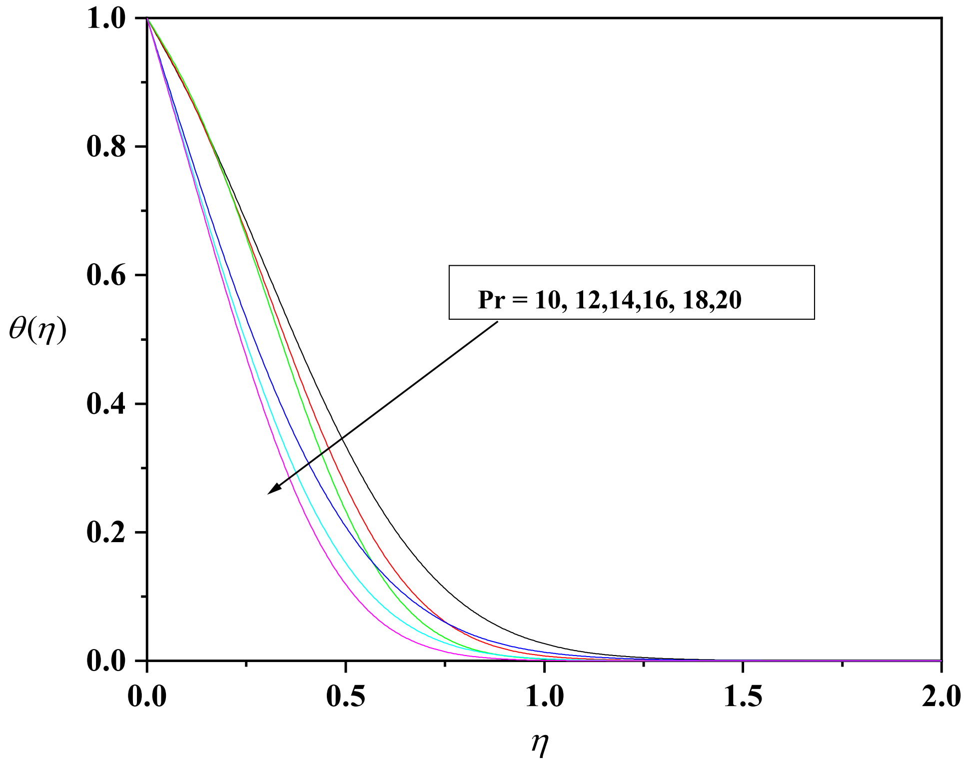


Fig.15 Effect of Pr ***on temperature profiles when*** $Bi1=0.2$, $Bi2=0.4$, ***δ=0.6,***

M=2, $Nt=Nb=0.1, Le=5,$ $\beta=5.0, f_w=0.5, n=2.$

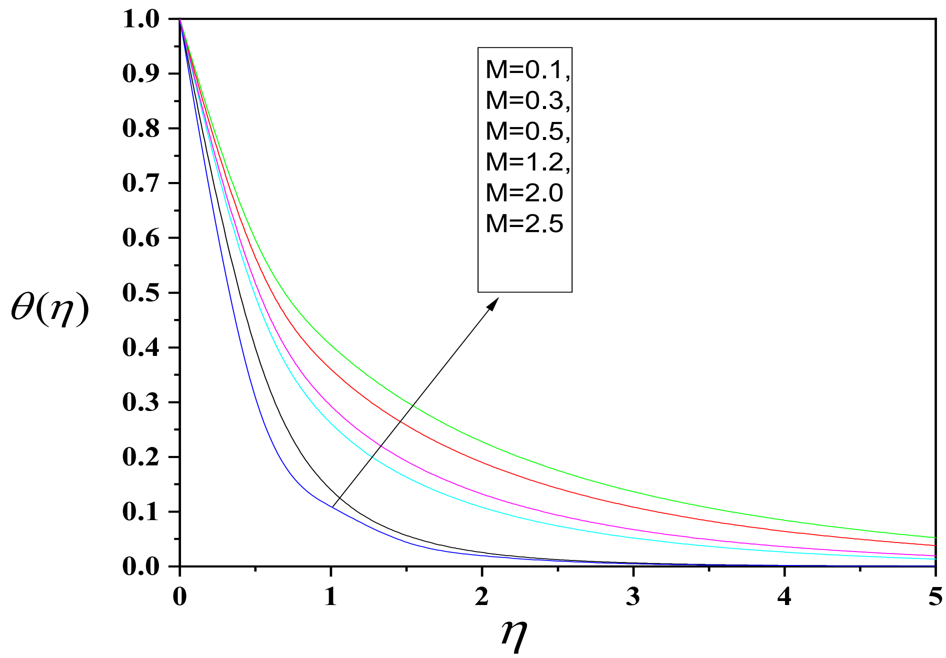


Fig16. Effect of M ***on temperature profiles when*** $Bi1 = 0.2$, $Bi2=0.4$. ***δ=0.6,***

$Nt = Nb = 0.1, Le = Pr = 5$, $\beta = 5.0, f_w = 0.5, n = 2.$

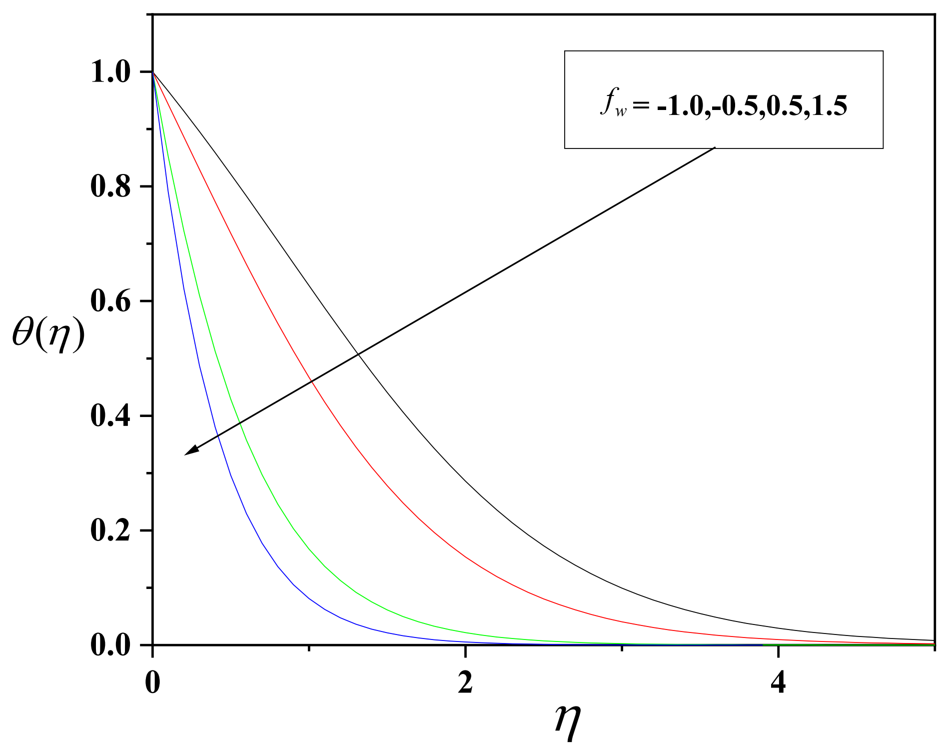


Fig17. Effect of suction/injection parameter f_w ***on Temperature profiles*** $\theta(\eta)$ ***when,*** $\delta=0.6$, $Bi1=0.2$, $Bi2=0.4$, $Nt=Nb=0.1, Le=Pr=5, M=2.$ $\beta=5.0, n=2.$

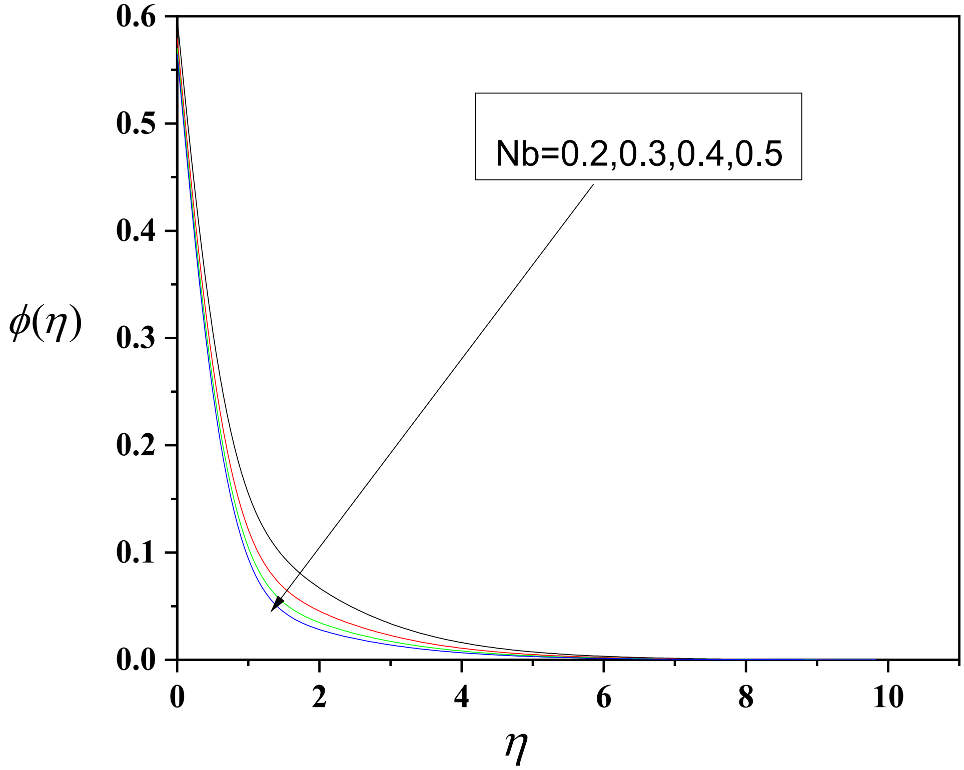


Fig 18.Effects of Nb on concentration profiles$\varphi(\eta)$,

When,M=2, n=2,δ=0.6,Nt=0.5, $Le = 5, Pr = 5,$ $f_w = 0.5,$ $\beta = 5.0$.

$Bi1 = 0.2,$ $Bi2 = 0.4.$

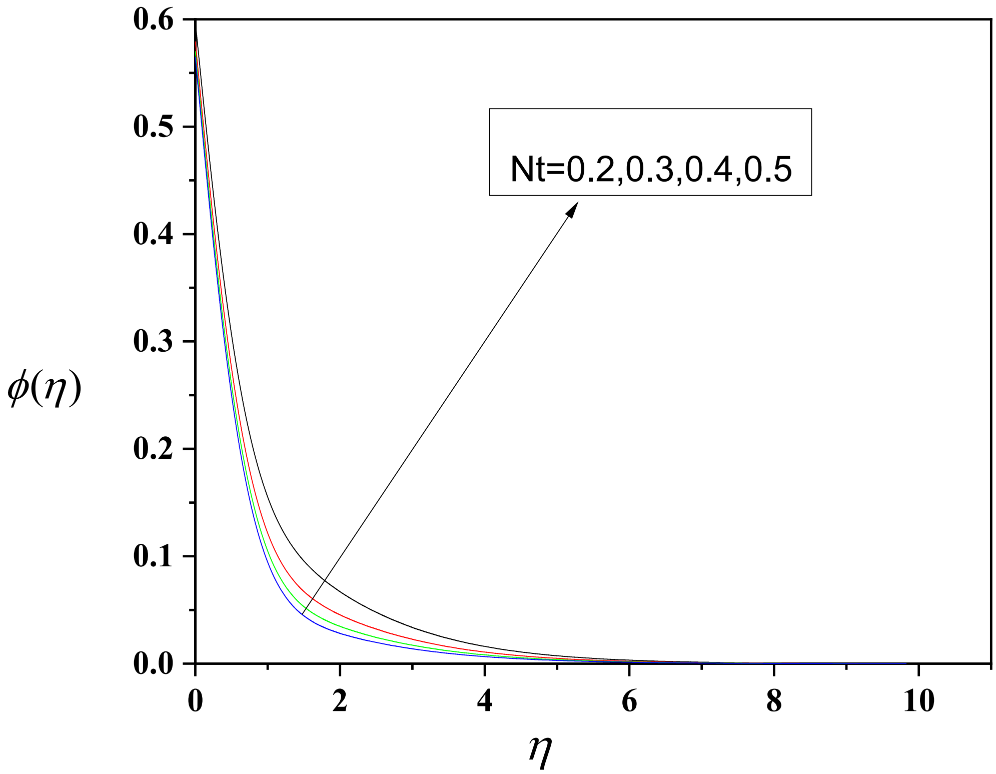


Fig 19. Effect of Nt on concentration profile,When,M=2,δ=0.6, n=2,Nb=0.2,

$Le = 5, Pr = 5, f_w = 0.5, \beta = 5.0$. $Bi1 = 0.2$, $Bi2$=0.4.

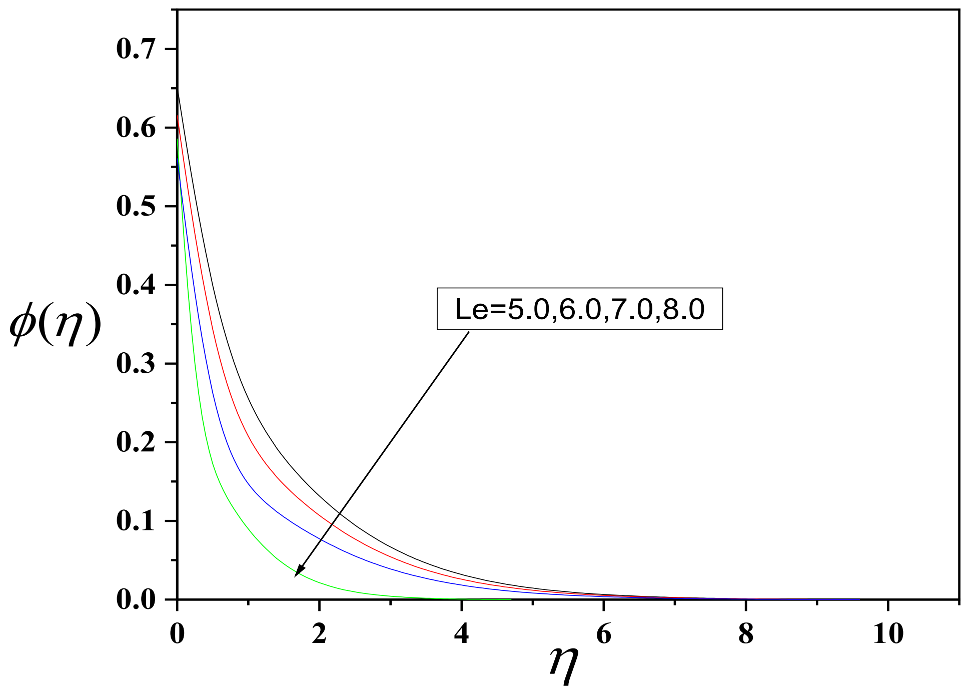


Fig20. Effect of Le on concentration profiles $\varphi(\eta)$, when δ=0.6,

$Nt = Nb = 0.1, Bi1 = 0.1, Bi2 = 0.3, M = 1, n = 2, \Pr = 5, f_w = 0.5, \beta = 5.0.$

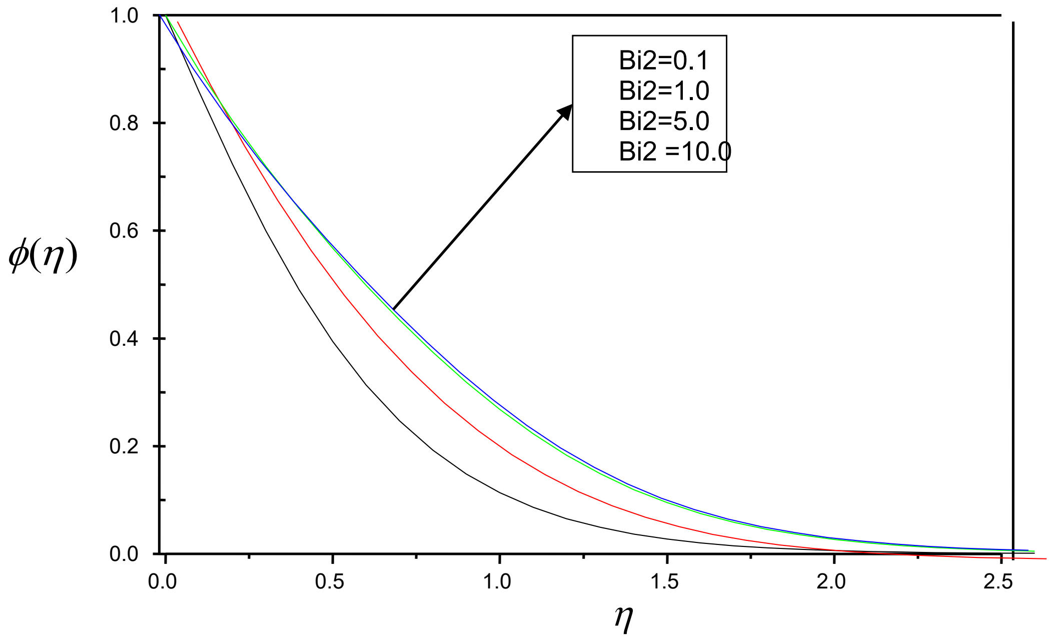


Fig21. Effect of $Bi2$ ***on concentration profiles*** $\phi(\eta)$ ***when*** $Nt = Nb = 0.1, Le = 5.0, Bi1 = 0.2, M = 1, n = 2, \Pr = 5, f_w = 0.5, \beta = 5.0.$