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Effect of chemical reaction on MHD unsteady free convection Walter's memory flow of Nano fluid with constant suction and Heat Sink

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Abstract
Effect of Chemical Reaction on MHD Unsteady free Convection Walter's Memory Flow of nano fluid with constant suction and heat sinks has been studied. The dimensionless governing equations are solved using comparison of harmonic and non harmonic part technique. The influences of the various parameters on the flow field, skin friction, rate of heat transfer and temperature field are extensively discussed from graphs and tables.

Keywords: mhd, Free convection, Heat Transfer, Chemical Reaction, Heat Sink, Suction, Mass Transfer, Nano fluid and Walter's Memory Flow

Introduction

MHD has attracted the attention of many scholars due to its diverse applications in geophysics and astrophysics. It is applied to study the stellar and solar structures, interstellar matter, radio propagation through ionosphere, design of MHD generators and accelerators in geophysics, design of underground water energy storage system, soil science and so on. The phenomenon of Mass Transfer is a common theory of stellar structure. Also observable effects are detected on the solar surface. The flow through porous media has become an important topic because of the recovery of crude oil from pores of reservoir rocks. Mohapatra and Senapati [1] have studied Magneto hydrodynamics Unsteady free convection flow with mass transfer through porous medium. Singh [2] has studied the effect of mass transfer on MHD free convection flow of a viscous fluid through a vertical channel. Dhal et. al. [3] have studied the mass transfer effect on MHD unsteady free convective Walter's Memory flow with constant suction and heat sink.

Nano fluids with or without the presence of magnetic field have many applications in the industries since materials of nanometer size have unique Chemical and Physical properties. Nano fluid study is more important in industries such as hot rolling, melting, spinning, extrusion, glass fiber production, wire drawing and filament, etc. Kashif et. al. [4] have analysied the numerical simulation of unsteady water based nano fluid flow and heat transfer between two orthogonally moving porous coaxial disks. Sheikholeslami et. al. [5] have studied the effects of MHD on Cu-water nano fluid flow and heat transfer by means of CVFEM. Dhal [6] has studied the unsteady MHD free convection flow in a nano fluid through porous medium with suction and heat source. MHD effects on heat transfer and entropy generation of nano fluid flow in an open cavity is discussed by Mehrez et. al. [7] Sheikholeslami et. al. [8] have discussed the effect of thermal radiation on magnetohydrodynamics nano fluid flow and heat transfer by means of two phase model. Eshetu et. al. [9] have discussed the boundary – layer flow of nano fluids over a moving surface in the presence of thermal radiation, viscous dissipation and chemical reaction. D. Vidyanandha Babu [10] has discussed the Effect of Dufour and thermal radiation on convection radiative nano fluid flow with suction and heat source.

In this problem, we try to investigate the Effect of Chemical Reaction on MHD Unsteady free Convection Walter's Memory flow of nano fluid with constant suction and heat sink.

2. Formulation of Problem

An unsteady two dimensional free conZection memory flow of an incompressible, electrically conducting nano fluid past an infinite vertical porous plate with heat sink and constant suction in the presence of chemical reaction has been considered. The X'- axis is taken along the vertical plate and Y' - axis is taken normal to the plate. A magnetic field of uniform strength B_0 acts normal to the plate and magnetic permeability is constant throughout the field. There exists free convection current in the surrounding area of the plate. It is assumed that fluid has constant properties and variation of density with temperature and mass concentration only as in body force term. Joulean dissipation and induced magnetic field are neglected. All the variables in the flow are the functions of y' and t' only as the plate is of infinite length. Initially, we assume that the plate and fluid are in the constant temperature T_p' and T_∞' and mass concentration C_p' and C_∞', respectively. After first order chemical reaction it is assumed that the temperature and mass concentration raise to $T' = T_p' + \in (T_p' - T_\infty')e^{i\omega' t'}$ and $C' = C_p' + \in (C_p' - C_\infty')$. Then by usual Boussinesq's approximation, the unsteady nano flow is governed by the following equations:

$$\frac{\partial v'}{\partial y'} = 0 \Rightarrow v' = -V_0(constant) \tag{1}$$

$$\frac{\partial u'}{\partial t'} - V_0\frac{\partial u'}{\partial y'} = \frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u'}{\partial y'^2} + g(\beta)_{nf}(T' - T_\infty') + g(\beta_c)_{nf}(C' - C_\infty') - \frac{\sigma B_0^2 u'}{\rho_{nf}} - B_1\left(\frac{\partial^3 u'}{\partial t\partial y'^2} - V_0\frac{\partial^2 u'}{\partial y'^2}\right) \tag{2}$$

$$\frac{\partial T'}{\partial t'} - V_0\frac{\partial T'}{\partial y'} = \frac{k_{nf}}{(\rho C_p)_{nf}}\frac{\partial^2 T'}{\partial y'^2} + S'(T' - T_\infty') + \frac{\nu_{nf}}{(\rho C_p)_{nf}}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3}$$

$$\frac{\partial C'}{\partial t'} - V_0\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y^2} - R'(C' - C_\infty')$$

With the following boundary conditions (4)

$$t > 0: \left| \begin{array}{c} u' = 0, T' = T_p' + \in (T_p' - T_\infty')e^{i\omega' t'}, C' = C_p' + \in (C_p' - C_\infty')e^{i\omega' t'}\ at\ y = 0 \\ u' = 0, T' = T_\infty', C' = C_\infty'\ as\ y \to \infty \end{array} \right\} \tag{5}$$

where μ_{nf} is the dynamic viscosity, k_{nf} is the thermal diffusivity, ρ_{nf} is the effective density, $(\rho C_p)_{nf}$ is the heat capacity, $(\beta)_{nf}$ is the coefficient of volumetric expansion of heat and $(\beta_c)_{nf}$ is the coefficient of volumetric expansion of mass of nano fluid. They are defined as

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}}, \rho_{nf} = (1-\phi)\rho_f + \phi\rho_s, (\rho C_p)_{nf} = (1-\phi)(\rho C_p)_f + \phi(\rho C_p)_s,$$

$$k_{nf} = \left[\frac{k_s + 2k_f - 2\phi(k_f - k_s)}{k_s + 2k_f + 2\phi(k_f - k_s)}\right]k_f,\ (\beta)_{nf} = (1-\phi)(\beta)_f + \phi(\beta)_s, (\beta_c)_{nf} = (1-\phi)(\beta_c)_f + \phi(\beta_c)_s$$

where σ is the electrical conductivity of the fluid, g is the acceleration due to Gravity and ϕ is the volume of the nano fluid. Let us introduce the dimensionless quantities

$$\left.\begin{array}{c} u = \frac{u'}{V_0}, t = \frac{t' V_0^2}{\upsilon_f}, y = \frac{y' V_0}{\upsilon_f}, \theta = \frac{T' - T_\infty'}{T_p' - T_\infty'}, C = \frac{C' - C_\infty'}{C_p' - C_\infty'}, R = \frac{R'\nu_f}{V_0^2}, Ec = \frac{V_0^2}{(T_p' - T_\infty')}, \\ Gr = \frac{g(\beta)_f \upsilon_f (T_W' - T_\infty')}{V_0^3}, Gm = \frac{g(\beta_C)_f \upsilon_f (C_W' - C_\infty')}{V_0^3}, Pr = \frac{\nu_f (\rho C_p)_f}{k_f}, Sc = \frac{\upsilon_f}{D}, \\ M = \frac{\sigma \nu_f B_0^2}{\rho_f V_0^2}, S = \frac{S'\upsilon_f}{V_0^2}, \omega = \frac{\omega'}{V_0^3}\upsilon_f, Rm = \frac{BV_0^2}{\upsilon f^2} \end{array}\right\} \tag{6}$$

where D is the mass diffusion, Gr is the Grashof number, Gm is the modified Grashof number, K is the permeability of porous medium, M is the Magnetic parameter, Sc is the Schmidt number, Pr is the Prandtl number, Ec is the Eckert number, S is the Sink strength, Rm is the Magnetic Reynold number, R is the chemical reaction parameter and ω is the Oscillating Parameter.

Substituting Equation (6) in equations (2)-(4) with boundary conditions (5), we have

$$\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \phi_0\frac{\partial^2 u}{\partial y^2} - \phi_1 Mu + \phi_2 Gr\theta + \phi_3 GmC - Rm\left(\frac{\partial^3 u}{\partial t\partial y^2} - \frac{\partial^3 u}{\partial y^3}\right) \tag{7}$$

$$Pr\frac{\partial\theta}{\partial t} - Pr\frac{\partial\theta}{\partial y} = \phi_4\frac{\partial^2\theta}{\partial y^2} + \phi_5 PrEc\left(\frac{\partial u}{\partial y}\right)^2 + PrS\theta \tag{8}$$

$$Sc\frac{\partial C}{\partial t} - Sc\frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} - RScC \tag{9}$$

with revised boundary conditions

$$\left.\begin{array}{c} u = 0, \theta = 1 + \in e^{i\omega t}, C = 1 + \in e^{i\omega t} \text{ for } y = 0 \\ u = 0, \theta \to 0, C \to 0 \text{ for } y \to \infty \end{array}\right\} \tag{10}$$

3. Method of Solution

To solve the above equations, we assume ω be very small and velocity, temperature and mass concentration in the neighborhood of the plate as

$$\left.\begin{aligned} u &= u_0 + u_1 \epsilon e^{i\omega t} \\ \theta &= \theta_0 + \theta_1 \epsilon e^{i\omega t} \\ C &= C_0 + C_1 \epsilon e^{i\omega t} \end{aligned}\right\} \tag{11}$$

Substituting equation (11) in equation (7)-(10) and comparing harmonic and non harmonic parts, we get the harmonic part as

$$Rmu_0''' + \phi_0 u_0'' + u_0' - \emptyset_1 M u_0 = -\emptyset_2 Gr\theta_0 - \emptyset_3 GmC_0 \tag{12}$$

$$\phi_4 \theta_0'' + Pr\theta_0' + PrS\theta_0 = -\phi_5 PrEc(u_0')^2 \tag{13}$$

$$C_0'' + ScC_0' - ScRC_0 = 0 \tag{14}$$

With boundary conditions

$$\left.\begin{aligned} u_0 = 0, \theta_0 = 1, C_0 = 1 \; at \; y = 0 \\ u_0 = 0, \theta_0 \to 0, C_0 \to 0 \; as \; y \to \infty \end{aligned}\right\} \tag{15}$$

As the equation (12) is 3rd order differential equation in the presence of elasticity, therefore, u_0 is expanded using Beard and Walter's rule as $u_0 = u_{00} + Rmu_{01}$ and substitute in equation (12), then we get by equation zeroth order and first order of Rm.

$$\phi_0 u_{00}'' + u_{00}' - \phi_1 M u_{00} = -(\emptyset_2 Gr\theta_0 + \emptyset_3 GmC_0) \tag{16}$$

$$\phi_0 u_{01}'' + u_{01}' - \phi_1 M u_{01} = -u_{00}''' \tag{17}$$

As we assume $Ec << 1$, using multiparameter perturbation technique, we write

$$\left.\begin{aligned} u_{00} &= u_{000} + Ecu_{001} \\ u_{01} &= u_{010} + Ecu_{011} \\ \theta_0 &= \theta_{00} + Ec\theta_{01} \\ C_0 &= C_{00} + EcC_{01} \end{aligned}\right\} \tag{18}$$

Using equation (18) in equation(13), (14), (16) and (17), and equating the zeroth and first order coefficients of Ec, we get

Zeroth-order of Ec

$$\left.\begin{aligned} \phi_0 u_{000}'' + u_{000}' - \phi_1 M u_{000} = -(\emptyset_2 Gr\theta_{00} + \emptyset_3 GmC_{00}) \\ \phi_0 u_{010}'' + u_{010}' - \phi_1 M u_{010} = -u_{000}''' \\ \phi_4 \theta_{00}'' + Pr\theta_{00}' + PrS\theta_{00} = 0 \\ C_{00}'' + ScC_{00}' - ScRC_{00} = 0 \end{aligned}\right\} \tag{19}$$

First order of Ec

$$\left.\begin{aligned} \phi_0 u_{001}'' + u_{001}' - \phi_1 M u_{001} = -(\emptyset_2 Gr\theta_{01} + \emptyset_3 GmC_{01}) \\ \phi_0 u_{011}'' + u_{011}' - \phi_1 M u_{011} = -u_{001}''' \\ \phi_4 \theta_{01}'' + Pr\theta_{01}' + PrS\theta_{10} = -\phi_5 Pr(u_{000}' + Rmu_{010}')^2 \\ C_{01}'' + ScC_{01}' - ScRC_{01} = 0 \end{aligned}\right\} \tag{20}$$

With the following boundary conditions

$$\left.\begin{aligned} u_{000} = u_{011} = u_{011} = 0, \theta_{00} = 1, \theta_{01} = 0, C_{00} = 1, C_{01} = 0 \; at \; y = 0 \\ u_{000} = u_{011} = u_{011} = 0, \theta_{00} = 0, \theta_{01} = 0, C_{00} = 0, C_{01} = 0 \; as \; y \to \infty \end{aligned}\right\} \tag{21}$$

Solving the differential equations (19)- (20) using (21), we get

$$\mathrm{u} = \left\{\left(a_3 e^{-b_3 y} + a_2 e^{-b_2 y} 2 + a_1 e^{-b_1 y}\right) + Ec\left(a_{25} e^{-b_3 y} + a_{18} e^{-b_1 y} + a_{19} e^{-2b_1 y} + a_{20} e^{-(b_3+b_2)y} + a_{21} e^{-(b_1+b_2)y} + a_{22} e^{-(b_3+b_1)y} + a_{23} e^{-2b_3 y} + a_{23} e^{-2b_2 y}\right)\right\} + Rm\left\{\left((a_7 + a_4) e^{-b_3 y} + a_5 e^{-b_2 y} 2 + a_6 e^{-b_1 y}\right) + Ec\left(\left((a_{34} + a_{26}) e^{-b_3 y} + a_{27} e^{-b_1 y} + a_{28} e^{-2b_1 y} + a_{29} e^{-(b_3+b_2)y} + a_{30} e^{-(b_1+b_2)y} + a_{31} e^{-(b_3+b_1)y} + a_{32} e^{-2b_3 y} + a_{33} e^{-2b_2 y}\right)\right)\right\} \tag{22}$$

$$\theta = e^{-b_2 y} + Ec\begin{pmatrix} a_{17}e^{-b_1 y} + a_{13}e^{-2b_1 y} + a_{14}e^{-(b_3+b_2)y} + a_{15}e^{-(b_1+b_2)y} \\ +a_{16}e^{-(b_3+b_1)y} + a_{11}e^{-2b_3 y} + a_{12}e^{-2b_2 y} \end{pmatrix} \quad (23)$$

$$C = e^{-b_1 y} \quad (24)$$

The non-dimensional rate of heat transfer/ Nusselt number,

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = b_1 + Ec(a_{17}b_1 + 2a_{13}b_1 + a_{14}(b_3+b_2) + a_{15}(b_1+b_2) + a_{16}(b_3+b_1) + 2a_{12}b_2 + 2a_{11}b_3) \quad (25)$$

The dimensionless rate of mass transfer/ Sherwood number,

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{\eta=0} = b_1 \quad (26)$$

The non-dimensional Skin friction at the plate is given by

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = \{(b_3a_3 + b_2a_2 + b_1a_1) + Ec(b_3a_{25} + b_1a_{18} + 2b_1a_{19} + (b_3+b_2)a_{20} + (b_1+b_2)a_{21} + (b_3+b_1)a_{22} + 2b_3a_{23} + 2b_2a_{23})\} + Rm\{(b_3(a_7+a_4) + b_2a_5 + b_1a_6) + Ec((b_3(a_{34}+a_{26}) + b_1a_{27} + 2b_1a_{28} + (b_3+b_2)a_{29} + (b_1+b_2)a_{30} + (b_3+b_1)a_{31} + 2b_3a_{32} + 2b_2a_{33}))\} \quad (27)$$

Where

$$\phi_0 = \frac{1}{(1-\phi)^{2.5}\left((1-\phi)+\phi\frac{\rho_s}{\rho_f}\right)}, \phi_1 = \frac{1}{\left((1-\phi)+\phi\frac{\rho_s}{\rho_f}\right)}, \phi_2 = (1-\phi)+\phi\frac{\beta_s}{\beta_f}, \phi_3 = (1-\phi)+\phi\frac{\beta_{c_s}}{\beta_{cf}}$$

$$\phi_4 = \frac{\left[\frac{k_s+2k_f-2\phi(k_f-k_s)}{k_s+2k_f+2\phi(k_f-k_s)}\right]}{(1-\phi)+\phi\frac{(\rho C_p)_s}{(\rho C_p)_f}}, \phi_5 = \frac{(1-\phi)+\phi\frac{\rho_s}{\rho_f}}{(1-\phi)^{2.5}\left((1-\phi)(\rho C_p)_f+\phi(\rho C_p)_s\right)}$$

$$b_1 = \frac{-\left(Sc+\sqrt{Sc^2+4Scr}\right)}{2}, b_2 = \frac{-\left(Pr+\sqrt{pr^2-4PrS\phi_4}\right)}{2\phi_4}, b_3 = \frac{1+\sqrt{1+4\phi_0\phi_1 M}}{2\phi_0}$$

$$a_1 = \frac{-\phi_3\, G_m}{\phi_0 b_1^2 - b_1 - \phi_1 M}, a_2 = \frac{-\phi_2\, G_r}{\phi_0 b_2^2 - 2 - \phi_1 M}, a_3 = -(a_2 + a_1)$$

$$a_4 = \frac{-b_3^3 a_3}{\phi_0 b_3^2 - b_3 - \phi_1 M}, a_5 = \frac{-b_2^3 a_2}{\phi_0 b_2^2 - b_2 - \phi_1 M}, a_6 = \frac{-a_1\, b_1^3}{\phi_0 b_1^2 - b_1 - \phi_1 M},$$

$$a_7 = -(a_4 + a_5 + a_6), a_8 = a_3b_3 + b_3\,(a_7 + a_4), a_9 = a_2b_2 + a_5b_{2,}a_{10} = a_1b_1 + a_6b_1$$

$$a_{11} = \frac{2\phi_4 Prb_3 a_8^2}{4\phi_4 b_3^2 - 2Prb_3 + PrS}, a_{12} = \frac{2\phi_4 Pr\, b_1 a_9^2}{4\phi_4 b_2^2 - 2Prb_2 + PrS}, a_{13} = \frac{2\phi_4 Prb_1 a_{10}^2}{4\phi_4\, b_1^2 - 2Prb_1 + PrS}$$

$$a_{14} = \frac{2\phi_4 Pr(b_3+b_2)a_8a_9}{\phi_4(b_3+b_2)^2 - Pr(b_3+b_2) + PrS}, a_{15} = \frac{2\phi_4 Pr(b_1+b_2)a_{10}a_9}{\phi_4(b_1+b_2)^2 - Pr(b_1+b_2) + PrS},$$

$$a_{16} = \frac{2\phi_4 Pr(b_3+b_1)a_{10}a_8}{\phi_4(b_1+b_3)^2 - Pr(b_1+b_3) + PrS}, \; a_{17} = -(a_{13} + a_{14} + a_{15} + a_{16})$$

$$a_{18} = \frac{-\phi_2 Gra_{17}}{\phi_0 b_1^2 - b_1 - \phi_1 M}, a_{19} = \frac{-\phi_2 Gra_{13}}{4\phi_0 b_1^2 - 2b_1 - \phi_1 M}, a_{20} = \frac{-\phi_2 Gra_{14}}{\phi_0(b_3+b_2)^2 - (b_3+b_2) - \phi_1 M}$$

$$a_{21} = \frac{-\phi_2 Gra_{15}}{\phi_0(b_1+b_2)^2 - (b_1+b_2) - \phi_1 M}, \; a_{22} = \frac{-\phi_2 Gra_{16}}{\phi_0(b_1+b_3)^2 - (b_1+b_3) - \phi_1 M},$$

$$a_{23} = \frac{-\phi_2 Gra_{11}}{4\phi_0 b_3^2 - 2b_3 - \phi_1 M}, \; a_{24} = \frac{-\phi_2 Gra_{12}}{4\phi_0 2 - 2b_2 - \phi_1 M},$$

$$a_{25} = -(a_{18} + a_{19} + a_{20} + a_{21} + a_{22} + a_{23} + a_{24})$$

$$a_{26} = \frac{-a_{25}b_3^2}{\phi_0 b_3^2 - b_3 - \phi_1 M},\ a_{27} = \frac{-a_{18}b_1^2}{\phi_0 b_1^2 - b_1 - \phi_1 M},\ a_{28} = \frac{-4a_{19}b_1^2}{4\phi_0 b_1^2 - 2b_1 - \phi_1 M},\ a_{29} = \frac{-a_2(b_3+b_1)^2}{\phi_0(b_3+b_1)^2 - (b_3+b_1) - \phi_1 M},$$

$$a_{30} = \frac{-a_{21}(b_2+b_1)^2}{\phi_0(b_2+b_1)^2 - (b_2+b_1) - \phi_1 M},\ a_{31} = \frac{-a_{22}(b_3+b_1)^2}{\phi_0(b_3+b_1)^2 - (b_3+b_1) - \phi_1 M}$$

$$a_{32} = \frac{-4a_{23}b_3^2}{4\phi_0 b_3^2 - 2b_3 - \phi_1 M},\ a_{33} = \frac{-4a_{24}b_2^2}{4\phi_0 b_2^2 - 2b_2 - \phi_1 M}$$

$$a_{34} = -(a_{26} + a_{27} + a_{28} + a_{29} + a_{30} + a_{31} + a_{32} + a_{33})$$

4. Results and Discussion

In this paper, Effects of Chemical Reaction on MHD Unsteady free Convection Walter's Memory Flow of Nano fluid with constant Suctio and Heat Sink has been studied. The effects of the parameters Gr, Gm, M, Rm, Ec, Pr, S, R and Sc on flow characteristics have been studied and shown by means of Graphs and Tables. In order to have Physical correlations, we choose suitable values of Parameters. The Graphs of Velocities, Heat and Mass concentration are taken with respect to y. The values of Skin friction, Nusselt number and Sherwood number for different values of flow parameters are shown in Tables.

Velocity profile: The velocity profiles are depicted in Figs (1-4). Figure (1) shows the effect of the parameters M and Gm on Velocity profile at any point of the fluid when Rm = 0.02, R = 2, S = 3, Sc = 2, Ec = 0.02, Gr = 2, Pr = 3.It is noticed that the velocity enhances with the increase of Magnetic parameter (M) and Modified Grashof number (Gm).

Figure-(2) shows the effects of the parameters Pr and Sc on Velocity profile at any point of the fluid when Gr = 2, S = 3, Gm = 2, Ec = 0.02, Rm = 0.02, M = 5, and R = 2. It is noticed that the velocity intially decreases, then increases with the increase of Schmidt number (Sc), where as decreases with the increase of Prandtl number (Pr).

Figure-(3) shows the effects of parameters S and R on Velocity profile at any point of the fluid, when Gr =2, S = 2, Gm = 2, Ec = 0.02, Rm = 0.02 and Pr = 2. It is noticed that the Source parameter (S) and Chemical Reaction Parameter (R) show reverse effects on velocity profile. In the initial stage, velocity increases with the increase of Source parameter (S) and slightly increases with the increase of Chemical parameter (R). But reverse tendency occurs near y = 0.7. Overall, velocity increases with increase in y, S and R.

Figure-(4) shows the effect of the parameters Ec and Rm on velocity profile at any point of the fluid, when Gr = 2, Sc = 2, Gm = 2, S = 2, R = 2 and Pr = 2. It is noticed that the velocity increases with the increase of Eckert number (Ec) and Magnetic Reynold number (Rm).

Heat profile: The Heat profiles are depicted in Fig-(5-6). Figure-(5) shows the effect of the parameters S and Pr on Heat profile at any point of the fluid, when Ec = 0.02, M = 5, Sc = 2 and R = 2. It is noticed that the temperature rises with the increase of Prandtl number (Pr) and Source parameter (S).

Figure-(6) shows the effect of the parameters Ec and M on Heat profile at any point of the fluid, when Pr = 3, S =3, Sc = 2 and R = 2. It is noticed that the temperature rises with the increase of Eckert number (Ec), where as temperature slightly increases initially and then rises rapidly with the increase of Magnetic parameter (M).

Mass concentration profile: The mass concentration profiles are depicted in Fig 7. Figure-(7) shows the effect of the parameters Sc and R on mass concentration profile at any point of the fluid in the absence of other parameters. It is noticed that the mass concentration increases with the increase of Schmidt number (Sc) and slightly increases with the increase of Chemical Reaction parameter (R).

Nusselt Number: The value of Nusselt number is depicted in Table-(1), which illustrates the effect of the parameters Pr, S, Ec, and M in the absence of other parameters. It is noticed that absolute values of Nusselt number at plate decreases with the increase of Prandtl number (Pr), Source parameter (S) and Magnetic parameter (M), where as increases with the increase of Eckert Number (Ec).

Skin friction: The values of Skin friction is depicted in Table-(2), which illustrates the effect of the parameters R, S, Pr, Gr, Gm, M, Ec, Rm and Sc on Skin friction at the plate. It is noticed that absolute value of Skin friction at plate increases with the increase of Grashof number (Gr), modified Grashof number (Gm) and Eckert number (Ec), where as decreases with the increase of Schmidt number (Sc), Magnetic parameter (M), Source parameter (S), Prandtl number (Pr), Chemical Reaction parameter (R) and Magnetic Reynold number (Rm).

Table 1: Absolute value of Nusselt Number

S	Pr	Ec	M	Absolute value of Nusselt Number
2	2	0.2	2	63.01
2	4	0.2	2	7.18
2	5	0.2	2	5.65
4	2	0.2	2	44.83
6	2	0.2	2	41.76
2	2	0.4	2	125.29
2	2	0.6	2	189.09
2	2	0.2	3	15.32
2	2	0.2	4	11.47

Table 2: Absolute value of shearing stress/skin friction:

Sc	Pr	M	Gm	Gr	S	R	Ec	Rm	Absolute value of shearing stress
2	2	2	2	2	2	5	0.2	0.2	6.91
3	2	2	2	2	2	5	0.2	0.2	5.63
4	2	2	2	2	2	5	0.2	0.2	5.04
2	3	2	2	2	2	5	0.2	0.2	2.88
2	4	2	2	2	2	5	0.2	0.2	2.82
2	2	2	3	2	2	5	0.2	0.2	24.25
2	2	2	4	2	2	5	0.2	0.2	57.64
2	2	2	2	3	2	5	0.2	0.2	8.13
2	2	2	2	4	2	5	0.2	0.2	9.24
2	2	2	2	2	2	6	0.2	0.2	6.56
2	2	2	2	2	2	7	0.2	0.2	6.24
2	2	2	2	2	3	5	0.2	0.2	5.07
2	2	2	2	2	4	5	0.2	0.2	4.34
2	2	3	2	2	2	5	0.2	0.2	0.8
2	2	4	2	2	2	5	0.2	0.2	0.66
2	2	2	2	2	2	5	0.3	0.2	11.08
2	2	2	2	2	2	5	0.4	0.2	15.25
2	2	2	2	2	2	5	0.2	0.3	6.41
2	2	2	2	2	2	5	0.2	0.4	5.92

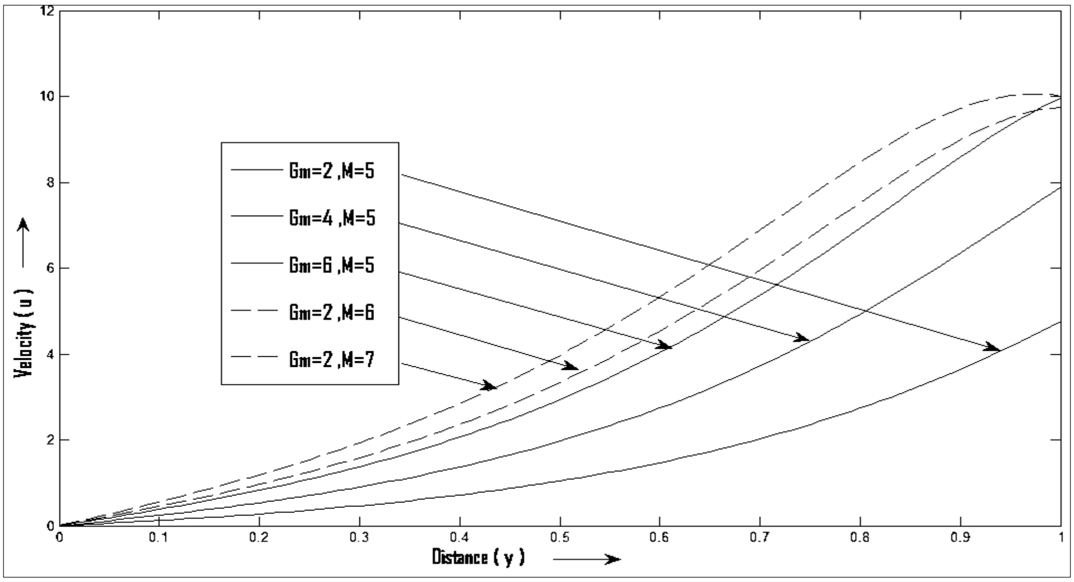

Fig 1: Effects of M and Gm on Velocity profile, when Gr = 2, Pr = 3, S = 3, Sc = 2, Ec = 0.02, Rm = 0.02 and R = 2.

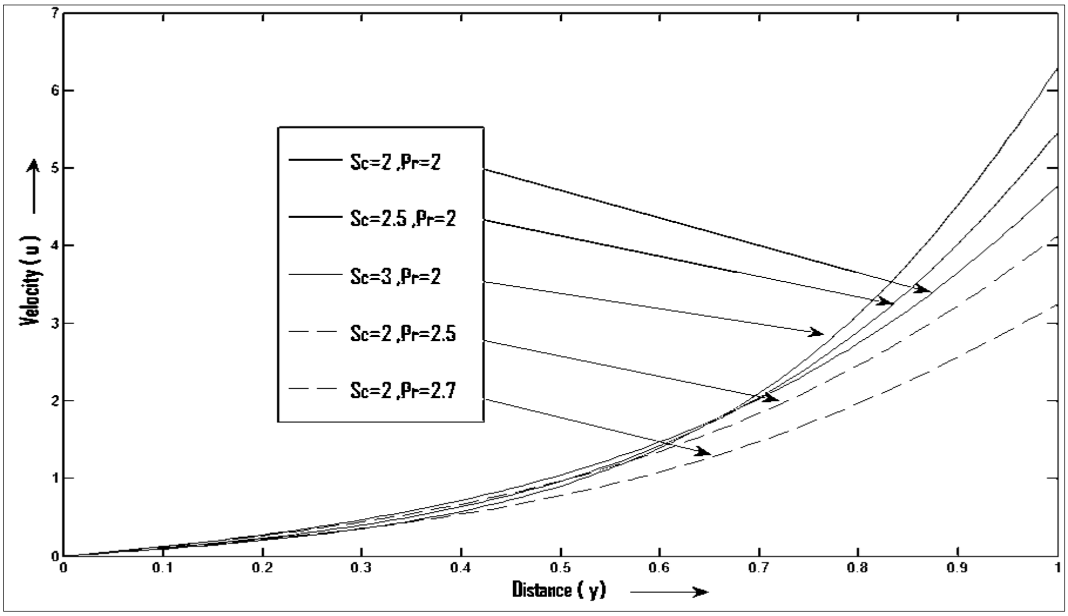

Fig 2: Effects of Sc and Pr on Velocity profile, when Gr = 2, S = 3, Gm = 2, Ec = 0.02, Rm = 0.02, M = 5 and R = 2.

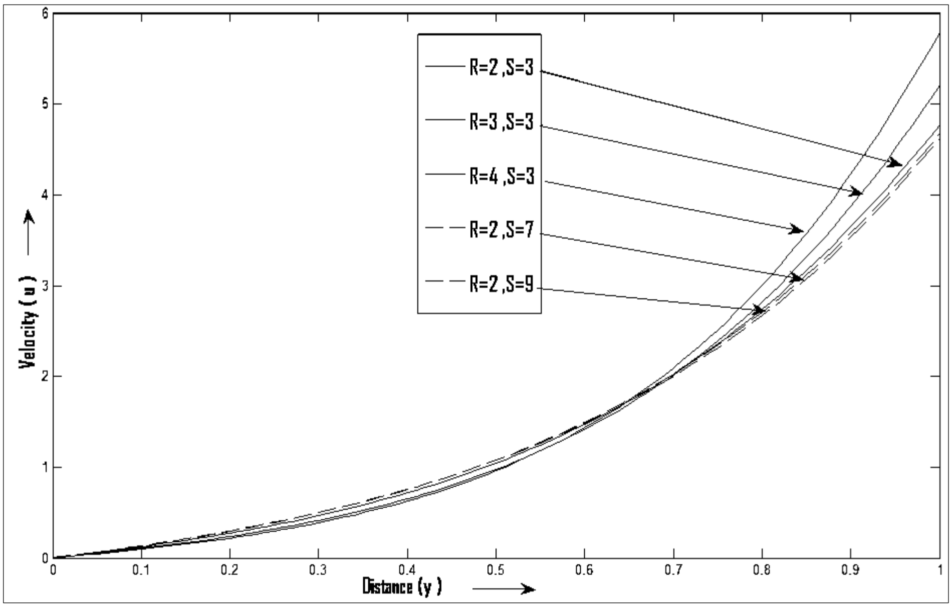

Fig 3: Effects of R and S on Velocity profile, when Gr =2, Sc = 2, Gm = 2, Ec = 0.02, Rm = 0.02 and Pr = 2.

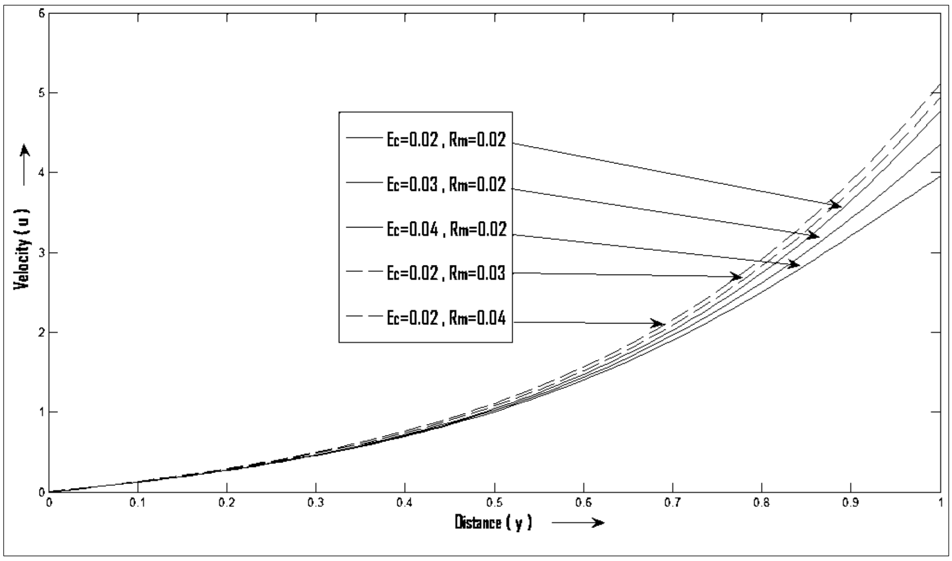

Fig 4: Effects of Ec and Rm on Velocity profile, when Gr = 2, Sc = 2, Gm = 2, S = 3, R = 2 and Pr = 2.

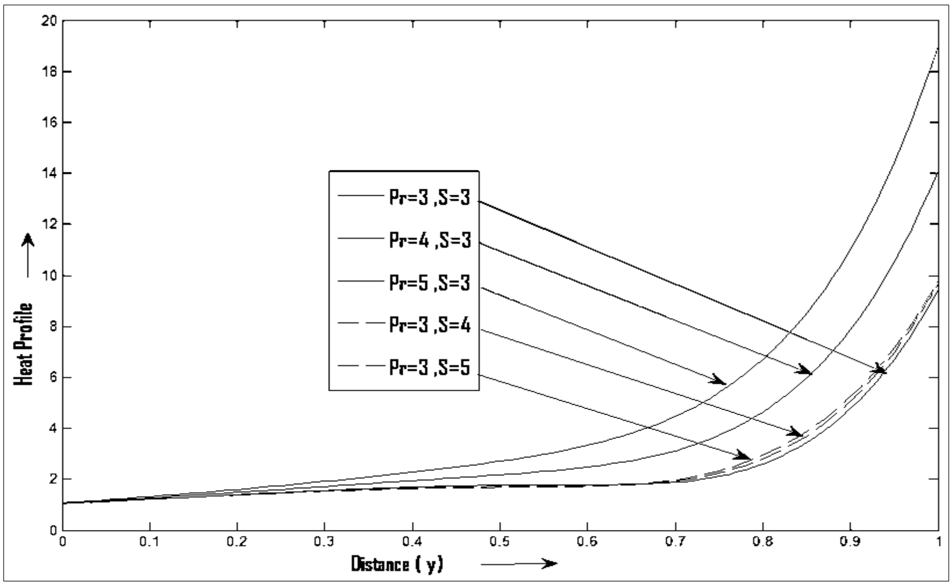

Fig 5: Effects of S and Pr on Heat profile, when Ec = 0.02, M = 5, Sc = 2 and R = 2.

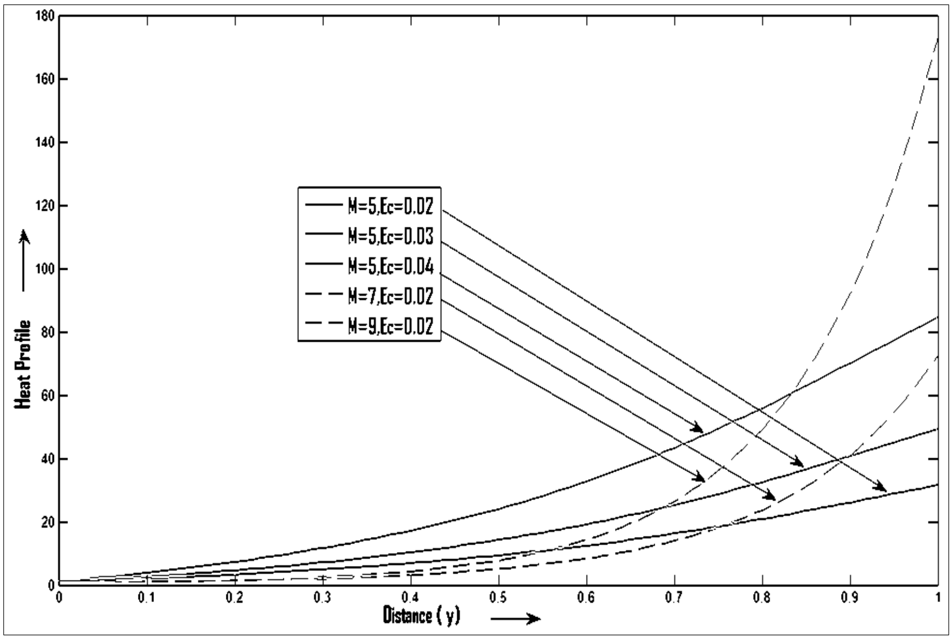

Fig 6: Effect of Ec and M on Heat profile, when Pr = 3, S = 3, Sc = 2 and R = 2.

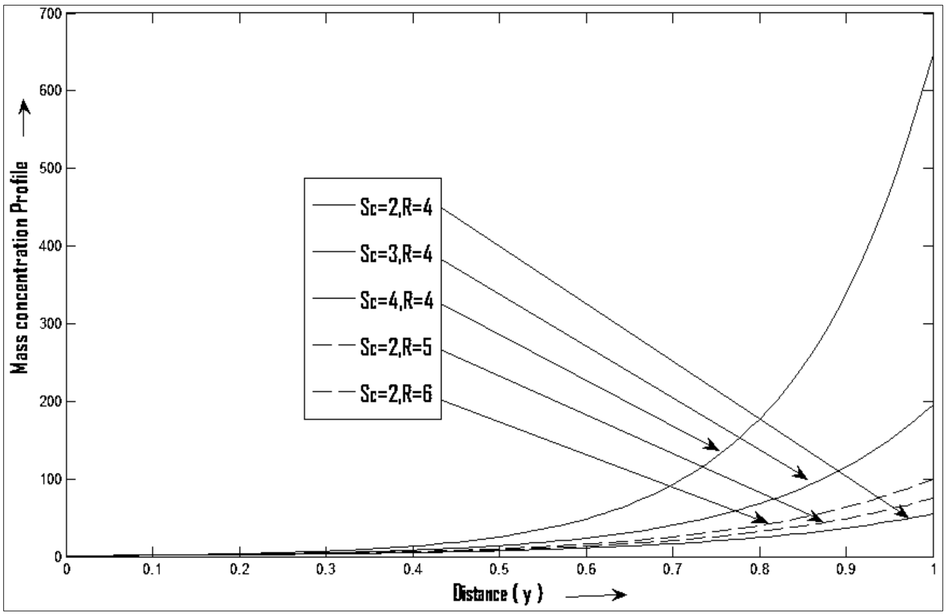

Fig 7: Effects of Sc and R on Mass Concentration profile, when other parameters are absent.

Conclusion

The following results are obtained due to the Effect of Chemical Reaction on MHD Unsteady free Convection Walter's Memory flow of nano fluid with constant Suction and Heat sink:

1. The velocity of nano fluid increases with the increase of M, Gm, Ec and Rm, but decreases with the increase of Pr and Ec which indicates that increase of Magnetic field strength which is dominant over the viscous force allows the fluid flow fast, where as velocity slow down as kinematic viscosity is dominant over thermal diffusion.
2. Heat rises with the enhansement of the value of Source parameter S, Prandtl number Pr, Chemical Reaction parameter R and Eckert number Ec. The Mass concentration distribution increases with the increase of Schmidt number Sc and Chemical Reaction Parameter R. It indicates heat and mass concentration enhance when Kinematic viscosity is dominant over mass diffusion and thermal diffusion.
3. The Skin friction at the plate enhances by diminishing the chemical reaction parameter. Kinematic viscosity is dominant over mass and thermal diffusion.

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