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Characteristic of Thermal Radiation on MHD Fluid Stream of Nano-Fluid over an Exponentially Elongating Sheet by Means of Warm and Mass Fluxes

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ABSTRACT

The present explore effort addresses the impact of radiation on MHD stream of an incompressible nano fluid due to an elongating elongating piece by warm and mass fluxes border situation. Similarity transformations are applied to attain the self-similar equations which are then solved numerically by means of shooting procedure alongside by means of 4th order Runge-Kutta method. Features of a variety of sundry constraints on the non-dimensional stream, thermal, nanoparticle volume fraction, local Nusselt & local Sherwood figures are visualized. Moreover the numerical values of friction factor, local Nusselt and Sherwood figures are also computed and analyzed.

1. Introduction

In recent years, the investigation of stream and warm transport over a elongating surface have achieved extensive attention for the reason that of its broad applications, suchas continuous casting, exchangers, metal spinning, bundle wrapping, foodstuff processing, destructive chemical processing, equipment and polymer extrusion. Crane [1] was the first who study the fluid of Newtonian stream caused by an elongating expanse. Many researchers Dutta *et al.,* [2], Chen and Char [3] and Gupta [4] modified the work of Crane [1] by taking the consequence of mass transport under various circumstances. Nadeem *et al.,* [5] took the exponential elongating sheet to discuss the warm transport phenomenon of water-based Nano-fluid. Mukhopadhyay *et al.,* [6] scrutinized the warm transport stream over a porous exponential elongating sheet by means of thermal radiation. Zhang *et al.,* [7] concentrates the warm transport of the power law Nano-fluid thin film occur due to a elongating sheet in the presence of stream slip consequence and magnetic field. The border layer

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stream of ferromagnetic fluid over a elongating surface is demonstrated by Majeed *et al.,* [8]. Pal and Saha [9] examined the unsteady elongating sheet to discuss the warm and mass transport in a thin liquid film by means of the consequence of non linear thermal radiation. Weidman [10] studied a unified formulation for stagnation point streams by means of elongating surfaces.

The study of magneto hydrodynamics(MHD) stream of an electrically conducting liquid over a elongating sheet has promising applications in modern metallurgical as well as in metal-working procedures [11-16]. Many professional techniques regarding polymers oblige the cooling of unbroken strips and filaments by sketch them from moving fluid. The closing product depends greatly on the rate of cooling that is governed by the structure of the border layer close to the elongating sheet. Mukhopadhyay *et al.,* [17] studied MHD stream of Casson fluid due to exponentially elongating sheet by means of thermal radiation. The characteristics of magneto hydro dynamics in bi-directional stream of Nano-fluid focus to second order slip stream and homogeneous– non-homogeneous reactions is investigated by Hayat *et al.,* [18]. Lin *et al.,* [19] examined unsteady MHD Nano-fluid flow of thermal transport in a finite film of thin pseudo-plastic in presence of heat source. Sheikholeslami *et al.,* [20] analyzed the MHD flow of Nano-fluid steam and warm transport by means of the help of two-phase model by means of radiation. Function of the HAM-based Mathematica enclose BVP h 2.0 on MHD Falkner–Skan stream of Nano-fluid is provided by Farooq *et al.,* [21]. Shehzad *et al.,* [22] presented an analytical study to investigate thermal radiation possessions in 3D stream of Jeffrey nano-fluid by means of internal warm creation and magnetic field.

The significance of radiation cannot be mistreated in the processes that are performed at extremely high temperature. The radiative possessions are also significant in gas turbines, armaments, aircraft, space vehicles and nuclear control plants [23-26]. The communication of radiation in thermally convective stream of viscous liquid over an inclined surface is derived by Moradi *et al.,* [27]. Sheikholeslami *et al.,* [28] proposed the impact of viscous Nano-fluid strean by means of two phase model with thermal radiation. non-turbulent stream of an Oldroyd-B liquid by means of nanoparticles with various constraints is examined by Hayat *et al.,* [29]. Ashraf *et al.,* [30] investigated the 3D radiative stream of Maxwell fluid flow by means of thermophoresis and convective situations. Hayat *et al.,* [31] developed a model of non- turbulent stream of Powell-Eyring Nano-fluid over a elongating sheet due to radiation property.

Additionally, the convective circumstances are extra useful and realistic in transpiration cooling process, fabric drying etc. Aziz [32] proposed the convective circumstance in border layer stream of viscous fluid past a flat cover. Hayat *et al.,* [33] studied the possessions of Joule warming and thermophoresis in elongated stream of Maxwell model under convective circumstance. Sakiadis stream of Maxwell fluid by means of convective border circumstance is developed by Mustafa *et al.,* [34]. Hayat *et al.,* [35] systematically discussed the stagnation aim stream of Maxwell fluid in the occurrence of warm radiation and convective circumstance. Hayat *et al.,* [36] investigated disposed magnetic field and warm source/sink aspects in stream of Nano-fluid by means of nonlinear warm radiation. Nonlinear radiative stream of 3D Burgers Nano-fluid by means of new mass flux consequence is worked out by Khan *et al.,* [11].

In the current manuscript, the thermal radiation possessions magneto hydro dynamic (MHD) stream of an incompressible nano fluid due to an exponentially elongating sheet by means of warm and mass fluxes circumstancesis studied. With the help of similarity transformations, the leading partial differential equations are changed into the self-similar ordinary differential equations which are afterwards solved numerically by the shooting process.

2. Formulation

Consider the exponentially elongating sheet of three dimensional hydromagnetic stream of an incompressible fluid. Warm and mass transport scrutiny is considered in the presence of thermal radiation, warm source/sink and destructive chemical reaction. A non-uniform magnetic field $B(x) = B_0\, exp(x/2l)$ is functional in the *y*-direction. Induced magnetic pitch for tiny magnetic Reynolds number is abandoned. We forced the warm and mass fluxes border circumstancesat the surface of the sheet. The leading equations of movement may be written as

(i) Continuity

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

(ii) Momentum

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u \tag{2}$$

(iii) Energy

$$\begin{aligned} u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}&=\alpha\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}\\ &\quad+\frac{(\rho c)_p}{(\rho c)_f}\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]\end{aligned} \tag{3}$$

(iv) Nanoparticle volume fraction

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

subject to the border circumstances

$$\begin{aligned} &u=U_w(x)=\mathrm{U}_0\exp\left(\frac{x}{l}\right),\ v=-V(x),\\ &\frac{\partial T}{\partial y}=-\frac{q_w(x)}{\alpha},\ \frac{\partial N}{\partial y}=-\frac{q_{np}(x)}{D_B},\ \ at\, y=0\end{aligned} \tag{5a}$$

$$u\to 0,\ T\to T_\infty,\ N\to N_\infty,\ \text{as}\, y\to\infty \tag{5b}$$

Here *u* and *v* indicate the stream components in the *x* and *y* directions correspondingly, v the kinematic viscosity, $\alpha=\dfrac{k}{\rho c_p}$ the diffusivity of thermal , *k* the density of fluid, ρ the conductivity of thermal , c_p the specific warm, *T* the liquid temperature, *T*∞ the ambient temperature, *N* the liquid concentration, *C*∞ the ambient concentration, $\alpha = k/\rho c_p$ the thermal diffusivity, *k* the thermal conductivity, *cp* the specific warm, $q_r = \frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial T}{\partial Y}$ the radiative warm flux, k^* the mean incorporation coefficient, σ^* the Stefan-Boltzmann constant, $(\rho c)_p$ the consequenceive warm capacity of nanoparticles, $(\rho c)_f$ warm capacity of the base fluid. *N* is nanoparticle volume, *D* the mass diffusion $U_w(x) = \mathrm{U}_0 \exp(x/l)$ is the elongating stream of sheet, *U*0 the reference stream, *l* the reference length, $q_w(x) = q_{w0}\,\mathrm{T}_0\sqrt{U_0/2\nu l}\,\exp(x/l)$ the variable warm flux, $q_{np}(x) = q_{np0} C_0 \sqrt{U_0/2\nu l}\,\exp(x/l)$ the unpredictable surface nanoparticle flux, U_0 , T_0 , q_{w0} , q_{np0} , N_0 , are the reference stream, temperature and warm flux, surface nanoparticle flux, nanoparticle volume fraction respectively, $V(x) = V_0 \exp(x/l)$ a special type of stream at the wall is considered (Bhattacharyya [12]) where V_0 is a constant. Here $V(x) > 0$ is the stream of suction and $V(x) < 0$ is the stream of injection.

Introducing similarity transformations as follows

$$\begin{aligned}
&\eta = y\left(\frac{U_0}{2\nu x}\right)^{1/2}\exp\left(\frac{x}{l}\right),\ \psi = \left(2\nu U_0 x\right)^{1/2} f(\eta)\exp\left(\frac{x}{l}\right),\\
&u = U_0 f'(\eta)\exp\left(\frac{x}{l}\right),\ v = -\sqrt{\frac{\nu U_0}{2l}}\exp\left(\frac{x}{l}\right)\left[f(\eta) - \eta f'(\eta)\right],\\
&T = T_\infty + \frac{q_{w0}}{\alpha} T_0 \exp\left(\frac{x}{l}\right)\theta(\eta), C = C_\infty + \frac{q_{np0}}{\alpha} C_0 \exp\left(\frac{x}{l}\right)\phi(\eta)
\end{aligned} \tag{6}$$

If the dimensional stream function $\psi(x,y)$ then $u = \frac{\partial\psi}{\partial y}$ and $u = -\frac{\partial\psi}{\partial x}$.

The continuity equation is automatically satisfied and using similarity transformation, the system of Eq. (2), (3) and (4) becomes

$$f''' + ff'' - 2f'^2 - Ha^2 f' = 0 \tag{7}$$

$$\left(1 + \frac{4}{3}R\right)\theta'' + \Pr\left(f\theta' + f'\theta + N_b\theta'\phi' + N_t\theta'^2\right) = 0 \tag{8}$$

$$\phi'' + Le(f\phi' - f'\phi) + \frac{N_t}{N_b}\theta'' = 0 \tag{9}$$

Here primes mean differentiation by means of respect to η, $Ha = \frac{\sigma B_0^2(x) l}{\rho U_w(x)}$ is the Hartmann number, $\Pr = \frac{\nu}{\alpha}$ is the Prandtl number, $R = \frac{4\sigma^* T_\infty^3}{kk^*}$ is the radiation constraint and $Le = \frac{\nu}{D_B}$ is the Lewis number, $N_b = \frac{(\rho c)_p \, q_{np0}}{(\rho c)_f \, \nu} N_0$ is the Brownian movement constraint and $N_t = \frac{D_T}{T_\infty} \frac{(\rho c)_p \, q_{w0}}{(\rho c)_f \, \alpha \nu} T_0$ is the thermophoresis constraint, respectively. The transformed border circumstances (5a) and (5b) are given by

$$\begin{aligned} &f(0) = S, \ f'(0) = -1, \ \theta(0) = -1, \ \phi(0) = -1 \\ &f'(\infty) = 0, \ \theta(\infty) = 0, \ \phi(\infty) = 0 \end{aligned} \tag{10}$$

where $S = \frac{-v_0}{\sqrt{\nu c / 2l}}$ is suction/injection constraint. Here the constraint is positive S >0 (v_0<0) for mass suction and negative S <0 (v_0>0) for mass injection.

The substantial quantities of attention are the local skin friction factor, the wall warm transport factor (or the local heat transfer factor) and the wall deposition flux (or the local Stanton number) which are defined as respectively where the factor of friction C_f, the warm transport $q_w(x)$ and the mass transport Sh_x from the wall are given by

$$\sqrt{2C_f \operatorname{Re}_x} = f''(0), \ C_f = \frac{u}{U_w \exp(x/l)} \left(\frac{du}{dy} \right)_{y=0}, \tag{11}$$

From the temperature field, we can study the rate of warm transport which is given by

$$\frac{Nu_x}{\sqrt{\operatorname{Re}_x}} = -\sqrt{\frac{x}{2l}} \left(1 + \frac{4}{3} R \right) \theta'(0), Nu_x = -\frac{x}{(T_w - T_\infty)} \left(\frac{\partial T}{\partial y} \right)_{y=0} \tag{12}$$

From the concentration field, we can study the rate of mass transport which is given by

$$\frac{Sh_x}{\sqrt{\operatorname{Re}_x}} = -\sqrt{\frac{x}{2l}} \phi'(0), \ Sh_x = -\frac{x}{(C_w - C_\infty)} \left(\frac{\partial C}{\partial y} \right)_{y=0} \tag{13}$$

where $\operatorname{Re}_x = U_0 x / \nu$ the local Reynolds number.

3. Method of Solution

The scheme of ODEs (7) – (9) subject to the border circumstances (10) are solved numerically using Runge–Kutta fourth-order integration by means of shooting procedure. A step size of $\Delta\eta = 0.01$ was certain to be satisfactory for a convergence standard of 10^{-6} in all belongings. The results are presented graphically in Figure 1 – 6 and conclusions are drawn for stream field and other physical quantities of interest that have significant possessions.

4. Results and Discussion

For the illustration of the marks, Eq. (7) –(9) by means of border circumstances(10) are solved numerically by Runge–Kutta fourth-order integration by means of shooting method and numerical values are plotted in Figure 2 – 6. The leading constraints are keeping fixed as *Ha*=1.0, *S* = 3.0, *Le* = 1.3, *R* = 0.1, Pr = 0.71, *Nt* = 0.8 and *Nb* = 0.5 throughout the computations. The influence of the involving constraints Hartmann number *Ha*, Lewis number *Le*, Radiation constraint *R*, thermophoresis number *Nt*, suction constraint *s* and Brownian movement constraint *Nb* on the stream, temperature and nanoparticle volume friction profiles. Figure 1(a)-(c), respectively, illustrate the stream, temperature and nanoparticle volume friction profiles for various values of suction constraint S. From Figure 1(a) , the stream profiles increase by means of increasing in suction constraint. It is also observed Figure 1(b) that the temperature decreases when suction constraint increases. Further, from Figure 1(c), it is found that nanoparticle volume friction decreases as suction constraint increases.

The outcome of the Hartmann number on the stream, temperature and nanoparticle volume friction profiles are offered in Figure 2(a)-(c), respectively. We observe from Figure 2(a) that the stream profiles increase by means of increasing values of Hartmann number. Physically by increasing magnetic field the Lorentz force increases. More resistance is offered to the movement of fluid and thus the stream of the fluid is increased. It is also seen Figure 2(b) that the temperature decreases as Hartmann number increases. In addition, from Figure 2(c) it is found that nanoparticle volume fraction profile increases, as Hartmann number increases.

Figure 3(a)-(b) display the possessions due to thermophoresis constraint *Nt* on temperature and nanoparticle volume fraction are represented. Due to amplify of thermophoresis constraint, both the temperature (Figure 3(a)) and nanoparticle volume fraction (Figure 3(b)) profiles enhance. Thermophoresis constraint *Nt* is the ratio of the nanoparticle diffusion to the thermal diffusion in the Nano-fluid. Due to amplify in *Nt* the temperature dissimilarity between the sheet and the fluid increases and as a consequence thermal border layer increases in this case. By means of the amplify in *Nt*, thermophoresis force increases which helps the nanoparticle to move from warm to freezing regions. Owing to this movement nanoparticle volume fraction increases.

Figure 4(a)-(b) depict the influence of radiation constraint *R* on thermal and volume of nanoparticle fraction profiles. It is eminent that well-built values of *R* improve the thermal profile. This is owing to the cause that an amplify in *R* corresponds to slighter mean inclusion factor. We observe from Figure 4(b) that as *R* amplify the nanoparticle volume fraction outline enlarges.

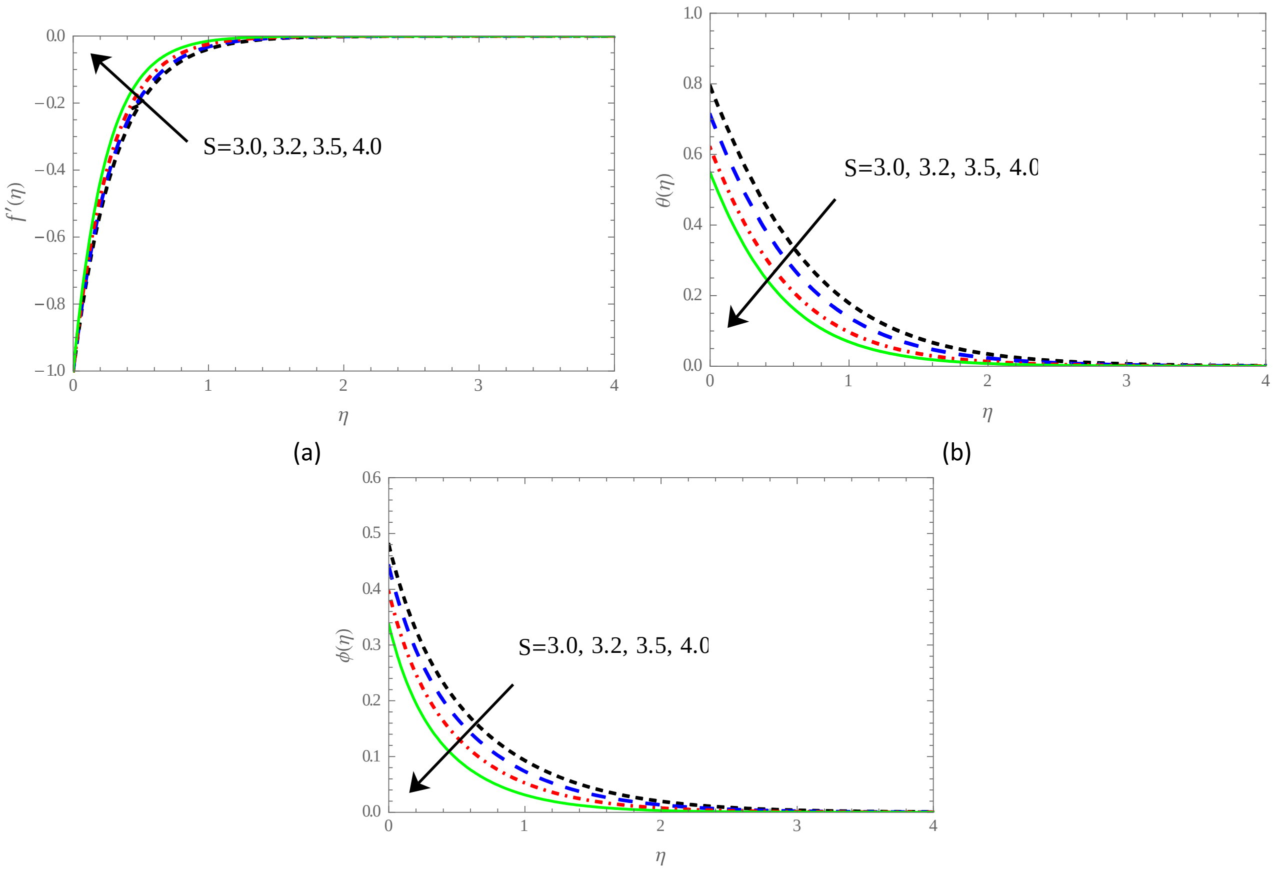
Finally, Figure 5 and 6 demonstrate the possessions of Lewis number *Le* and movement of Brownian constraint N_b on the nanoparticle volume fraction outlines, respectively. It is pragmatic from Figure (5) that nanoparticle volume fraction distribution decreases as Lewis number increases. This is probably because of the fact that an amplify in *Le* results in smaller Brownian diffusion coefficient D_B which restricts nanoparticles to infiltrate deeper into fluid. Consequently, a thinner nanoparticle volume fraction occurs for a higher Lewis number *Le*. Moreover, the reduction is occurs in nanoparticle volume fraction profile by means of increasing values of Brownian movement constraint N_b. This may consequence in the thickening of thermal border layer. Actually, a rise in Brownian movement causes an increase in the diffusion of nanoparticles which reduces the concentration inside the border layer.

Numerical data of the influences of a variety of constraints of importance on heat transfer rate and mass transfer rate are deliberated in Table 1. Tabulated ideals obviously specify that the value of Nusselt number amplifies by increasing *R* while it dwindles by means of an amplify in the values of

Ha and *S*. On the other hand, Sherwood number increases by increasing the values of *Ha* and *R*, but opposite behaviors for higher *S*.

Table 1
Numerical values of local Nusselt number and local Sherwood number for different values of Ha, R and S when Ha=1.0, Nt=0.8, Nb=0.5, Pr=0.71, R=0.1 and Le = 1.3.

Constraints(fixed values)	Constraints	$\mathrm{Re}_x^{-1/2} Nu_x$	$\mathrm{Re}_x^{-1/2} Sh_x$
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *R*=0.1, *Le*=1.3	*Ha*=1.0	0.451145	0.294788
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *R*=0.1, *Le*=1.3	1.5	0.438589	0.287824
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *R*=0.1, *Le*=1.3	3.0	0.403746	0.267842
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	*R*=0.10	0.460557	0.381022
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	0.15	0.466654	0.377892
Nt=0.8, *Nb* = 0.5, *S*=3.0, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	0.30	0.467774	0.377317
Nt=0.8, *Nb* = 0.5, *R*=0.1, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	*S*=0.5	0.415307	0.251433
Nt=0.8, *Nb* = 0.5, *R*=0.1, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	0.6	0.423403	0.262577
Nt=0.8, *Nb* = 0.5, *R*=0.1, *Pr*=0.71, *Ha*=1.0, *Le*=1.3	0.8	0.440726	0.278440

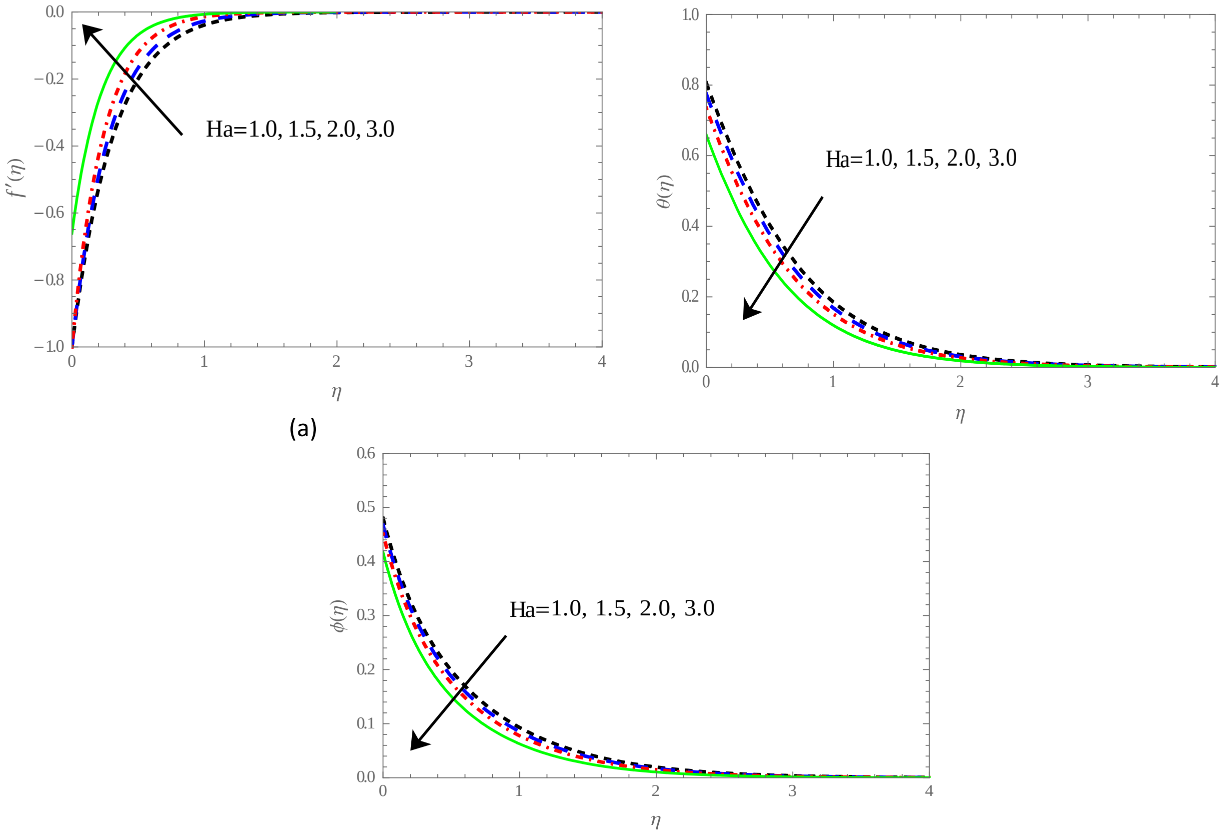


(a)

(b)

(c)

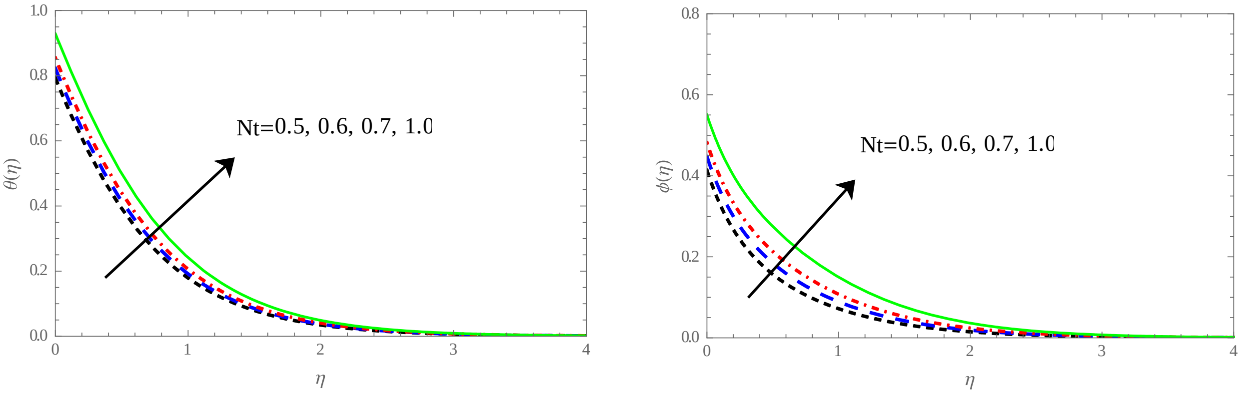
Fig. 1. (a) Consequence of S on $f'(\eta)$ (b) Consequence of S on $\theta(\eta)$ (c) Consequence of S on $\phi(\eta)$



(a) (b)

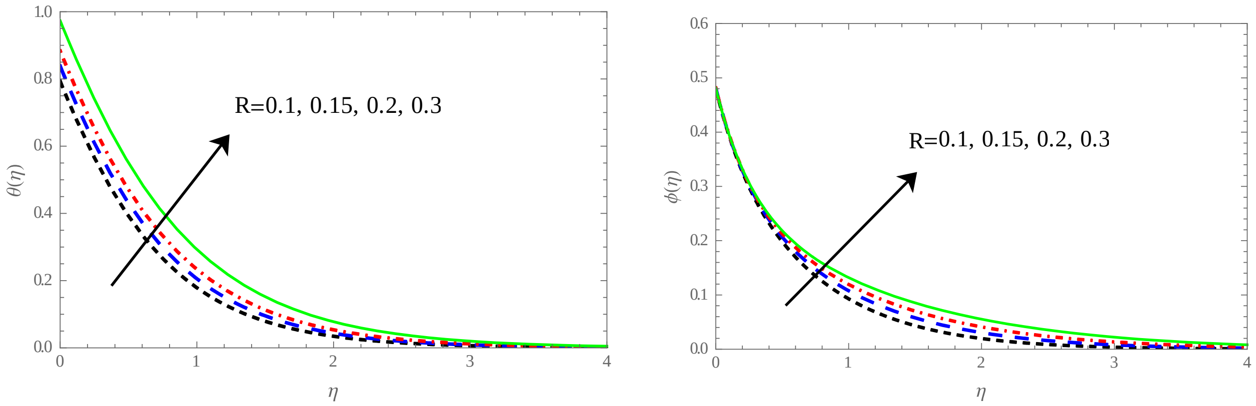
(c)

Fig. 2. (a) Consequence of Ha on $f'(\eta)$ (b) Consequence of Ha on $\theta(\eta)$ (c) Consequence of Ha on $\phi(\eta)$



(a) (b)

Fig. 3. (a) Consequence of Nt on $\theta(\eta)$ (b) Consequence of Nt on $\phi(\eta)$



(a) (b)

Fig. 4. (a) Consequence of R on $\theta(\eta)$ (b) Consequence of R on $\phi(\eta)$

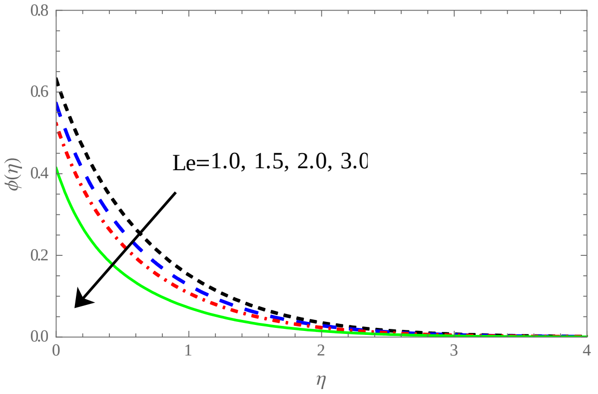


Fig. 5. Consequence of Le on $\phi(\eta)$

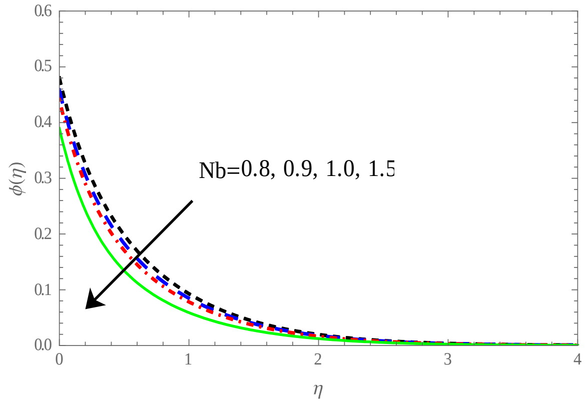


Fig. 6. Consequence of Nb on $\phi(\eta)$

5. Conclusion

Combined possessions of thermal radiation and Magnetohydrodynamics in stream of Nano-fluid and warm and mass transport analysis by an exponentially starching sheet by means of warm and mass flux circumstances have been examined. The leading PDEs have been rendered into a lay down of nonlinear joined, ODEs using appropriate transformations and the consequential well-posed border value problem has been solved numerically using the Runge–Kutta fourth order based shooting method. Possessions of pertinent constraints on stream, temperature and nanoparticle volume friction fields are discussed by means of graphical illustrations. From the present study, the main conclusions may be summarized as follows

i. Stream profile and border layer thickness increase via mixed convection constraint k.
ii. Temperature field hðgÞ yields a decrease via larger Prandtl number
iii. The nanoparticle volume fraction increases as the value of squeeze constraint decreases.
iv. Upper values of ratio constraint A marks in the decline of temperature summary and enhancement in local rate heat transfer .
v. The nanoparticle volume fraction increases as the value of squeeze constraint decreases.
vi. Local rate of mass transfer is increasing function of n; A; Sc and c

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