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Effects of Chemical Reaction with heat source on MHD Heat and Mass Transfer Nanofluid flow on a continuously moving surface.

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Abstract: We have investigated a two dimensional steady flow on a continuously moving surface with effects of chemical reaction and heat source. In this problem, the nanofluid model includes with Brownian and thermophoresis effects. A mathematical formulation has designed for momentum, temperature and nanofluid solid volume profiles. The coupled partial differential equations are solved using the Nactsheim-Swigert shooting technique with the six order Runge-Kutta iteration Method. The results for the dimensionless velocity, temperature, and nanofluid solid volume profiles are discussed with the help of graphs. Various parameter values Nusselt number, skin friction coefficient are derived with thermophoresis parameter, magnetic parameter , Eckert number, Levis number, Chemical reaction parameter and heat generating absorption parameter and discussed with values.

Keywords: Nanofluid, Magentohydrodynamics (MHD), moving surface, chemical reaction, heat source.

Introduction: A Nanofluid is a fluid containing nanometer sized particles called as nano particles. These fluids are colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides or carbon nano tubes. Common base fluids include water, ethylene glycol and oil.Nanofluid is a two-phase mixture in which the solid phase consists of nano-seized particles. Nanofluid technology can help to develop better oils and lubricants .Magneto Hydrodynamics (MHD) is the academic discipline concerned with the dynamics of electrically conducting fluids include magnetic field. These fluids include salt water, liquid metals and ionized gases or plasmas.

The term nanofluid has been introduced by Choi[1].This novel fluid have been used potentially in numerous application in heat and mass transfer as well as micro electronics, fuel cells, Pharmaceutical sections.Sakisdis [2] was the first another to analyze the boundary layer flow on a continuous moving surface. Crane [3] found an exact solution of the boundary layer flow of the Newtonian fluid caused by the stretching of an elastic sheet moving in its own plane linearly.Buongiorno [4] was first who formulated the nanofluid model taking into account the effects of Brownian motion and thermophoresis. In his work he indicated that although there are some elements those affect nanofluid flow such as intertia, Brownian diffusion, thermophoresis, diffusiporesis, Magnus effect, fluid drainage and gravity only. Brownian diffusion and thermophoresis are important mechanisms in nanofluids. Wang [5] investigated the free convection flow on a vertical stretching surface.

Pop et al [6] obtained similarity solution by considering viscosity as an inverse function of temperature of the plate. There are several numerical studies on the modeling of natural convection heat transfer in nnaofluids.Gbadeyan et al [7] numerically studied natural convection flow of a nanofluid over a vertical plate with a uniform surface heat flux. Fang et al [8] used a second order a slip flow in their research. Choi and Eastman [9] discovered that the addition of less than 1% of nanoparticles into the base fluid doubles the heat conductivity of the fluid. Hamad et al [10] obtained the flow and mass transfer over a permeable sheet without fluid slip.Soundalgekar et al [11] studied the problem of flow of incompressible viscous fluid past a continuously moving semi-infinite plate by considering variable viscosity and variable temperature. Muthucumaraswamy [12] studied the effects of chemical reaction on vertical oscillating plate with variable temperature.Makinde [13] studied the effects of temperature dependent viscosity on free convective flow past a vertical porous plate in the presence of a magnetic field, thermal radiation and a first order homogeneous chemical reaction.

In this paper we have investigated a two dimensional steady flow on a continuously moving surface with effects of chemical reaction and heat source. The governing partial differential equations are converted into nonlinear ordinary differential equations and then solved numerically by using famous method Nactsheim-Swigert [14] shooting technique with sixth order Runge-Kutta Method. The results of dimensionless parameters velocity, temperature and nanofluid solid volume profiles are discussed with the help of graphs and table values.

Mathematical Formulation

Consider a two dimensional steady flow of a incompressible nanofluid which is electricity conducting and past a continuously moving surface with the uniform velocity U in the presence of magnetic field of strength B_0 is applied parallel to the y axis and chemical reaction with heat source is considered in the flow region it is assumed that the induced magnetic field, the external electric field are negligible due to polarization of charges. Let us consider x axis to be focused along the surface and y axis normal to the surface.

The physical flow model and coordinate system is shown in figure-1under the above approximation and using the usual boundary layer approximation.

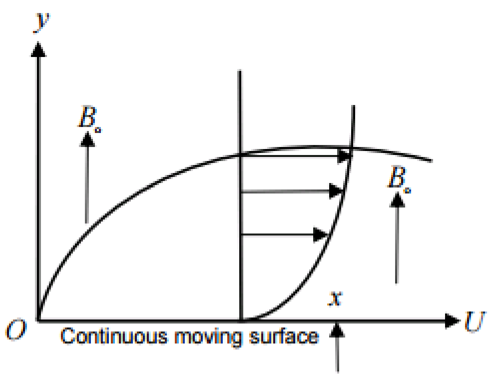

Fig 1. Coordinate system for continuously moving surface

The governing equation of conservation of mass, momentum, energy and nano particle volume in the presence of magnetic field and viscosity dissipation towards a continuously moving surface can be written in Cartesian coordinates x & y.

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

$$u\,\frac{\partial u}{\partial x}+v\,\frac{\partial v}{\partial y}=\frac{1}{\rho}\frac{\partial}{\partial y}\left(u\,\frac{\partial u}{\partial y}\right)-\frac{\sigma_e B_0^2 u}{\rho} \tag{2}$$

$$u\,\frac{\partial T}{\partial x}+v\,\frac{\partial T}{\partial y}=\frac{\partial}{\partial y}\left(\propto\,\frac{\partial T}{\partial y}\right)+\frac{u}{\rho c_\phi}\left(\frac{\partial u}{\partial y}\right)^2+\frac{\sigma_e B_0^2 u^2}{\rho c_\phi}+T\left\{D_B\left(\frac{\partial T}{\partial y}\,\frac{\partial C}{\partial y}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right\}+\frac{Q_0}{\rho c_\rho}(T-T_\infty) \tag{3}$$

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

And the Boundary conditions are:

$$u=U=ax\,,v=0,T=T_\omega(x),C=C_\omega(x)\text{ at }y=0$$

$$u=0\,,T=T_\infty\,,C=C_\infty\text{ as }y\rightarrow\infty \tag{5}$$

Where α is a thermal diffusivity, Q_0 is a heat generation coefficient, ρ is the density, σ_e is the electrical conductivity, C_p is the specific heat and constant pressure, μ is the thermal viscosity, D_B is the Brownian diffusion coefficient , D_T is the thermophoresis diffusion coefficient and K_r is the rate of chemical reaction.

The equations (2) – (4) can be transformed into the ordinary differential equation by using the following similarity transformations.

$$\left.\begin{aligned}&\eta=y\sqrt{\frac{a}{V_\infty}}\,,\Psi=x\sqrt{aV_\infty}\,f(\eta)\\&\theta(\eta)=\frac{T-T_\infty}{T_\omega-T_\infty}\,,\theta(\eta)=\frac{C-C_\infty}{C_\omega-C_\infty}\end{aligned}\right\} \tag{6}$$

Where v_∞ reference kinematic viscosity it will be assumed the temperature and concentration difference between the moving surface and the free stream various A x^n and B x^n

$$T_\omega(x)-T_\infty=Ax^n \tag{7}$$

$$C_w(x)-C_\infty=Bx^n \tag{8}$$

Where A & B are constants, n is exponent parameter and x is measure from the leading edge of the surface.

From the above transformations the non dimensional, non linear, coupled differential equations are obtained as:

$$f''' + f f'' - f'^2 - R_{e_m}^2 f' = 0 \quad (9)$$

$$\theta'' - nP_r f'\theta + P_r f \theta' + P_r E_C f''^2 + R_{e_m}^2 P_r E_C f'^2 + P_r N_b \theta' \varphi' + P_r N_t \theta'^2 + \lambda P_r \theta = 0 \quad (10)$$

$$\varphi'' + L_e f\varphi' - n L_e f' \varphi + \left(\frac{N_t}{N_b}\right)\theta'' + \gamma L_e R_{e_x} \varphi = 0 \quad (11)$$

Where

$E_C = \frac{U^2}{C_p(T_\omega - T_\infty)}$ (Eckert number)

$P_r = \frac{V_\infty}{\alpha}$ (Prandtl number)

$\lambda = \frac{Q_0}{(T_\omega - T_\infty)\rho c_\rho}$ (Heat source parameter)

$R_{e_x} = B_0\sqrt{\frac{\sigma_e}{\rho\ a}}$ (Magnetic parameter)

$L_e = \frac{V_\infty}{D_B}$ (Lewis number)

$R_{e_x} = \frac{\alpha x^2}{V_\infty}$ (Local Reynolds number)

$\gamma = \frac{V_\infty K_r}{U^2}$ (Chemical reaction parameter)

$N_b = \frac{(\rho C)_\rho D_B(\varphi_\omega - \varphi_\infty)}{V_\infty (\rho C)_f}$ (Brownian motion parameter)

$N_t = \frac{(\rho C)_\rho D_T(T_\omega - T_\infty)}{V_\infty T_\infty(\rho C)_f}$ (Thermo phoresis parameter)

The corresponding Boundary conditions are

$$\left.\begin{array}{l} f = 0, f = 1, \theta = 1, \varphi = 1 \text{ at } \eta = 0 \\ f = 0, \theta = 0, \varphi = 0 \text{ as } \eta \to \infty \end{array}\right\} \quad (12)$$

The physical quantities of Skin friction(C_f), the local Nusselt number(N_u), and the local Sherwood number (Sh) are calculated by the following equations:

$$\left.\begin{aligned} C_f\,(R_{e_x})^{-1/2} &= -f''(0) \\ N_u\,(R_{e_x})^{-1/2} &= -\theta'(0)\ and \\ S_h\,(R_{e_x})^{-1/2} &= -\varphi'(0) \end{aligned}\right\} \qquad (13)$$

Where $R_{e_x} = \frac{ax^2}{V_\infty}$ is the local Reynolds number .

NUMERICAL ANALYSIS:

The set of non dimensional, non linear couple boundary layer equations (9) – (11) with boundary conditions (12) doesn't possess a closed form analytical solution. Hence it has been solved numerically using the Nactsheim- Swigert shooting iteration technique together with a sixth- order Runge-Kutta iterations scheme. In shooting method, the missing initial conditions f'(0) , θ' (0) , Φ' (0) by the shooting techniques until the boundary conditions at infinity f'(∞) , θ' (∞) , Φ' (∞) decay exponentially to zero. The accuracy of the assumed missing initial conditions is then verified via comparison with the computed value of the dependent variable at the terminal point with its given value there. The entire computation procedure is implemented using a program written and carried out using Mathematica computer language. From the process of numerical computation the fluid velocity, the temperature, the concentration, the Skin friction coefficient, Nusselt number and Sherwood number are proportional to f'(η) , θ (η) , Φ (η) f''(η) , θ' (η) , Φ' (η).

RESULTS AND DISCUSSION:

The heat and mass transfer problem associated with MHD flow of the nanofluids over a continuously moving surface has been studied. Table 1 indicates the values of skin friction, Nusselt Number and Sherwood Number for different values of the physical parameters.

Figure 2 shows dimensionless velocity profile for different values of magnetic parameter (Re_{m}) where $\mathrm{Pr} = 0.7,\ n = 0.5\ ,\mathrm{Nb} = 0.5, \mathrm{Nt} = 0.5, \mathrm{Le} = 1, \lambda = 0.0, \mathrm{Rex} = 0.5, \mathrm{Ec} = 0.3, \gamma = 0.5$. It is observed that magnetic parameter increases when the velocity decreases.

Figure 3 displays dimensionless velocity distribution for different values of exponent parameter (n) where $\mathrm{Pr} = 0.7,\ \mathrm{Rem} = 0.3\ ,\mathrm{Nb} = 0.5, \mathrm{Nt} = 0.5, \mathrm{Le} = 1, \lambda = 0.0, \mathrm{Rex} = 0.5, \mathrm{Ec} = 0.3, \gamma = 0.5$. It is noted that that exponent parameter increases when the velocity increases.

Figure 4 exhibits dimensionless temperature profile for different values of magnetic parameter (Re_{m}) where $\mathrm{Pr} = 0.7,\ n = 0.5\ ,\mathrm{Nb} = 0.5, \mathrm{Nt} = 0.5, \mathrm{Le} = 1, \lambda = 0.0, \mathrm{Rex} = 0.5, \mathrm{Ec} = 0.3, \gamma = 0.5$. It is observed that magnetic parameter increases when the temperature increases.

Figure 5 displays dimensionless temperature distribution for different values of exponent parameter (n) where $\mathrm{Pr} = 0.7,\ \mathrm{Rem} = 0.3\ ,\mathrm{Nb} = 0.5, \mathrm{Nt} = 0.5, \mathrm{Le} = 1, \lambda = 0.0, \mathrm{Rex} = 0.5, \mathrm{Ec} = 0.3, \gamma = 0.5$. It is noted that that exponent parameter increases when the temperature decreases.

Figure 6 shows dimensionless concentration distribution for different values of chemical reaction parameter (γ) where $\mathrm{Pr} = 0.7$, $\mathrm{Rem} = 0.3$, $\mathrm{Nb} = 0.5$, $\mathrm{Nt} = 0.5$, $\mathrm{Le} = 1$, $\lambda = 0.0$, $\mathrm{Rex} = 0.5$, $\mathrm{Ec} = 0.3$, $n = 0.5$. It is observed that that chemical reaction parameter increases when the concentration decreases.

Figure 7 exhibits dimensionless concentration profile for different values of magnetic parameter ($\mathrm{Re_m}$) where $\mathrm{Pr} = 0.7$, $n = 0.5$, $\mathrm{Nb} = 0.5$, $\mathrm{Nt} = 0.5$, $\mathrm{Le} = 1$, $\lambda = 0.0$, $\mathrm{Rex} = 0.5$, $\mathrm{Ec} = 0.3$, $\gamma = 0.5$. It is observed that magnetic parameter increases when the concentration decreases.

Figure 8 displays dimensionless concentration distribution for different values of exponent parameter (n) where $\mathrm{Pr} = 0.7$, $\mathrm{Rem} = 0.3$, $\mathrm{Nb} = 0.5$, $\mathrm{Nt} = 0.5$, $\mathrm{Le} = 1$, $\lambda = 0.0$, $\mathrm{Rex} = 0.5$, $\mathrm{Ec} = 0.3$, $\gamma = 0.5$.It is noted that that exponent parameter increases when the concentration decreases.

Figure 9 shows dimensionless velocity profiles for different values of heat source parameter (λ) where $\mathrm{Pr} = 0.7$, $\mathrm{Rem} = 0.3$, $\mathrm{Nb} = 0.5$, $\mathrm{Nt} = 0.5$, $\mathrm{Le} = 1$, $n = 3.0$, $\mathrm{Rex} = 0.5$, $\mathrm{Ec} = 0.3$, $\gamma = 0.5$. It is observed that heat source parameter increases when the velocity decreases.

Figure 10 shows dimensionless concentration profiles for different values of heat source parameter (λ) where $\mathrm{Pr} = 0.7$, $\mathrm{Rem} = 0.3$, $\mathrm{Nb} = 0.5$, $\mathrm{Nt} = 0.5$, $\mathrm{Le} = 1$, $n = 3.0$, $\mathrm{Rex} = 0.5$, $\mathrm{Ec} = 0.3$, $\gamma = 0.5$. It is observed that heat source parameter increases when the concentration decreases.

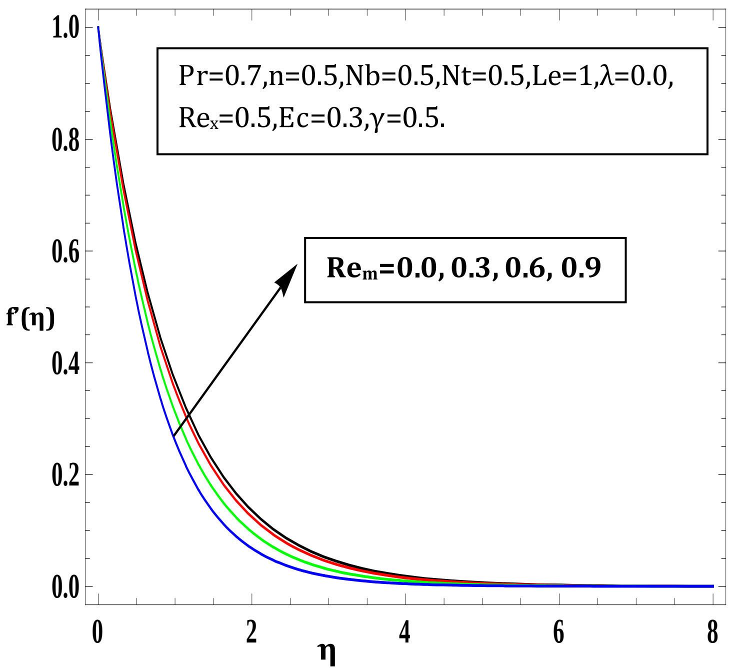

Fig.2: Effects of magnetic parameter ($\mathrm{Re_m}$) on velocity Profiles

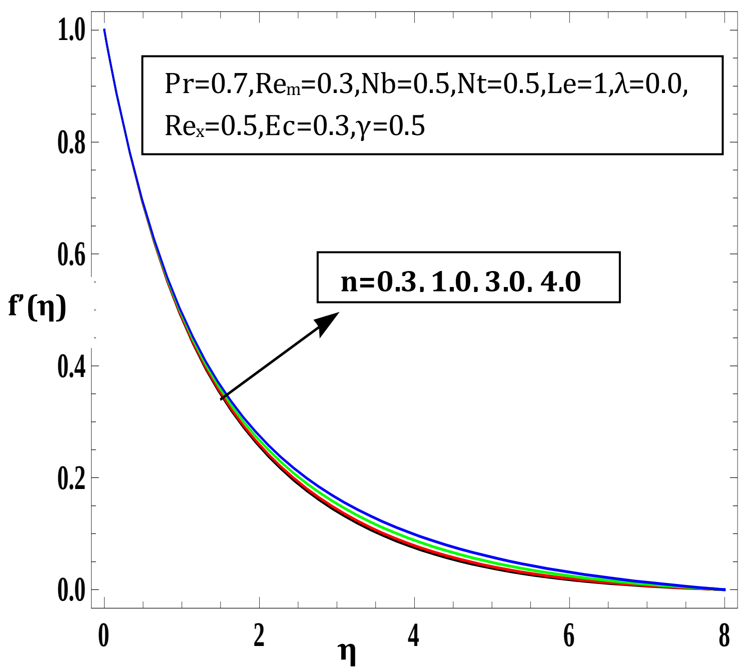

Fig.3: Effects of exponent parameter (n) on velocity Profiles

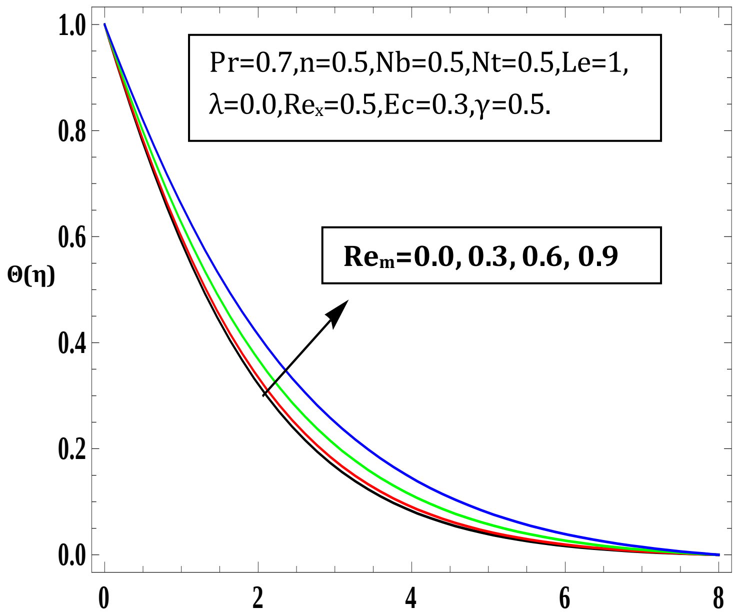

Fig.4: : Effects of magnetic parameter (Re_m) on temperature profile

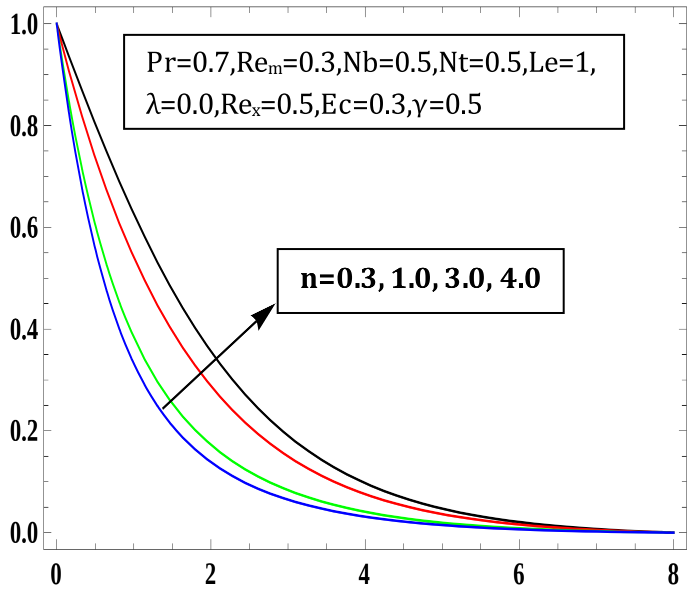

Fig.5: : Effects of exponent parameter (n) on temperature Profiles

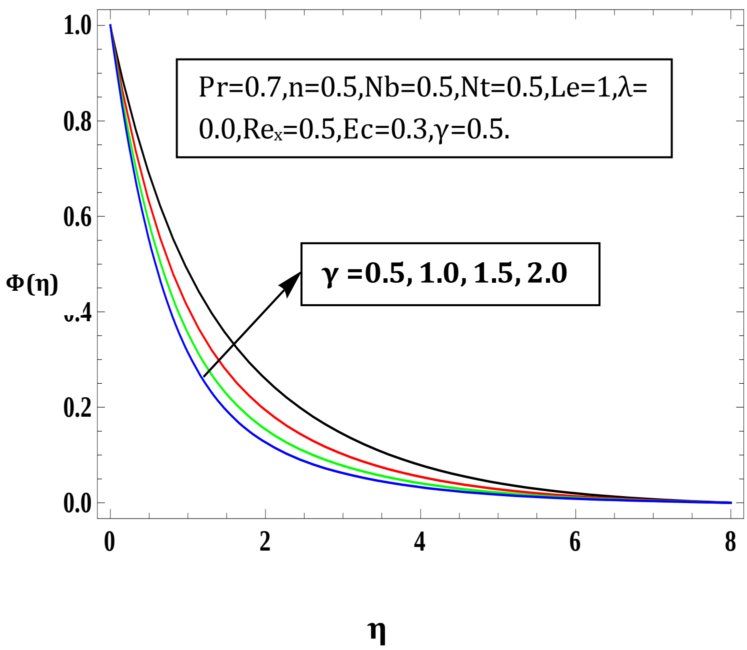

Fig.6: : Effects of chemical reaction parameter (γ) on concentration Profiles

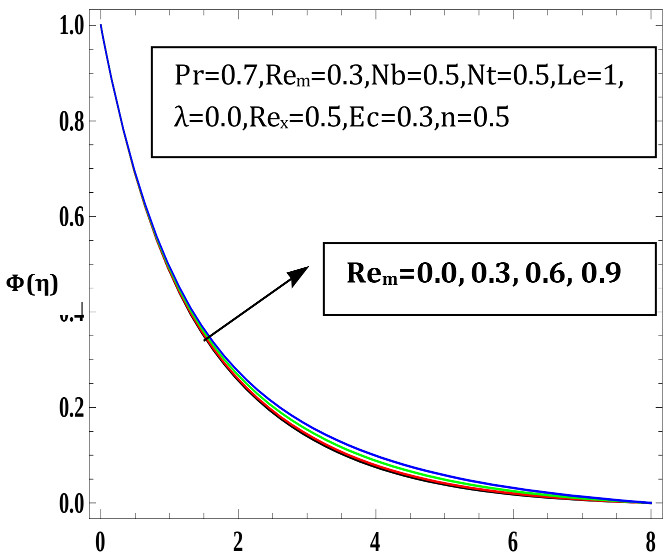

Fig.7: Effects of magnetic parameter (Re_m) on concentration Profiles

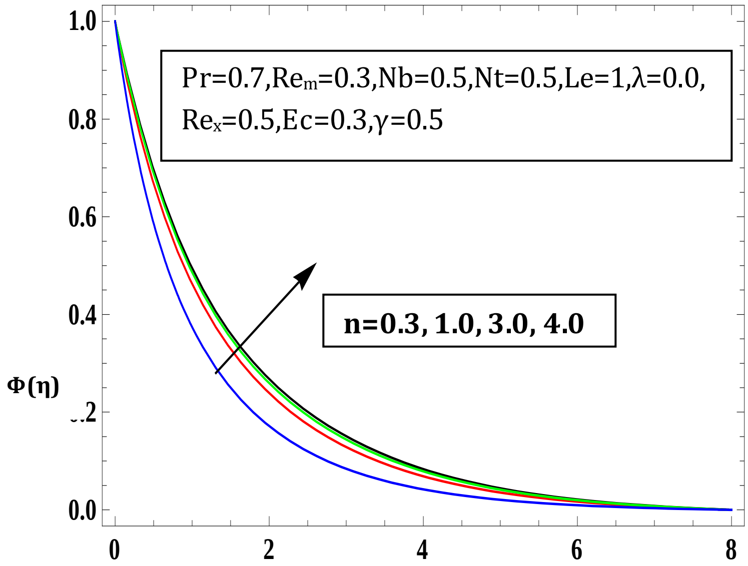

Fig.8: **Effects of exponent parameter (n) on concentration Profiles**

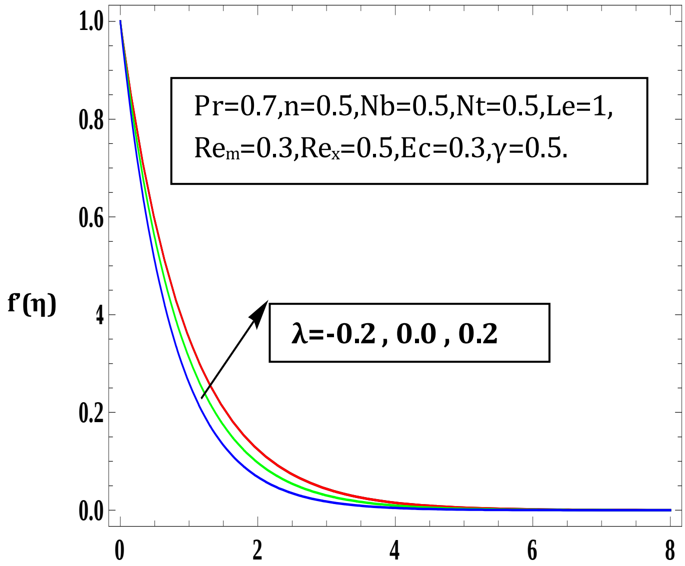

Fig.9: **Effects of heat source parameter (λ) on velocity Profiles**

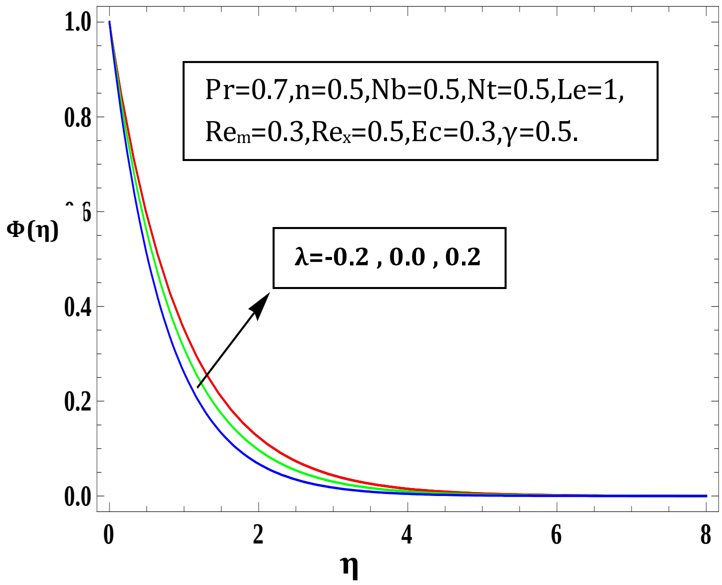

Fig.10: **Effects of heat source parameter (λ) on concentration Profiles**

Table 1 : The values of skin friction, Nusselt Number and Sherwood Number for different values of the physical parameters

Re_m	Pr	n	Nb	Nt	Le	λ	Re_x	Ec	f'' (0)	θ'(0)	φ'(0)
0.3	0.7	0.5	0.1	0.5	1	0.5	0.5	0.3	1.0006	0.4824	0.7623
0.3	0.7	0.5	0.3	0.5	1	0.5	0.5	0.3	1.0441	0.4681	0.7626
0.3	0.7	0.5	0.5	0.5	1	0.5	0.5	0.3	1.1661	0.4293	0.7346
0.3	0.7	0.5	0.7	0.5	1	0.5	0.5	0.3	1.3453	0.3752	0.7708
0.3	0.7	0.5	0.5	0.1	1	0.5	0.5	0.3	1.0816	0.5194	0.9218
0.3	0.7	0.5	0.5	0.3	1	0.5	0.5	0.3	1.0646	0.4999	0.837
0.3	0.7	0.5	0.5	0.5	1	0.5	0.5	0.3	0.9845	0.4807	0.7624
0.3	0.7	0.5	0.5	0.7	1	0.5	0.5	0.3	0.9647	0.4632	0.696

Conclusion:

The effects of chemical reactions and each source on MHD Heat and Mass transfer flow of a nanofluid on continuously moving surface is investigated. The governing equations and boundary conditions are reduced to ordinary differential equations by using Nactsheim-Swigert shooting technique together with Runge-Kutta sixth order iteration scheme.

- The increase in magnetic parameter is to decrease in velocity and concentration profiles.
- The increase in exponent parameter is to decrease in temperature and concentration profiles.
- The increase of chemical reaction parameter is to decreases in temperature and concentration profiles.
- The heat transfer coefficient of nanofluid increase with the decreases of velocity and concentration profiles

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