The impact of thermal buoyancy and mass buoyancy on the mass transfer flow of heat and mass past a semi-infinite moving vertical porous plate with a uniform magnetic field imbedded and exhibiting the Soret effect

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Abstract : *With a pressure gradient, thermal radiation field, and chemical reaction present, the current work aims to analyse the thermodiffusion effect on an unsteady simultaneous convective heat and mass transfer flow of an incompressible, electrically conducting, heat-generating/absorbing fluid along a semi-infinite moving porous plate embedded in a porous medium. Under the influence of a transverse magnetic field, it is assumed that the plate, which is permeable and embedded in a uniform porous medium, moves at a constant speed with suction and injection velocity effects in the flow direction. The free stream is further considered to consist of an exponentially varying time function placed on top of a mean velocity, temperature, and concentration field. Analytical regular perturbation approach is used to solve the flow distribution-governing equations of continuity, momentum, energy, and diffusion. For variations in the numerous relevant physical parameters, such as the chemical reaction parameter, Soret number, heat generation parameter, magnetic parameter, Prandtl number, Schmidt number, positive real constant, and time, the flow behaviour of the velocity, temperature, and concentration variation has been discussed.*

Keywords: *Heat Generation/Absorption, Chemical Reaction, MHD, Thermal Radiation, Thermal Diffusion, Heat and Mass Transfer, Semi-Infinite Vertical Plate*

I. Introduction:

Studies of viscous incompressible magnetohydrodynamic fluxes through porous media have been well studied in the last few decades, both theoretically and experimentally. The vast applications of this type of fluid flow in many industrial and engineering sectors, including food processing, coating and glass-fiber production (extraction of polymer sheets), paper production, hot rolling, and polymer processing, have made the theoretical study of such a fluid flow past an infinite heated vertical porous plate embedded with porous medium subjected to the act of uniform magnetic field very useful. Because magnetohydrodynamic flows through porous media have numerous and consistent applications in manufacturing and various industries, including geophysical problems, astrophysics, and the development of magnetic generators for low-cost electrical energy production, the study of these flows is also of great interest. The idea of viscous flow through a porous material with a permeable surface wall is helpful for analysing how temperature and pressure affect soil water movement. Takhar et al. [1] examined the erratic free convection flows across the semi-infinite vertical plates.

The MHD behaviour of free porous convection heat transport of water at 400C via a porous media is another area of study for Thakar and Ram [2]. MHD-free oscillatory convection Couette flow via a permeable When talking about how temperature and pressure affect soil water movement, surface walls are helpful. The unsteadiness of MHD free convection oscillatory Couette flow over a porous material with periodic wall temperature was examined by Raju and Varma [3]. Radiation impacts are crucial in space technology research because of the high temperatures involved in the processes. Thermal energy has received more attention recently due to advancements in hypersonic travel, rocket combustion chambers, missiles, gas-cooled nuclear reactors, and power plants for interplanetary travel.Analyse the need for a better knowledge of radiative transfer in these processes and radiation as a mode of energy transfer. Thermal radiating MHD boundary layer flows have been considered by several authors (Raju et al., [4]; Nath et al., [5]; Raptis and Perdikis, [6]; Bakier, [7]; Kim, [8]; Chamkha and Khaled [9]) with applications in diverse fields of astrophysical fluid dynamics. The integration of heat and mass transfer processes with chemical reaction phenomena is a significant field that has garnered significant interest in recent decades. The impact of a homogeneous first-order chemical reaction on the flow past an infinite vertical plate embedded with a uniform heat flux that started impulsively has been investigated by Das et al. [10].have studied the influence of homogeneous first order chemical reaction over the flow past an impulsively started infinite vertical plate embedded with uniform heat flux. The unsteady behavior of MHD-free convection and chemically reactive flow past an infinite vertical porous plate was discussed by Raju et al. [11]. Chamka [12] analysed the MHD flow past a uniformly stretched vertical permeable surface having heat generation/absorption. As per, Mahdy and Ah-med [13], the Soret effect, for instance, has been utilized for mixture between gases with very light molecular weight, and in isotope separation (H_2, H_e). Raju et al. [14] studied the Soret effects due to natural convection between heated inclined plates subjected to the act of magnetic field. Recently Ablel-Rahman [15] discussed the effect of thermal diffusion over MHD flow of combined free forced convection and heat along with mass transfer flow of a viscous fluid through a porous medium in presence of heat generation. Chemical and thermo diffusion effects with simultaneous thermal and mass diffusion in MHD flow of mixed convection type with Ohmic heating was discussed by Reddy, A. et al. [16].More generally Sarma et al. [17] worked on MHD free convection and mass transfer flow past an accelerated vertical plate in presence ofchemical reaction and radiation. Ahmed and Batin [18] discussed the combined magneto-hydrodynamic heat and mass transfer flow with embedded magnetic field and viscous dissipative effects. Mutuku-Njane and Makinde [19] analysed on hydromagnetic boundary layer flow of nanofluids for a permeable wall with moving surface in presence of Newtonian heating.

The MHD transient free convection flow of a Newtonian fluid past an infinite vertical porous plate is analysed by Umamaheswar and Raju [20]. Srinivasacharya et al. [21] have examined the Soret and Dufour effects on mixed convection along a vertical wavy surface along a porous medium with varied properties. Hayday et al. [22] describe free convection from a vertical plate with step discontinuity in surface temperature. Merkin [23] studied the movement of convective boundary layers naturally occurring in a heat-generating embedded porous media with a continuous surface heat flux. Kim [24] studied the behaviour of semi-infinite vertical porous moving plate with changing suction during unstable MHD convective heat transfer.

Inspired by the aforementioned research, we examined the thermal diffusion effect on an unstable simultaneous system in this article. Convective heat and mass transfer via a semi-infinite moving porous plate that is subjected to a porous medium in the presence of a chemical reaction, a pressure gradient, and a thermal radiation field. The fluid is an incompressible, electrically conducting, heat-absorbing/generating fluid. The consideration of a double diffusion fluid (thermal and mass diffusion), a heat source, and the chemical reaction of a radiating fluid passing through or past a porous surface in a conducting field constitute the novelty of this work. Even if many scholars researched in related topics, there are still a lot of crucial areas that need to be focused on. Thus, the writers are still motivated to continue their research.

II. MATHEMATICAL FORMULATION:

Considering an unsteady two-dimensional incompressible laminar electrically conducting and heat generating/absorbing fluid flow past along a semi-infinite vertical porous plate having a porous medium in the presence of thermal radiation, thermal diffusion with heat and mass transfer in presence of chemical reaction . A uniform transverse magnetic field is subjected to the act of the plate. The absences of applied voltage generate which implies the no presence of the electric field. The magnetic Reynolds number and transversely applied magnetic field are assumed to be very small and hence the induced magnetic field is negligible in comparison. Since the plate is semi infinite in length so all the flow variables are functions of y and t only. Under the above consideration and the usual Boussinesq's approximation the governing flow equations are given as

Equation of Continuity

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Velocityequation:

$$\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}=\frac{-1}{\rho}\frac{\partial p}{\partial x}+v\frac{\partial^2 u^*}{\partial y^2}+g\beta(T^*-T_\infty)+g\beta^*(C^*-C_\infty)-\frac{v}{K^*}u^*-\frac{\sigma}{\rho}B_0^2u^* \quad (2)$$

Temperature equation:

$$\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}=\alpha\left(\frac{\partial^2 T^*}{\partial y^2}-\frac{1}{K}\frac{\partial q_r}{\partial y^*}\right)+Q(T^*-T_\infty)-K_1(C^*-C_\infty) \quad (3)$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*}+v^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^*} \quad (4)$$

By considering the Rosseland approximation the radiative heat flux in y direction is defined by

$$q_r=\frac{-4}{3}\frac{\sigma_s}{K_e}\frac{\partial T^{*4}}{\partial y^*} \quad (5)$$

Where K_e and σ_s are the mean absorption coefficient andStefan-Boltzmann constant respectively. It should be remarked that by using the Rosseland approximation we limit our investigation to optically thick fluids. It is considered that the heating due to viscous dissipation is discarded for small velocities in energy conservation Equation (3) andBoussinesq's approximation is defined to describe buoyancy force in Equation (2). It is also assumed that the, the suction velocity, free stream velocity, the plate concentration, the plate temperature follow an exponentially decreasing /increasing small perturbation law.

Under these considerations, the appropriate boundary conditions for the velocity, temperature and concentration distributions are the temperature differences are small, and then Equation (5) can be linearized by expanding T^{*4} into Taylor series about T_∞, and neglecting higher order terms to give:

$$T^{*4}\cong aT_\infty^3T^*-3T_\infty^4 \quad (6)$$

The heating due to viscous dissipation is neglected for small velocities in energy conservation Equation (3) and Boussinesq's approximation is used to describe buoyancy force in Equation (2). It is assumed that the free stream velocity, the suction velocity, the plate temperature and the plate concentration follow an exponentially increasing or decreasing small perturbation law. Under these considerations, the appropriate boundary conditions for the velocity, temperature and concentration distributions are

$$\left.\begin{array}{l} u^*=u_p^*, T^*=T_W+\in(T_W-T_\infty)e^{n^*}, C^*=C_W+\in(C_W-C_\infty)e^{n^*t} \text{ at } y^*=0 \\ u^*\to U_\infty^*=U_0\left(1+\in Ae^{n^n}\right), T^*\to T_\infty, C^*\to C_\infty, \text{ as } y^*\to\infty \end{array}\right\} \quad (7)$$

From the equation of continuity, it is observed that the suction velocity normal to the plate is a function of time only and we shall got this in the form

$$v^*=-V_0(1+\in Ae^{nt}) \quad (8)$$

Here A is a real positive constant, $\in$ and $\in A$ are negligible and considered to be less than unity, and V_0 is scale of suction velocity and this is a non-zero positive constant. Outside the boundary layer, Equation (2) gives

$$\frac{-1}{\rho}\frac{\partial p}{\partial x}=\frac{dU_\infty^*}{dt^*}+\frac{v}{k^*}U_\infty^*+\frac{\sigma}{\rho}B_0^2U_\infty^* \quad (9)$$

Now introduce non-dimensional parameters as follows

$$\Pr = \frac{\rho v C_p}{K} = \frac{v}{\alpha}, Gr = \frac{vg\beta(T_w - T_\infty)}{U_0 v_0^2}, n = \frac{n^* v_0^2}{v}$$
$$Gm = \frac{vg\beta^*(C_w - C_\infty)}{U_0 v_0^2}, Kr = \frac{K_1 v}{v_0^2}, \delta = \frac{Qv}{\alpha v_0^2}$$
$$R = \frac{KK_e}{4\sigma_s T_\infty^3}, S_0 = \frac{D_1(T_w - T_\infty)}{v(C_w - C_\infty)}, M = \frac{\sigma B_0^2}{\rho v_0^2}, F = \frac{D_1}{v}. \tag{10}$$
$$K = \frac{K^* v_0^2}{v^2}, N = Mv + \frac{1}{K}, \frac{1}{\Gamma} = \frac{1}{\Pr}\left[1 + \frac{a}{3R}\right]$$

$$u = \frac{u^*}{U_0}, v = \frac{v^*}{U_0}, U_\infty = \frac{U_\infty^*}{U_0}, y = \frac{v_0 y^*}{v}, U_p = \frac{u_p^*}{U_0}$$
$$t = \frac{v_0^2 t^*}{v}, \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, Sc = \frac{v}{D}$$

After applying boundary conditions and introduce nondimensional parameters the governing Equations (2)-(5) reduce to

$$\frac{\partial u}{\partial t} - (1{+}\epsilon\, Ae^{nt})\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + Gr\theta + GmC + N(U_\infty - u). \tag{11}$$
$$\frac{\partial \theta}{\partial t} - (1{+}\epsilon\, Ae^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{\Gamma}\frac{\partial^2 \theta}{\partial y^2} + \alpha\delta\theta - \frac{Kr}{S_0}FC. \tag{12}$$
$$\frac{\partial C}{\partial t} - (1{+}\epsilon\, Ae^{mt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}. \tag{13}$$

The boundary conditions (7) are given by the following dimensionless form

$$u = U_p, \theta = 1{+}\epsilon\, e^{nt}, C = 1{+}\epsilon\, e^{nt} \text{ at } y = 0 \tag{14}$$
$$u \to U_\infty, \theta \to 0, C \to 0 \text{ at } y \to \infty$$

III. SOLUTION OF THE PROBLEM :

In order to reduce the above system of partial differential equations with boundary conditions to a system of ordinary differential equations with prescribed boundary conditionsin non-dimensional form, for epsilon to

be very small compared to unity i.e.ϵ<<1, the expressions for the velocity, temperature and concentration distributions are presented by the help of or according to regular perturbation law as follows:

$$U(y) = U_0(y){+}\epsilon\, e^{nt}U_1(y) \tag{15}$$
$$\theta(y) = \theta_0(y){+}\epsilon\, e^{mm}\theta_1(y) \ldots \tag{16}$$
$$C(y) = C_0(y){+}\epsilon\, e^{mn}C_1(y) \tag{17}$$

Substituting these Equations (15)-(17) into Equations (11)-(13) and equating the harmonic and non-harmonic terms, also neglecting the coefficient of $O(\epsilon^2)$, we get the following pairs of Zeroth order and first order equations.

$$-U_0' = -NU_0 + U_0'' + Gr\theta_0 + GmC_0 \tag{18}$$
$$U_1 - AU_0' - U_1' = -NU_1 + U_1'' + Gr\theta_1 + GmC_1 \tag{19}$$
$$-\theta_0' = \frac{1}{\Gamma}\theta_0'' + \alpha\delta\theta_0 - \frac{Kr}{S_0}FC_0 \tag{20}$$
$$n\theta_1 - A\theta_0' - \theta_1' = \frac{1}{\Gamma}\theta_1'' + \alpha\delta\theta_1 - \frac{Kr}{S_0}FC_1 \tag{21}$$
$$-C_0' = \frac{1}{Sc}C_0{}' \tag{22}$$
$$nC_1 - AC_0' - C_1' = \frac{1}{Sc}C_1'' \tag{23}$$

Here primes denote differentiation with respect to y.
The corresponding prescribed perturbed boundary conditions are

$$u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \text{ at } y = 0$$
$$u_0 \to U_\infty, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \text{ as } y \to \infty \tag{24}$$

The solutions of Equations (18)-(23) with corresponding boundary conditions (24) are given by

$$U_0(y) = C_{19}e^{m_{19}y} + m_{22}e^{m_6 y} + m_{23}e^{-\delta y} \tag{25}$$
$$\theta_0(y) = C_6 e^{m_6 y} + (1 - C_6)e^{-sy}. \tag{26}$$
$$C_0(y) = e^{-sy}. \tag{27}$$
$$U_1(y) = C_{25}e^{m_{25}y} + m_{32}e^{m_{19}y} + m_{33}e^{m_6 y} + m_{34}e^{-\delta y} + m_{35}e^{m_8 y} + m_{36}e^{m_{14}y} + m_{37}e^{m_4 y}. \tag{28}$$
$$\theta_1(y) = C_8 e^{m_8 y} + m_{12}e^{m_{14}y} + m_{16}e^{-\delta y} + m_{16}e^{m_6 y}. \tag{29}$$
$$C_1(y) = C_4 e^{m_4 y} + (1 - C_4)e^{-\delta y}. \tag{30}$$

By virtue of Equations (15)-(17) we obtain the solutions for the velocity, temperature and concentrationdistribution as follows

$$U(y,t) = (C_{19}e^{m_{19}y} + m_{22}e^{m_6 y} + m_{23}e^{-S y}) \tag{31}$$
$$+\in e^{mi}(C_{25}e^{m_{25}y} + m_{32}e^{m_{19}y} + m_{33}e^{m_6 y} + m_{34}e^{-8y} + m_{35}m^{m_8 y} + m_{36}e^{m_{14}y} + m_{37}e^{m_4 y}). \tag{32}$$
$$\theta(y,t) = \left(C_6 e^{m_6 y} + (1 - C_6)e^{-\delta y}\right) + \in e^{nt}\left(C_8 e^{m_8 y} + m_{12}e^{m_{14}y} + m_{16}e^{-\delta y} + m_{16}e^{m_6 y}\right). \tag{33}$$
$$C(y,t) = \left(e^{-\delta y}\right) + \in e^{mt}\left(C_4 e^{m_4 y} + (1 - C_4)e^{-\delta y}\right). \tag{34}$$

Given the velocity boundary layer, we can now calculate the skin friction at the surface wall as

$$\tau = \left.\frac{\partial U(y,t)}{\partial y}\right)_{y=0} = (C_{19}m_{19} + m_{22}m_6 - Scm_{23}) \tag{35}$$
$$+\in e^{nt}(C_{25}m_{25} + m_{32}m_{19} + m_{33}m_6 - m_{34}Sc + m_{35}m_8 + m_{36}m_{14} + m_{37}m_4)$$

We calculate the heat transfer coefficient in terms of Nusselt number as follows

$$Nu = \left.\frac{\partial\theta(y,t)}{\partial v}\right) = (C_6 m_6 - (1 - C_6)Sc) + \in e^{wt}(C_8 m_8 + m_{12} m_{14} - m_{16} Sc + m_{16} m_6) \tag{36}$$

Similarly the mass transfer coefficient in terms of Sherwood number as follows

$$Sh = \left.\frac{\partial C(y,t)}{\partial y}\right)_{y=0} = -Sc + \in e^{nt}\left(C_4 m_4 - Sc(1 - C_4)\right) \tag{37}$$

RESULTS AND DISCUSSION:

An analytical regular perturbation method is applied to solve the flow distribution's governing equations of continuity, momentum, energy, and diffusion. Considering a semi-infinite vertical porous plate with a porous medium, an unsteady two-dimensional incompressible laminar fluid flow that conducts electricity and generates or absorbs heat in the presence of thermal radiation, thermal diffusion that transfers heat, and mass transfer that occurs in the presence of a chemical reaction. We found that, in the absence of diffusion effects, all parameter impacts on temperature, velocity, and concentration profiles accord well with results that have already been published. Plotting of the graphs is done for different parameters while holding other parameters constant for these sets of values.

$Up = 0.5; A = 0.5; n = 0.5; \in = 0.2; F = 0.6$
$\alpha = 1; M = 2; K = 0.1; R = 1; t = 1$
$a = 0.6; Gr = 5.0; Gm = 5.0; Kr = 0.2$
$Pr = 0.7; Sc = 0.6; S0 = 1; \delta = 0.3; Nc = 0.5$

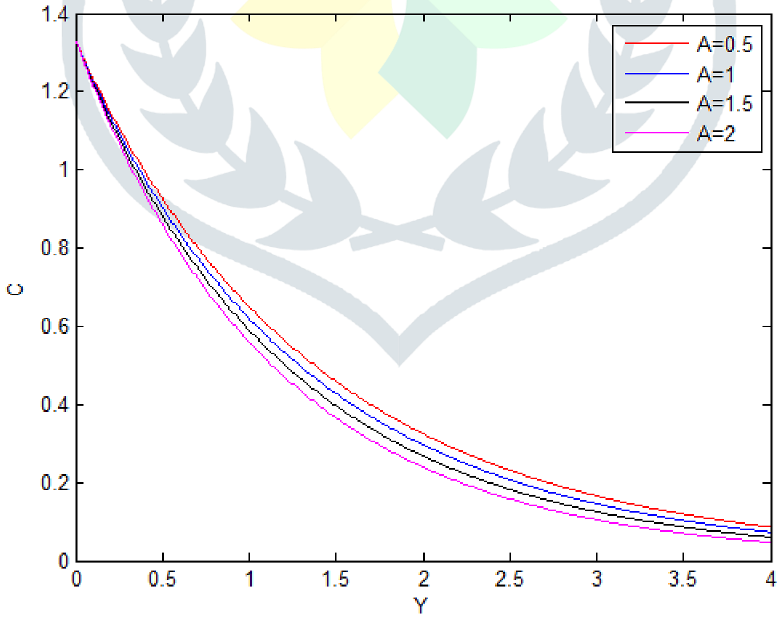

Fig. 1 Behaviour of concentration over A

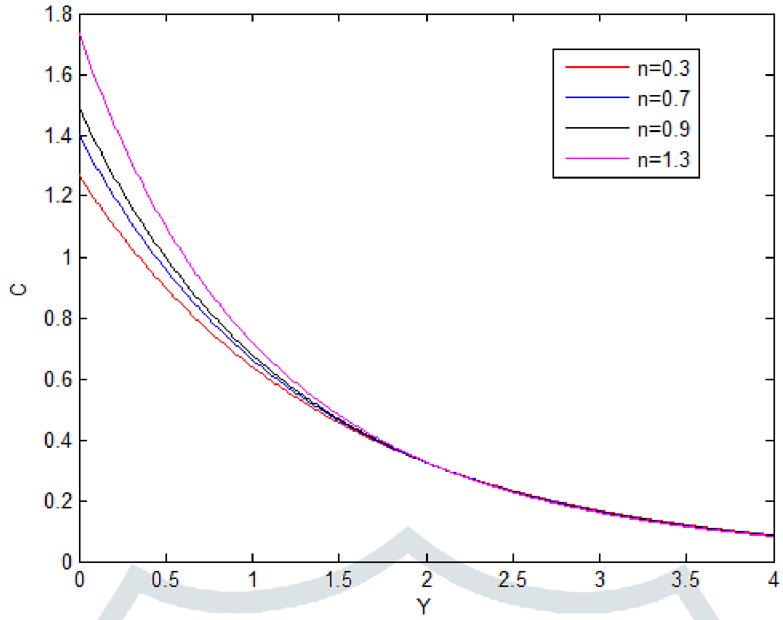

Fig. 2 Behaviour of concentration over n

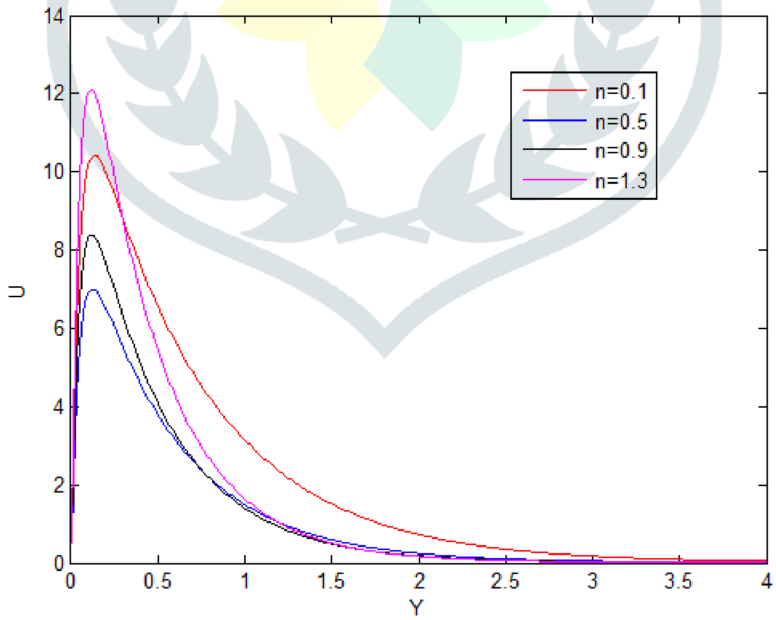

Fig. 3 Behaviour of velocity over n

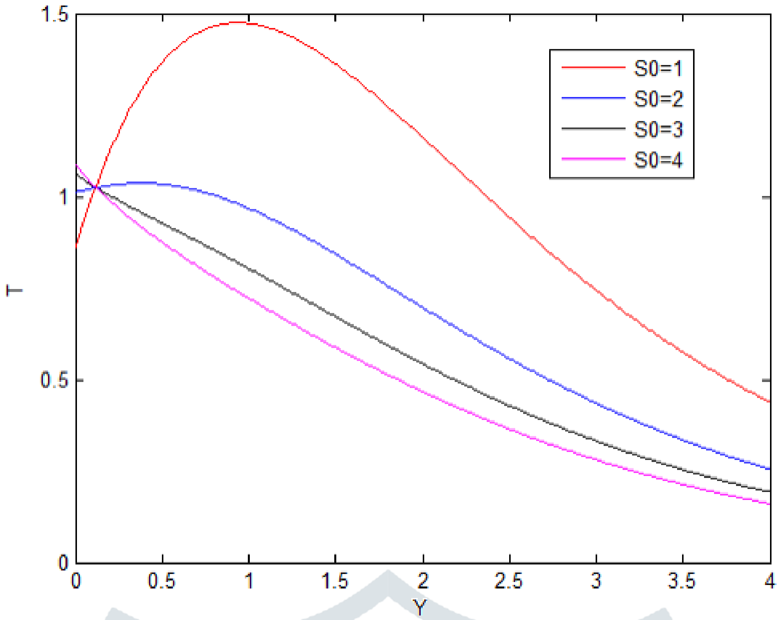

Fig. 4 Behaviour of Temperature over S_0

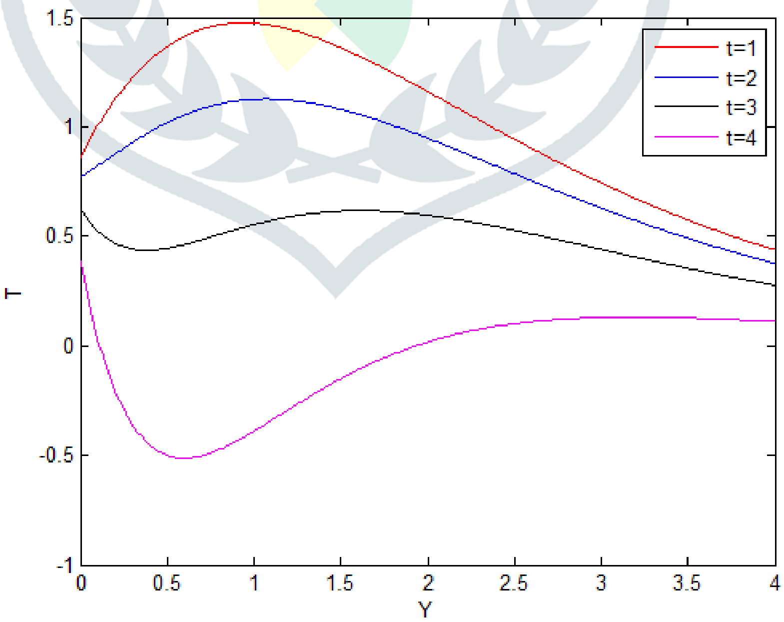

Fig. 5 Behaviour of temperature over t

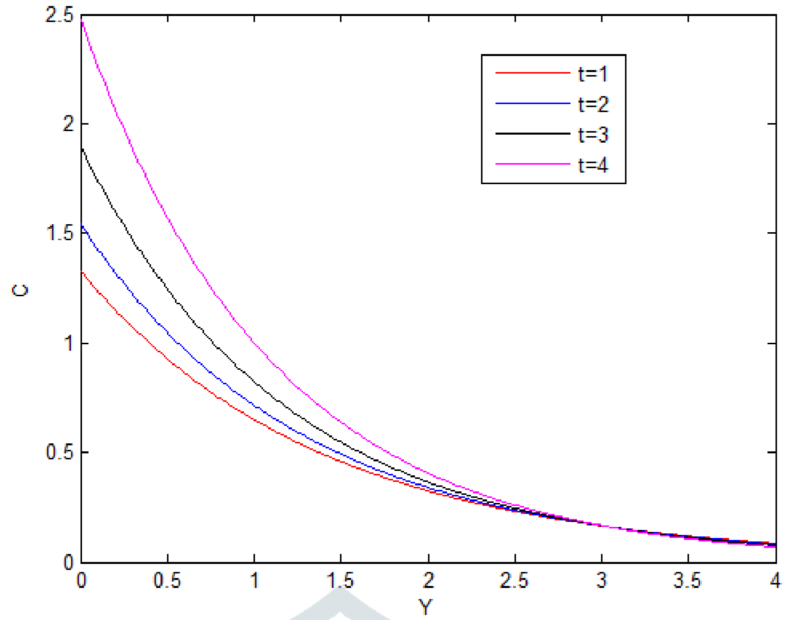

Fig.6 Behaviour of concentration over t

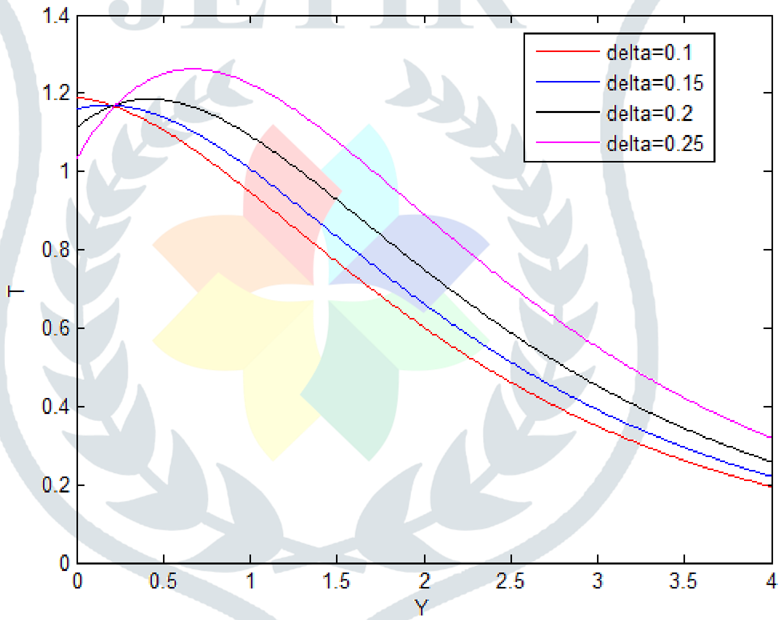

Fig.7 Behaviour of temperature over Heat generation parameter

CONCLUSION :

We have considered thermo diffusion effect on an unsteady simultaneous convective heat and mass transfer flow of a incompressible, electrically conducting, heat generating/absorbing fluid along a semi-infinite moving porous plate embedded in a porous medium with the presence of chemical reaction, pressure gradient and thermal radiation field. An increase in A , t and n leads to a raise in the velocity but a reverse effect is seen in the case of S_0 . An increase in both nand results an increase in thermal boundary layer thickness. However, thermal boundary layer decreases as t, S_0 increase. Concentration profile increases with an increase in n and t while reverse effect is found in the case of A. This work can be extended for other non-Newtonian fluids such as viscoelastic fluid, Rivlin Ericksen fluid.

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