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MHD And Thermal Radiation Effects of a Nanofluid over a Stretching Sheet Using HAM

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Abstract: In the present paper, we made an attempt to identify the governing conditions of heat and flow of a nanofluid over a flat plate using Homotopy analysis method (HAM). The arrangement of coupled nonlinear differential (CND) conditions is obtained from the partial differential conditions which will be determined by the homotopy analysis method (HAM). These methods will be useful to draw the conclusion based on the numerical and Graphical results of various parameters such as speed (velocity), concentration and temperature for different values of developing parameters shown in figures. Variations of skin-friction coefficient, Sherwood number and local Nusselt number have shown alongside. Finally conclusions have been drawn based on both diagrams and numerical results, it indicates that the non-linear partial differential equations are changed into a system of CN ODE's and solved mathematically by using HAM method with shooting technique.

Keywords : MHD; thermophoresis parameter; Brownian motion parameter; transpiration parameter; thermal radiation; Heat source; HAM.

I. INTRODUCTION

Nanofluids are attracting a great deal of interest due to the enormous applications. It defines an important class of fluids, which has a distinctive ability to improve the thermal properties of fluids. The compelling thermal conductivity of the base fluid is appreciably enhanced as a consequence of the addition of small amount of nanoparticles according to the experimental verification by Choi [1]. Kleinstreuer and Feng [2] derived the experimental and theoretical investigations of nanofluid thermal conductivity improvement. The examination to compare heat transfer and nanofluid thermal conductivity improvements given by Yu et al. [3]. Eapen et al. [4] derived the classical nature of thermal conduction in nanofluids. Chitra and Sendhilnathan [5] investigated on the thermal studies of nanofluids related to their applications. The effects of thermophoresis and Brownian motion added into nanofluid method were first derived by Buongiorno [6]. Immense literature on nanofluid flow can be found in [7-11].

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Heat transfer and the boundary layer flow from nanofluids over an expanding sheet act as key areas of present research. These studies discover wide applications in the spectrum of engineering and allied sciences. Heat transfer characteristics plays crucial role in the boundary layer stream of a nanofluid. Kuznetsov and Nield [12] have considered Brownian motion and thermophoresis effect to observe the natural convective boundary-layer stream of a nanofluid. Khan and Pop [13] followed the same to identify the boundary layer of a nanofluid past a expanding sheet by assuming the fixed surface temperature.Magnetohydrodynamic boundary-layer flow of nanofluid and heat transfer has wide applications in almost all areas. Mabood et al. [14] addressed a study on Magnetohydrodynamic boundary layer flow of nanofluids over a nonlinear stretching sheet in occurence of heat transfer effect. Analytical solution of natural convective flow of a nanofluid over a expanding sheet under the influence of magnetic field was presented by Hamad [15]. Ibrahim et al. [16] described MHD stagnation point flow and heat transfer due to nanofluid. MHD limit layer stream of a nanofluid past a wedge was completed by Srinivasacharya et al. [17]. Numerous procedures in engineering areas happen at high temperature and information of radiation imperative for the designing the equipments namely missiles, storage bed, the automic power plants etc., Nadeem and Ul-Haq [18] studied effect of magnetodydrodynamic and radiation affects on flow of a nanofluid in a porous shrinking sheet. The influence of radiation on MHd flow of a non-Newtonian fluid was given by Khan et al. [19]. Turkyilmazoglu and pop[20] proposed the combined effects of heat and mass transfer on natural convective flow of some nanofluids. Olarewaju etal [21] developed a model on nanofluids with thermal radiation effects. Sometimes we may be observed that difference between ambient fluid and the surface, this may cause the strong influence on the heat transfer characteristics. Ögut [22] prepared the natural convection flow of nanofluid based on water in an inclined enclosure with a heat source effect. MHD stream of a nanofluid over a porous sheet based on Heat source and chemical reaction effects was studied by Anwar et al.[23]. Chamkha and Alymhd [24] derived the free convective flow of a nanofluid past a vertical plate in occurence of the heat source. MHD boundary layer flow of a nanofluid over a convectively heated expanding sheet under the influence of heat source with convective slip flow conditions was described by Uddin et al. [25]. Representative investigations deals with absorption or heat generation effects have been reported previously by authors Khan [26], Ifsana et al. [27], Ganga [28], Ahmed [29], etc.,

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From the existing literature, there is no evidence reported that the impacts of radiation and heat source on MHD boundary layer stream of a nanofluid. Using suitable transformations to convert these basic governing conditions into ordinary differential equations and these are solved mathematically by using HAM. The outcome of incorporated physical constraints on temperature concentration, and velocity sketches are shown graphically. Also the heat, friction factor as well as mass transfer are deliberated by diagrams and tables.

II. FORMULATION OF THE PROBLEM

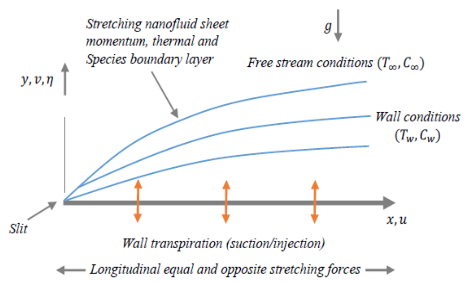

Fig. 1 Nanofluid expanding sheet flow

In the present study, we try to understand the laminar, incompressible, steady, boundary layer flow of a nanofluid. The concurrent use of two equivalent and inverse forces along the x-axis actuates flow given by the affect of non-linear expanding sheet which was extended with a speed (velocity) $u_w = ax^n$ with the origin fixed,

where n - nonlinear expanding parameter, a- fixed constant x-coordinate of stretching surface. Importance of this law was given by Krajnik et al [30] here we observed that constant temperature and concentration of expanding surface T_w and C_w are thought to be more than the fixation C_∞ and ambient temperature T_∞. Recently, Rana and Bhargava [31] were noted presence of pressure gradient and Neglecting buoyancy. Pressure gradient presence, conservation equations and edge effects, mass, energy, momentum and nano-particle species equations are.

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0, \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}, \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_m\nabla^2 T+\tau\left[D_B\frac{\partial C}{\partial y}.\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]-\frac{1}{(\rho c)_f}\left(\frac{\partial q_r}{\partial y}\right)+\frac{Q_0}{(\rho c)_f}(T-T_\infty) \quad (3)$$

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

where u,v :speed parts along the directions of x and y axis,

ν : kinematic viscosity of nanofluid,

$\alpha_m=\frac{k_m}{(\rho c)_f}$: thermal diffusivity of nano liquid,

$\tau=\frac{(\rho c)_p}{(\rho c)_f}$: extent between the warmth limit of the base liquid and compelling warmth limit of the nanoparticles

ρ_p : Nano-particles density,

ρ_f : Base fluid density

D_B : Coefficient of Brownian- diffusion,

D_T : Coefficient of thermophoretic dissemination

c : volumetric coefficient.

The detail limit conditions given as follows

At y = 0:

$$v=v_w(x),\quad u_w=ax^n,\quad T=T_w,\quad C=C_w,$$

as $y\to\infty$:

$$u = v = 0;\ T=T_\infty,\ C=C_w, \quad (5)$$

$v_w(x)$ -variable velocity component

suction case represented by $v_w(x) < 0$

injection case represented by $v_w(x) > 0$.

Equation (5) representing the wall transverse velocity which was extended by Rana and Bhargava [31] by including the wall transpiration. Similarity transformations

$$\xi=y\sqrt{\frac{a(n+1)}{2\nu}}x^{\frac{n-1}{2}},\qquad u=ax^n f'(\xi),$$

$$v=-\sqrt{\frac{a\nu(n+1)}{2}}x^{\frac{n-1}{2}}\left(f+\left(\frac{n-1}{n+1}\right)\xi f'\right),$$

$$\theta(\xi)=\frac{T-T_\infty}{T_w-T_\infty},\qquad \phi(\xi)=\frac{C-C_\infty}{C_w-C_\infty}. \quad (6)$$

Rosseland diffusion will help to simulate the thermal radiation in accordance with the radiative heat flux q_r as follows

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}=\frac{16\sigma^* T_\infty^3}{3(\rho c)_f k^*}\frac{\partial^2 T}{\partial y^2} \quad (7)$$

where σ^* : Stefan–Boltzmann constant

k^* : coefficient of Rosseland mean absorption.

Conversion of these transformation into the governing equations (1) to (4) gives the changed form of the energy, species (nano-particle) concentration and conservation equations for momentum.

$$f'''+ff''-\frac{2n}{n+1}f'^2-Mf'=0, \quad (8)$$

$$\left(1+\frac{4}{3}R\right)\theta''+Pr\,f\,\theta'+Pr\,Nb\,\theta'\phi'+Pr\,Nt\,\theta'^2++Pr\,Q\,\theta=0, \quad (9)$$

$$\phi''+\frac{1}{2}Le\,f\,\phi'+\frac{Nt}{Nb}\theta''=0. \quad (10)$$

The boundary layer conditions are

$$f=S,\quad f'=1,\quad \theta=1,\quad \phi=1\quad at\quad \xi=0,$$
$$f'=1,\quad \theta=0\quad \phi=0\qquad as\ \xi\to\infty,\tag{11}$$

where $\Pr=\dfrac{\nu}{\alpha}$: Prandtl number;

$Nb=\dfrac{(\rho c)_p D_B (C_w-C_\infty)}{(\rho c)_f \nu}$: Parameter of Brownian motion; $Nt=\dfrac{(\rho c)_p D_T (T_w-T_\infty)}{(\rho c)_f \nu T_\infty}$: thermophoresis parameter,

$Le=\dfrac{\nu}{D_B}$: Lewis number and

$R=\dfrac{4\sigma^* T_\infty^3}{k^* k}$: radiation parameter,

$Q=\dfrac{Q_0}{(n+1)\nu(\rho c)_f}$: heat source parameter,

$S=-\dfrac{v_w(x)}{\sqrt{a\nu(n+1)}}\sqrt{2}x^{\frac{n-1}{2}}$: wall transpiration parameter (suction/injection).

Non-dimensional local Nusselt number Nu_x, skin friction coefficient C_f and local Sherwood number Sh_x are

$$C_f=\frac{\tau_w}{\rho U_w^2},\ \text{where}\ \tau_w=\mu_B\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)_{y=0},$$

$$Nu_x=\frac{xq_w}{k(T_w-T_\infty)}\ \text{and}$$

$$Sh_x=\frac{xq_m}{D_B(C_w-C_\infty)},\tag{12}$$

where q_w and q_m are the heat and mass motions at the surface individually, k is the Nanofluid thermal conductivity given by

$$q_w=\left(-\left(k+\frac{16\sigma^* T_\infty^3}{3k^*}\right)\left(\frac{\partial T}{\partial y}\right)\right)_{y=0},$$

$$q_m=-D_m\left(\frac{\partial C}{\partial y}\right)_{y=0}.\tag{13}$$

Substituting q_w and q_m in the preceding equations, we get

$$Re_x^{1/2}C_f\sqrt{\frac{2}{n+1}}=f''(0),$$

$$Re_x^{-1/2}Nu_x\sqrt{\frac{2}{n+1}}=-\left(1+\frac{4}{3}R\right)\theta'(0)$$

(14)

$$Re_x^{-1/2}Sh_x\sqrt{\frac{2}{n+1}}=-\phi'(0)$$

where $Re_x=\dfrac{U_w x}{\nu}$ is the local Reynolds number.

III. HAM SOLUTION

In view of this, we consider the initial guesses f_0, θ_0 and ϕ_0 of f, θ and ϕ in the given form

$$f_0(\xi)=S+\varsigma,$$
$$\theta_0(\xi)=e^{-\xi},$$
$$\phi_0(\xi)=e^{-\xi}.$$

Chosen linear operators

$$L_1(f)=f'''-f',$$
$$L_2(\theta)=\theta''-\theta,$$
$$L_3(\phi)=\phi''-\phi,$$

with the following properties

$$L_1\left(C_1+C_2e^{\xi}+C_3e^{-\xi}\right)=0,$$
$$L_2\left(C_4e^{\xi}+C_5e^{-\xi}\right)=0,$$
$$L_3\left(C_6e^{\xi}+C_7e^{-\xi}\right)=0,$$

where C_i are constants.

construction of 0^{th} order deformation conditions

$$(1-p)L_1(f(\xi;p)-f_0(\xi))=p\hbar_1 N_1[f(\xi;p)],\tag{15}$$

$$(1-p)L_2(\theta(\xi;p)-\theta_0(\xi))=p\hbar_2 N_2[f(\xi;p),\theta(\xi;p),\phi(\xi;p)],\tag{16}$$

$$(1-p)L_3(\phi(\xi;p)-\phi_0(\xi))=p\hbar_3 N_3[f(\xi;p),\theta(\xi;p),\phi(\xi;p)],\tag{17}$$

supporting to the conditions

$$f(0;p)=S,\quad f'(0;p)=1,\quad f'(\infty;p)=1,$$
$$\theta(0;p)=1,\quad \theta(\infty;p)=0,$$
$$\phi(0;p)=1,\quad \phi(\infty;p)=0,\tag{18}$$

where

$$N_1[f(\xi;p),\theta(\xi;p),\phi(\xi;p)] = \frac{\partial^3 f(\xi;p)}{\partial \xi^3} + f(\xi;p)\frac{\partial^2 f(\xi;p)}{\partial \xi^2} - \frac{2n}{1+n}\left(\frac{\partial f(\xi;p)}{\partial \xi}\right)^2 - M\frac{\partial f(\xi;p)}{\partial \xi}, \quad (19)$$

$$N_2[f(\xi;p),\theta(\xi;p),\phi(\xi;p)] = \left(1+\frac{4}{3}R\right)\frac{\partial^2\theta(\xi;p)}{\partial \xi^2} + \Pr\left(f(\xi;p)\frac{\partial\theta(\xi;p)}{\partial\xi}\right) + \Pr\left(Nb\frac{\partial\theta(\xi;p)}{\partial\xi}\frac{\partial\phi(\xi;p)}{\partial\xi} + Nt\left(\frac{\partial\theta(\xi;p)}{\partial\xi}\right)^2 + +Q\theta(\xi;p)\right), \quad (20)$$

$$N_3[f(\xi;p),\theta(\xi;p),\phi(\xi;p)] = \frac{\partial^2\phi(\xi;p)}{\partial\xi^2} + \frac{1}{2}Le\left(f(\xi;p)\frac{\partial\phi(\xi;p)}{\partial\xi}\right) + \frac{Nt}{Nb}\frac{\partial^2\theta(\xi;p)}{\partial\xi^2}, \quad (21)$$

where $p \in [0,1]$ is the embedding parameter, $\hbar_1, \hbar_2$ and $\hbar_3$ are non-zero auxiliary parameters and N_1, N_2 and N_3 are nonlinear operators.

The nth-order deformation by using the boundary conditions are as follows

$$L_1\left(f_n(\xi) - \chi_n f_{n-1}(\xi)\right) = \hbar_1 R_n^f(\xi), \quad (22)$$

$$L_2\left(\theta_n(\xi) - \chi_n \theta_{n-1}(\xi)\right) = \hbar_2 R_n^\theta(\xi), \quad (23)$$

$$L_3\left(\phi_n(\xi) - \chi_n \phi_{n-1}(\xi)\right) = \hbar_3 R_n^\phi(\xi), \quad (24)$$

$$f_n(0)=0, \quad f_n'(0)=0, \quad f_n'(\infty)=0,$$
$$\theta_n(0)=0, \quad \theta_n(\infty)=0,$$
$$\phi_n(0)=0, \quad \phi_n(\infty)=0, \quad (25)$$

$$R_n^f(\xi) = f_{n-1}''' + \left[\sum_{i=0}^{n-1} f_{n-1-i} f_i'' - \frac{2n}{n+1}\left(\sum_{i=0}^{n-1} f_{n-1-i}' f_i'\right) - M f_{n-1}'\right], \quad (26)$$

$$R_n^\theta(\xi) = \left(1+\frac{4R}{3}\right)\theta_{n-1}'' + \Pr\left[\sum_{i=0}^{n-1} f_{n-1-i}\theta_i' + Nb\sum_{i=0}^{n-1}\theta_{n-1-i}'\phi_i' + +Nt\sum_{i=0}^{n-1}\theta_{n-1-i}'\theta_i' + Q\theta_{n-1}\right], \quad (27)$$

$$R_n^\phi(\xi) = \phi_{n-1}'' + \frac{1}{2}Le\left(\sum_{i=0}^{n-1} f_{n-1-i}\phi_i'\right) + \frac{Nt}{Nb}\theta_{n-1}'', \quad (28)$$

$$\chi_n = \begin{cases} 0, & n \le 1, \\ 1, & n > 1. \end{cases} \quad (29)$$

Convergence of HAM solution

Equations (8) to (10) in relevance to the limit conditions (11) can be planned by utilizing above introductory suppositions referenced above and direct administrators (Liao [34], Abbasbandy [35]) and the suitable esteem for the non-zero parameters $\hbar_1, \hbar_2$ and $\hbar_3$ have determined by plotting the $\hbar$-curves in Figure 1. it is seen that the valid regions of $\hbar_1, \hbar_2$ and $\hbar_3$ are about [-1.1, -0.1]. For $\hbar_1 = \hbar_2 = \hbar_3 = -0.52$ results indicating that the good correlation with the obtained results. Convergence of adopted method has given in Table 1.

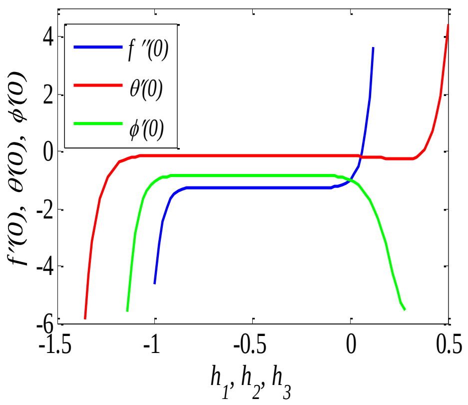

Figure 1: $\hbar$**-curves of** $f''(0), \theta'(0)$ **and** $\phi'(0)$ **- 15th order approximation.**

$M = 0.5, R = 0.1, \Pr = 2.0, n = 1.5, S = 0.5,$

$Nb = Nt = 0.2, Q = 0.1, Le = 2.0.$

Table 1; Combination of HAM for various degrees of approximations when

Order	$-f''(0)$	$-\theta'(0)$	$-\phi''(0)$
5	1.903651	0.169773	0.834825
10	1.903677	0.167740	0.844751
15	1.903677	0.167613	0.844049
20	1.903677	0.167591	0.844287
25	1.903677	0.167588	0.844253

30	1.903677	0.167588	0.844256
35	1.903677	0.167588	0.844256
40	1.903677	0.167588	0.844256

IV. RESULTS AND DISCUSSION

In the present paper numerical solutions and graphical representations are carried out through HAM the following default parameter for computations:

$M = 0.5, R = 0.1, Pr = 2.0, n = 1.5, S = 0.5, Nb = Nt = 0.2, Q =$

Figures 2-4 shows that the magnetic parameter M increases then we observed decrease in velocity profiles and also the velocity boundary layer thickness becomes thinner. Force can cause the reduction in the fluid velocity. Figure 3,4 representing the addition of warm limit layer thickness and fixation profiles by expanding the attractive parameter M.

Nanoparticles and the thermal concentration profile thicknesses can cause decrease the stream limit layer displayed in Figure 5. The effect of transpiration parameter shown in Figures 8 and 9 for the flow boundary layer and thermal boundary layer, respectively

Figure 10 elucidates the changes that are noticed in nanofluid temperature profiles due to increase in the values of thermal radiation parameter R. It is worth noticing that the nanofluid temperature increases as thermal radiation increase due to the fact that the conduction impact of the nanofluid improves in the presence of thermal radiation. Subsequently higher estimations of radiation parameter mean higher surface warmth motion thus, improve the temperature inside the limit layer locale. It is likewise shown that warm limit layer thickness increments with expanding the estimations of warm radiation.

More warmth move between the plate and nanofluid can cause the decrease of warm limit thickness when Prandtl number reaches to higher values shown in figure 11.

The contrasts of heat generation parameter Q on temperature profiles are established in Fig. 12. It is witnessed that with the increment in heat age parameter the temperature profile $\theta(\xi)$ increase.

Figs. 13 and 14 shown that the Brownian parameter Nb increments will demonstrate the effect on the temperature field increments though the fixation profiles diminishes. The dynamic the development of Brownian particles, the more and temperature will increment. Fig. 15 and 16 shown the temperature and focus profiles of thermophoresis parameter individually. Here, we likewise saw that expanding the estimation of Nt came about the fixation profiles and temperature increment.

Impact of Lewis number on the fixation circulation is shown in Figure 17. This figure uncovers that the focus limit layer thickness diminishes as expands, which is normal in light of the fact that an incredible of Lewis number builds the mass exchange rate; thus expanding of abatements the fixation profiles.

Fig. 18 speaks with the impact of warm radiation and warmth source consistent parameter on neighborhood Nusselt number. It is seen that the higher the estimation of warm radiation parameter R will prompts the higher temperature inclination. Be that as it may, with the higher estimation of warmth source Q and it will diminish the thickness of temperature slope limit layer.

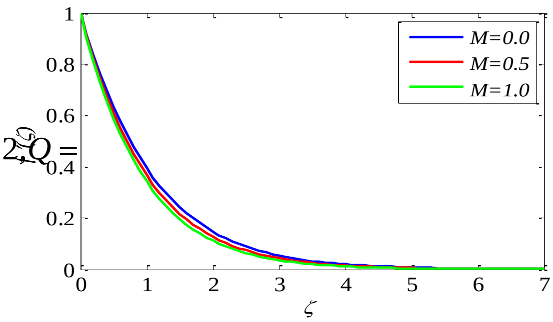

Fig. 2. Effect of M on $f'(\xi)$.

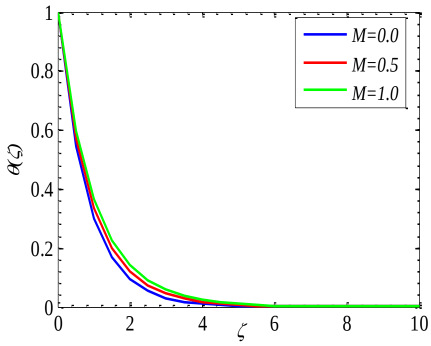

Fig. 3. Effect of M on $\theta(\xi)$.

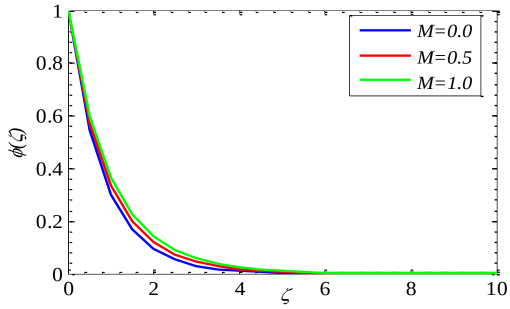

Fig. 4. Effect of M on $\phi(\xi)$.

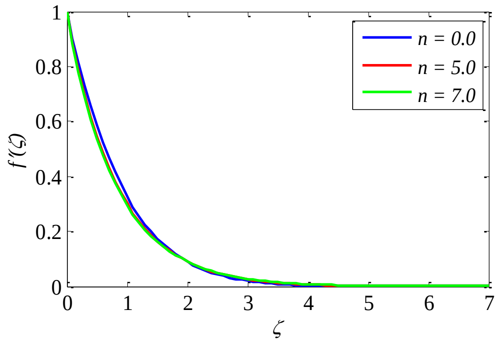

Fig. 5. Effect of n on $f'(\xi)$.

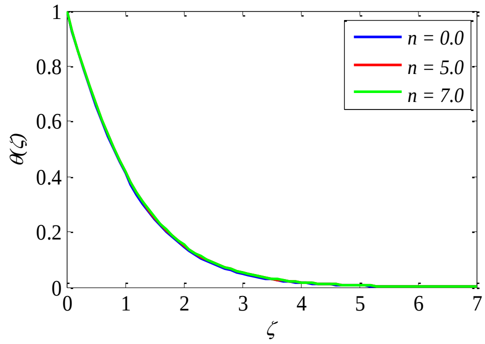

Fig. 6. Effect of n **on** $\theta(\xi)$.

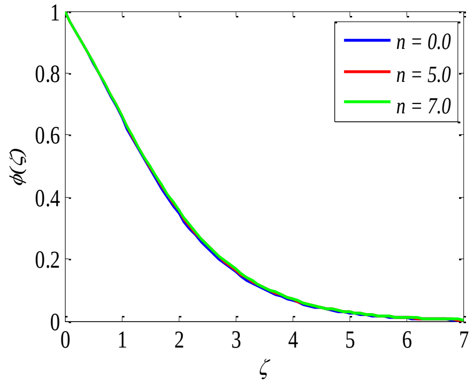

Fig. 7. Effect of n **on** $\phi(\xi)$.

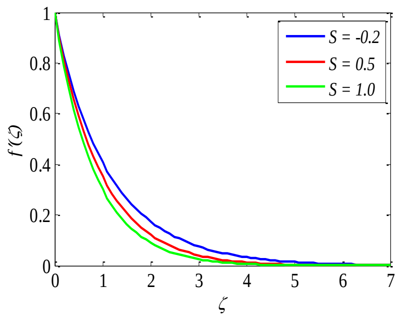

Fig. 8. Effect of S **on** $f'(\xi)$.

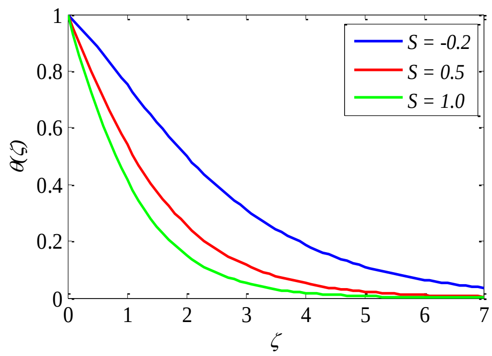

Fig. 9. Effect of S **on** $\theta(\xi)$.

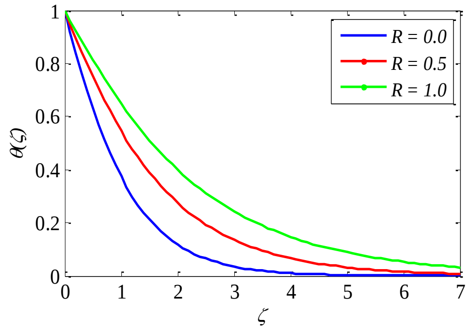

Fig. 10. Effect of R **on** $\theta(\xi)$.

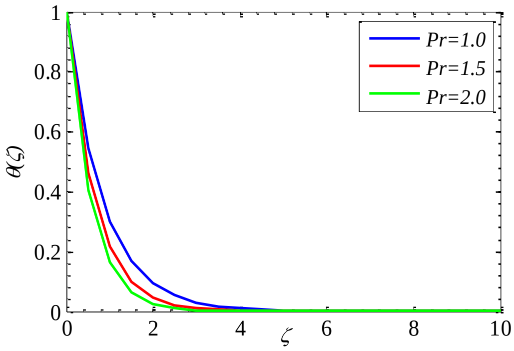

Fig. 11. Effect of Pr **on** $\theta(\xi)$.

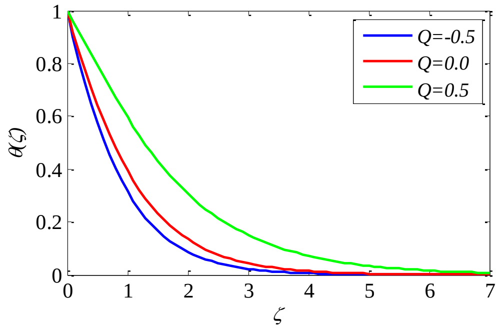

Fig. 12. Effect of Q **on** $\theta(\xi)$.

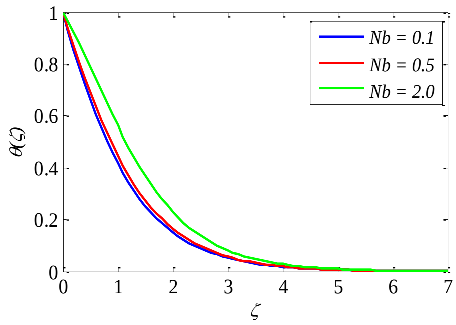

Fig. 13. Effect of Nb **on** $\theta(\xi)$.

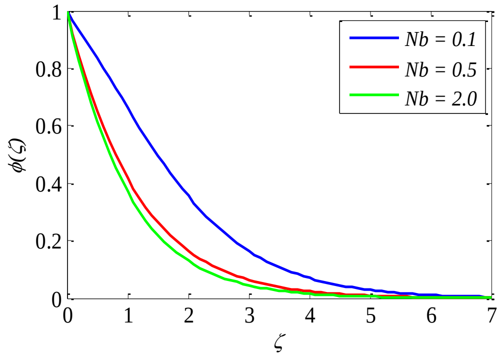

Fig. 14. Effect of Nb **on** $\phi(\xi)$**.**

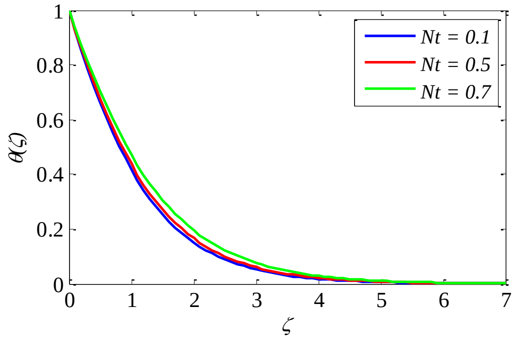

Fig. 15. Effect of Nt **on** $\theta(\xi)$**.**

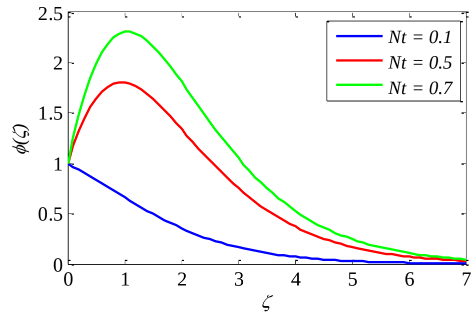

Fig. 16. Effect of Nt **on** $\phi(\xi)$**.**

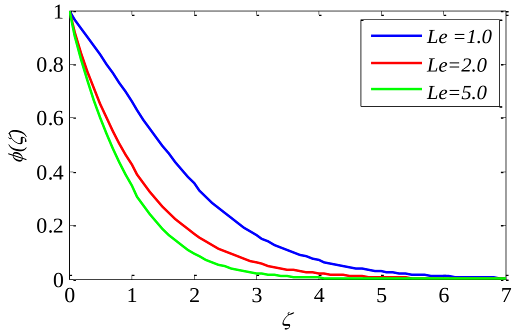

Fig. 17. Effect of Le **on** $\phi(\xi)$**.**

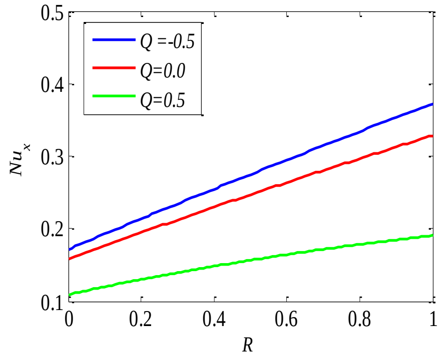

Fig.18. Effect of R **and** Q **on** Nu_x **.**

V. CONCLUSION

In the present paper, we made an endeavor to consider the effects of the warm radiation, heat source on consistent MHD limit layer of nanofluid past over an extending level plate under suction and infusion. The overseeing non-direct fractional differential conditions are changed into an arrangement of coupled non-straight ODE's and comprehended numerically by utilizing HAM strategy with shooting system by utilizing the closeness factors. At the point when Brownian movement consistent builds, warm limit layer will likewise be increments though the convergence of nanoparticles diminishes. The parameter of Thermophoresis has a similar impact on the warm limit layer where as differing impact on the nanoparticles focus is watched. The speed diminishes with increment in the estimations of attractive factor parameter, transpiration parameter and extending sheet parameter. The temperature diminishes with increment in the estimations of Prandtl number and transpiration parameter. The fixation diminishes with increment in the estimations of Schmidt number.

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