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HEAT AND MASS TRANSFER ON MHD FLUID FLOW OVER A SEMI INFINITE FLAT PLATE WITH RADIATION ABSORPTION, HEAT SOURCE AND DIFFUSION THERMO EFFECT

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ABSTRACT

Analytical investigation is carried out to analyze the unsteady, two-dimensional, laminar, boundary layer flow of a viscous incompressible electrically conducting and heat absorbing fluid along a semi-infinite vertical permeable moving plate in the presence of Diffusion-thermo and radiation absorption effects. The set of ordinary differential equations are solved by using perturbation technique. The effects of the various fluid flow parameters on velocity, temperature and concentration fields with in the boundary layer have been analyzed with the help of graphs. Numerical values of local skin-friction coefficient, nusselt number and Sherwood number are tabulated.

Keywords: *Diffusion-thermo, Heat Absorption, Radiation Absorption, MHD, Unsteady.*

1. INTRODUCTION

Fluid dynamics of various fluids have many engineering and industrial applications. In particular combined heat and mass transfer from different processes with porous media has a wide range in engineering and industrial applications oil recovery, underground energy transport, geothermal reservoirs, cooling of nuclear reactors, drying of porous solids, packed-bed catalyst reactors and thermal insulation. When heat and mass transfer occur simultaneously between the fluxes, the driving potentials are of more intricate nature. An energy flux can be generated not only by temperature gradients but by composition gradients. The energy flux caused by a called Dufour or Diffusion thermo effect. Generally the thermal diffusion and the diffusion thermo effects are of smaller order magnitude than the effects prescribed by Fourier's laws and are often neglected in heat and mass transfer processes. However, there are exceptions. Thermal-diffusion effect, for instance, has been utilized for isotope separation and in mixture between gases with very light molecular weight (Hydrogen-Helium) and of medium molecular weight (Nitrogen-air) the diffusion-thermo effect was found to be of a magnetic such that it cannot be neglected. Umamaheswar *et al.* (2016) studied the effects of chemical reaction, radiation absorption and thermal diffusion. Srinivasacharya *et al.* (2015) reported on the effects of dufour along a vertical wavy surface. Hayday *et al.* (1967) analyzed natural convection flow from a vertical plate with discontinuous thermal boundary conditions considering different aspects of the problem. Effects of free convection currents and mass transfer on the unsteady flow of an electrically conducting and viscous incompressible fluid around an accelerated infinite vertical porous plate subjected to variable suction in presence of a transverse magnetic field, have been studied by Hossain and Mandal (1985). The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Possible heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electrical chips and semi conductor wafers. Merkin (2012) has been inspected all effects with convective boundary layer flow. Raptis (1998) has been given experimental work through porous medium. Raptis and Singh (1983) have been performed all the results in an accelerated vertical plate. The interaction of buoyancy with thermal radiation has in increased greatly the last decade due to its importance in many practical applications. Thermal radiation effect is important under many isothermal and non-isothermal situations. If the entire system involving the polymer extrusion process is placed in a thermally controlled environment, then thermal radiation could be important. The knowledge of radiation heat transfer in the system can perhaps, lead to a desired product with sought characteristics. The effect of radiation on flow and heat transfer over a vertically oscillating porous flat plate embedded in porous medium with oscillating surface temperature is investigated by Kim (2000). Convection in porous media can also be applied to underground coal gasification, ground water hydrology, iron blast furnaces, wall cooled catalytic reactors, cooling of nuclear reactors, solar power collectors, energy efficient drying processes, cooling of electronic equipments and natural convection in earth's crust. Abiodun *et al.* (2015) have been explained radiation absorption effect through porous materials with effect of chemical reaction and radiation absorption on the unsteady MHD natural convection flow, by considering one of the plate moves with a constant velocity in the direction of fluid flow while the other plate is stationary. Anilkumar (2011) performed to obtain the nonsimilar solution of an unsteady laminar mixed convection on a continuously moving vertical plate. Aydin and Kaya (2009) analytically explained the problems the effects of MHD mixed convection fluid about a permeable vertical flat plate applying numerical method. The mixed convective boundary layer flows over a

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flat plate are investigated by Bhattacharyya *et al*. (2013). The combined effects of heat and mass transfer with chemical reaction are of great importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering, and hence received of considerable amount of attention in recent years. The study of chemical reaction with heat transfer in porous medium has important engineering applications e.g., tabular reactors, oxidation of solid materials and synthesis of ceramic materials. Heat and mass transfer effects on the unsteady flow of a micropolar fluid through a porous medium bounded by a semi-infinite vertical plate in a slip-flow regime are studied taking into account a homogeneous chemical reaction of the first order numerically studied by Chaudhary and Jha (2008). Patil and Chamkha (2013) have been experimented chemical reaction effect along with porous medium. Patil *et al*. (2009) have been explained chemical reaction in the presence of heat generation. Sahin and Karabi (2014) numerically studied chemical reaction effect on impulsively-started vertical plate. Soundalgekar and Wavre (1997) exhibited all effects on unsteady free convection flow past an infinite plate.

Recently, Durga Prasad *et al.* (2015) focuses on unsteady, two-dimensional, laminar, boundary layer flow of a viscous incompressible electrically conducting fluid long a semi-infinite vertical permeable moving plate in the presence of Diffusion-thermo and radiation absorption effects. In this paper we consider unsteady simultaneous convective heat and mass transfer flow along a vertical permeable plate embedded in a fluid-saturated porous medium in the presence of mass blowing or suction, diffusion-thermo and radiation absorption effects, magnetic field effects and absorption effects. In all above investigations it is noticed however they have not considered ε^2 . In the present work, the set of ordinary differential equations are solved by considering ε^2 in regular perturbation method. The effect of non-dimensional governing parameters on velocity, temperature and concentration profiles are discussed are presented through graphs. Numerical values of local skin-friction coefficient, Nusselt number and Sherwood number are tabulated.

2. ANALYSIS OF THE FLOW OF THE PROBLEM

We consider unsteady two-dimensional flow of an incompressible, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable plate embedded in a uniform porous medium which is subject to slip boundary condition at the interface of porous and fluid layers. A uniform transverse magnetic field of strength B_0 is applied in the presence of radiation and concentration buoyancy effects in the direction of y^* - axis. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that induced magnetic field and Hall Effect are negligible.

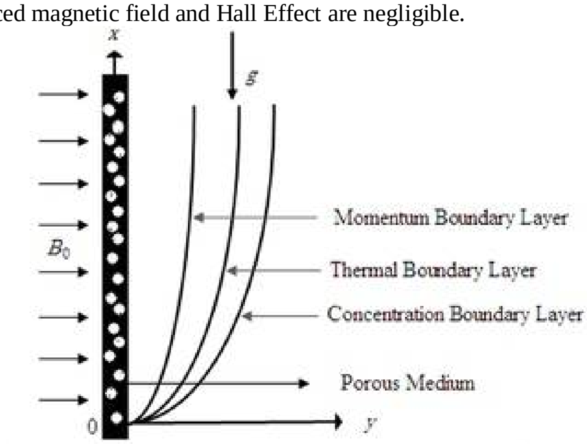

Fig. 1 Problem Configuration

It is assumed that there is no applied voltage which implies the absence of electric field. Since the motion is two dimensional and the length of the plate is large enough so all the physical variables are independent of x^*. The wall is maintained at constant temperature T_w and concentration C_w, higher than the ambient temperature T_∞ and the concentration C_∞ , respectively. Also, it is assumed that there exists a homogeneous first-order chemical reaction with rate constant R between the diffusing species and the fluid. It is assumed that the porous medium is homogeneous and present everywhere in local thermodynamic equilibrium. Rest of properties of fluid and the porous medium are assumed to be constant. In the above assumptions the governing equations as follows:

Continuity Equation:

$$\frac{\partial \upsilon^*}{\partial y^*}=0 \tag{1}$$

Momentum Equation:

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

Energy Equation:

$$\frac{\partial T}{\partial t^*}+\upsilon^*\frac{\partial T}{\partial y^*}=\alpha\frac{\partial^2 T}{\partial y^{*2}}-\frac{Q_0}{\rho C_p}(T-T_\infty)+\upsilon\frac{Q_1^*}{\rho C_p}(C-C_\infty)+\frac{D_m}{C_s}\frac{K_T}{\rho C_p}\frac{\partial^2 C}{\partial y^{*2}} \tag{3}$$

Mass Diffusion Equation:

$$\frac{\partial C}{\partial t^*}+\upsilon^*\frac{\partial C}{\partial y^*}=D\frac{\partial^2 C}{\partial y^{*2}}-K_1(C-C_\infty) \tag{4}$$

Where x^* *and* y^* are the dimensional distances along to the plate. u^* *and* v^* are the components of dimensional velocities along x^* *and* y^* directions. G is the gravitational acceleration, T^* is the dimensional temperature of the fluid near the plate, T_∞ is the stream dimensional temperature, C^* is the dimensional concentration, C_∞ is the stream dimensional concentration, β_T *and* β_C are the thermal and concentration expansion coefficients, respectively. p^* is the pressure, C_p is the specific heat of constant pressure, B_0 is the magnetic field coefficient, μ is the viscosity of the fluid, q_r^* is the radiative heat flux, ρ is the density, K is the thermal conductivity, σ is the density magnetic permeability of the fluid, $\upsilon=\frac{\mu}{\rho}$ is the kinematic viscosity, D is the molecular diffusivity, Q_0 is the dimensional heat absorption coefficient, Q_1^* is the coefficient of proportionality of the absorption of the radiation and R is the chemical reaction. The fourth and fifth terms of RHS of the Eq.(2) denote the thermal and concentration buoyancy effects, respectively. The second and third term on the RHS of the Eq.(3) denote the inclusion of the effect of thermal radiation and heat absorption effects, respectively.

$$u^*=u_p^*,\quad T=T_w+\varepsilon(T_w-T_\infty)e^{n^*t^*},C=C_w+\varepsilon(C_w-C_\infty)e^{n^*t^*}\,at\,y^*=0$$
$$u^*=U_\infty^*=U_0(1+\varepsilon e^{n^*t^*}),\quad T\to T_\infty, C\to C_\infty \qquad as \quad y \quad \to\infty \tag{5}$$

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Where U_p, C_w *and* T_w are the wall dimensional velocity, concentration and temperature, respectively. U_∞^*, C_∞ *and* T_∞ are the free stream dimensional velocity, concentration and temperature, respectively. U_0 *and* n^* are constants. It is clear from Eq.(1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$\upsilon^* = -V_0(1+\varepsilon A e^{n^* t^*}) \tag{6}$$

Where A is a real positive constant, ε *and* εA are small less than unity, and V_0 is a scale of suction velocity which has non-zero positive constant. Outside the boundary layer, Eq.(2) gives

$$-\frac{1}{\rho}\frac{dp^*}{dx^*} = \frac{dU_\infty^*}{dt^*} + \frac{\sigma}{\rho}B_0^2 U_\infty^* + \frac{\upsilon}{K^*}U_\infty^* \tag{7}$$

Introducing the non-dimensional quantities

$$u = \frac{u^*}{U_0}, v = \frac{v^*}{V_0}, \eta = \frac{v_0 y^*}{v}, U_\infty = \frac{U_\infty{}^*}{U_0}, t = \frac{v_0{}^2 t^*}{v}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, c = \frac{C - C_\infty}{C_w - C_\infty},$$
$$n = \frac{n^* v}{V_0{}^2}, \quad U_p = \frac{u^*{}_p}{U_0}, \; G\gamma_T = \frac{gv(T_w - T_\infty)\beta_T}{U_0 V^2{}_0}, \quad G\gamma_c = \frac{gv(C_w - C_\infty)\beta_c}{U_0 V^2{}_0},$$
$$M = \frac{\sigma v B^2{}_0}{\rho V^2{}_0}, \quad \Pr = \frac{\mu C_p}{K} = \frac{v}{\alpha}, \quad \phi = \frac{Q_0 v}{\rho C_p V^2{}_0}, \quad Q_1 = \frac{Q^*{}_1 v^2 (C_w - C_\infty)}{V^2{}_0 (T_w - T_\infty)\rho C_p},$$
$$Sc = \frac{v}{D}, \quad \gamma = \frac{K_1 v}{V^2{}_0}, \quad D_u = \frac{D_m K_t (C_w - C_\infty)}{C_s K (T_w - T_\infty)}, \quad K = \frac{V^2{}_0 K^*}{V^2} \tag{8}$$

In the view of the above non-dimensional variables, the basic field of Eqs. (2)- (4) can be expressed in non-dimensional form as

$$\frac{\partial u}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial u}{\partial \eta} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial \eta^2} + G\gamma_T \theta + G\gamma_C C + N(U_\infty - u) \tag{9}$$

$$\frac{\partial \theta}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial \eta} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial \eta^2} + Q_1 C - \phi\theta + \frac{Du}{\Pr}\left(\frac{\partial^2 C}{\partial \eta^2}\right) \tag{10}$$

$$\frac{\partial C}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial C}{\partial \eta} = \frac{1}{Sc}\frac{\partial^2 C}{\partial \eta^2} - \gamma C \tag{11}$$

Where, $N = \left(M + \frac{1}{K}\right)$

The corresponding boundary conditions (5) in dimensionless form are

$$u = U_p, \theta = 1 + \in e^{nt}, C = 1 + \in e^{nt} \quad at \quad \eta = 0$$
$$u \to U_\infty = (1 + \in e^{nt}), \theta \to 0, C \to 0 \quad as \quad \eta \to \infty \tag{12}$$

3. NUMERICAL SOLUTIONS BY TWO TERM PERTURBATION TECHNIQUE

Equations (9) – (11) represent a set of partial differential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as:

$$u = f_0(\eta) + \varepsilon e^{nt} f_1(\eta) + \varepsilon^2 e^{2nt} f_2(\eta) + O(\varepsilon^3) + \cdots\cdots \tag{13}$$
$$\theta = g_0(\eta) + \varepsilon e^{nt} g_1(\eta) + \varepsilon^2 e^{2nt} g_2(\eta) + O(\varepsilon^3) + \cdots\cdots \tag{14}$$
$$C = h_0(\eta) + \varepsilon e^{nt} h_1(\eta) + \varepsilon^2 e^{2nt} h_2(\eta) + O(\varepsilon^3) + \cdots\cdots \tag{15}$$

Substituting (13)-(15) into Eqs.(9)-(11) and equating the coefficient of ε^0, ε^1 and ε^2, we get the following pairs of equations for (f_0, g_0, h_0), (f_1, g_1, h_1) and (f_2, g_2, h_2).

$$f_0'' + f_0' - Nf_0 = -G\gamma_T g_0 - G\gamma_C h_0 - N \tag{16}$$
$$f_1'' + f_1' - (N+n) f_1 = -G\gamma_T g_1 - G\gamma_C h_1 - (N+n) - Af_0' \tag{17}$$
$$f_2'' - N f_2' - 2nf_2 + f_2' = -G\gamma_T g_2 - G\gamma_C h_2 - (N+n) - Af_1' \tag{18}$$
$$g_0'' + \Pr g_0' - \Pr\phi g_0 = -\Pr Q_1 h_0 - Duh_0'' \tag{19}$$
$$g_1'' + \Pr g_1' - \Pr(n+\phi) g_1 = -\Pr Q_1 h_1 - Duh_1'' - \Pr Ag_0' \tag{20}$$
$$g_2'' + \Pr g_2' - \Pr(2n+\phi) g_2 = -\Pr Q_1 h_2 - Duh_2'' - \Pr Ag_1' \tag{21}$$
$$h_0'' + Sch_0' - Sc\gamma h_0 = 0 \tag{22}$$
$$h_1'' + Sch_1' - Sc(\gamma+n) h_1 = -Ah_0' Sc \tag{23}$$
$$h_2'' + Sch_2' - Sc(\gamma+2n) h_2 = -Ah_1' Sc \tag{24}$$

Where the prime denotes ordinary differentiation with respect to y. The corresponding boundary conditions are

$$f_0 = U_p, \; f_1 = 0, \; f_2 = 0, \; g_0 = 1, \; g_1 = 1, \; g_2 = 0,$$
$$h_0 = 1, h_1 = 1, h_2 = 0 \qquad at\, \eta = 0$$
$$f_0 = 1, \; f_1 = 1, \; f_2 = 0, \; g_0 \to 0, \; g_1 \to 0,$$
$$g_2 \to 0, h_0 \to 0, h_1 \to 0, h_2 \to 0 \quad as\, \eta \to \infty \tag{25}$$

The solutions of the Equations (16) – (24) with the help of boundary conditions (25) are

$$f_0 = B_4\, e^{-m_6\eta} - A_3 e^{-m_2\eta} - A_2 e^{-p_1\eta} + 1 \tag{26}$$
$$f_1 = B_5\, e^{-m_3\eta} - A_4 e^{-m_6\eta} - A_{10} e^{-m_2\eta} + 1 - B_1\, e^{-p_1\eta} - B_2\, e^{-m_5\eta} - B_3\, e^{-m_4\eta} \tag{27}$$
$$f_2 = q_{20} e^{-m_{10}\eta} + q_{12} e^{-m_3\eta} + q_{13} e^{-m_6\eta} + q_{14} e^{-m_2\eta} + q_{15} e^{-p_1\eta} + q_{16} e^{-m_5\eta} + q_{17} e^{-m_4\eta} + q_{18} e^{-m_5\eta} + q_{19} e^{-q_1\eta} \tag{28}$$
$$g_0 = (1 - A_1) e^{-m_2\eta} + A_1 e^{-p_1\eta} \tag{29}$$
$$g_1 = A_9 e^{-m_5\eta} + A_6 e^{-p_1\eta} + A_7 e^{-m_2\eta} + A_8 e^{-m_4\eta} \tag{30}$$
$$g_2 = q_6 e^{-m_5\eta} + q_7 e^{-m_2\eta} + q_8 e^{-p_1\eta} + q_9 e^{-m_4\eta} + q_{10} e^{-q_1\eta} + q_{11} e^{-q_5\eta} \tag{31}$$
$$h_0 = e^{-p_1\eta} \tag{32}$$
$$h_1 = A_5 e^{-p_1\eta} + (1 - A_5) e^{-m_4\eta} \tag{33}$$
$$h_2 = q_4 e^{-q_1\eta} + q_2 e^{-m_4\eta} + q_3 e^{-p_1\eta} \tag{34}$$

The velocity, temperature and concentration distributions can be expressed as:

$$u(\eta,t) = (B_4\, e^{-m_6\eta} - A_3 e^{-m_2\eta} - A_2 e^{-p_1\eta} + 1) + \varepsilon e^{nt}(B_5\, e^{-m_3\eta} - A_4 e^{-m_6\eta} - A_{10} e^{-m_2\eta} + 1 - B_1\, e^{-p_1\eta} - B_2\, e^{-m_5\eta} - B_3\, e^{-m_4\eta}) + \varepsilon^2 e^{2nt}(q_{20} e^{-m_{10}\eta} + q_{12} e^{-m_3\eta} + q_{13} e^{-m_6\eta} + q_{14} e^{-m_2\eta} + q_{15} e^{-p_1\eta} + q_{16} e^{-m_5\eta} + q_{17} e^{-m_4\eta} + q_{18} e^{-q_5\eta} + q_{19} e^{-q_1\eta}) \tag{35}$$

$$\theta(\eta,t) = ((1 - A_1) e^{-m_2\eta} + A_1 e^{-p_1\eta}) + \varepsilon e^{nt}(A_9 e^{-m_5\eta} + A_6 e^{-p_1\eta} + A_7 e^{-m_2\eta} + A_8 e^{-m_4\eta}) + \varepsilon^2 e^{2nt}(q_6 e^{-m_5\eta} + q_7 e^{-m_2\eta} + q_8 e^{-p_1\eta} + q_9 e^{-m_4\eta} + q_{10} e^{-q_1\eta} + q_{11} e^{-q_5\eta}) \tag{36}$$

$$C(\eta,t) = (e^{-p_1\eta}) + \varepsilon e^{nt}(A_5 e^{-p_1\eta} + (1 - A_5) e^{-m_4\eta}) + \varepsilon^2 e^{2nt}(q_4 e^{-q_1\eta} + q_2 e^{-m_4\eta} + q_3 e^{-p_1\eta}) \tag{37}$$

The Skin-friction coefficient, the Nusselt number and the Sherwood number are important physical parameters for this type of boundary layer flow which are defined and determined as follows:

$$C_f = \left(\frac{\partial u}{\partial \eta}\right)_{\eta=0} = (-m_6 B_4 + m_2 A_3 + P_1 A_2) + \varepsilon e^{nt}(-m_3 B_5 - m_6 A_4 + m_2 A_{10} + P_1 B_1 + m_5 B_2 + m_4 B_3) + \varepsilon^2 e^{2nt}(-m_{10} q_{20} - m_3 q_{12} - m_6 q_{13} - m_2 q_{14} - p_1 q_{15} - m_5 q_{16} - m_4 q_{17} - q_5 q_{18} - q_1 q_{19}) \quad (38)$$

$$Nu_x = \left(\frac{\partial \theta}{\partial \eta}\right)_{\eta=0} = (-m_2(1-A_1) - p_1 A_1) + \varepsilon e^{nt}(-m_5 A_9 - p_1 A_6 - m_2 A_7 - m_4 A_8) + \varepsilon^2 e^{2nt}(m_5 q_6 - m_2 q_7 - p_1 q_8 - m_4 q_9 - q_1 q_{10} - q_5 q_{11}) \quad (39)$$

$$Sh_x = \left(\frac{\partial C}{\partial \eta}\right)_{\eta=0} = -p_1 + \varepsilon e^{nt}(-p_1 A_5 - m_4(1-A_5)) + \varepsilon^2 e^{2nt}(-q_1 q_4 - m_4 q_2 - p_1 q_3) \quad (40)$$

Where $\mathrm{Re}_x = \dfrac{V_0 x}{\upsilon}$ is the local Reynolds number.

4. RESULTS AND DISCUSSIONS

The unsteady simultaneous convective heat and mass transfer flow along a vertical permeable plate embedded in a fluid-saturated porous medium in the presence of mass blowing or suction, diffusion-thermo and radiation absorption effects, magnetic field effects and absorption effects is investigated by solving nonlinear ordinary differential equations using perturbation technique. It should be mentioned that in the absence of the concentration buoyancy and heat absorption effects and $\varepsilon^2 = 0$, all of the flow and heat transfer solutions reported above are consistent with those reported earlier by Durga Prasad(2015).

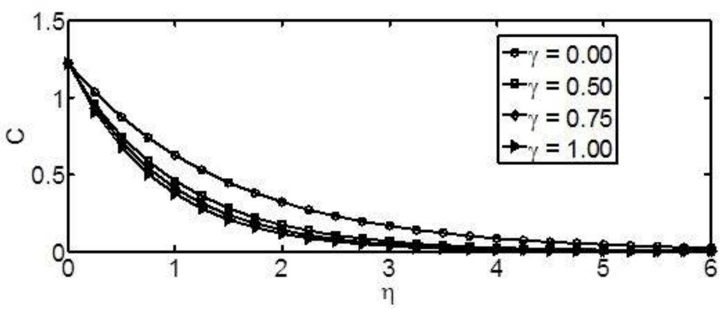

Fig. 2 Effects of γ on Concentration profiles

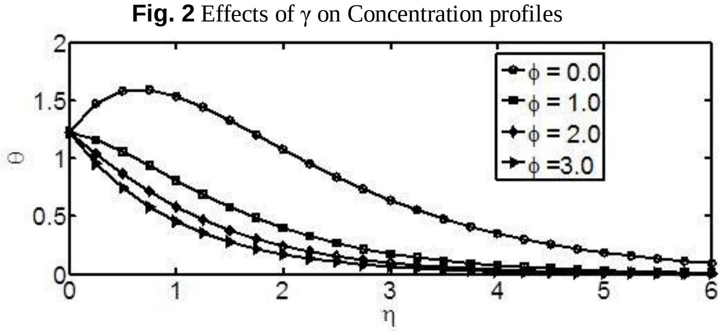

Fig. 3 Effects of ϕ on temperature profiles

The effects of different emerging parameters on the fluid velocity, temperature and concentration fields presented in Figs.1-12 and investigated. For numerical results we considered Sc = 0.6, ε = 0.2, n = 0.1, ϕ = 1, Up = 0.5, A = 0.5, t = 1, $G\gamma_T$ = 4, $G\gamma_C$ = 2, Q_1 = 2, Du = 0.5, M = 2, K = 0.5, γ = 0.5, Pr = 0.71. These values are kept as common in entire study except the variations in the respective figures and tables.

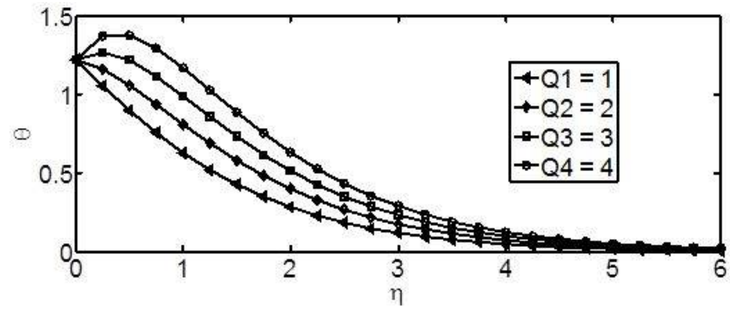

Fig. 4 Effects of Q_1 on temperature profiles

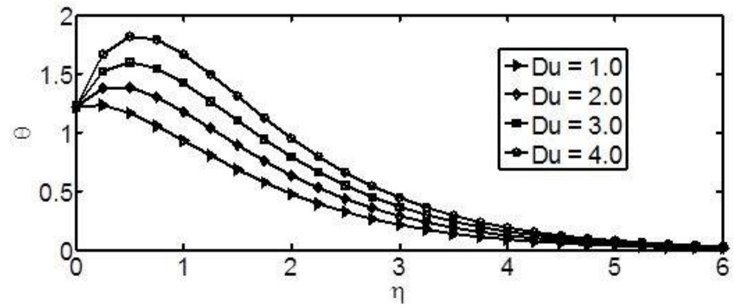

Fig. 5 Effects of Du on temperature profiles

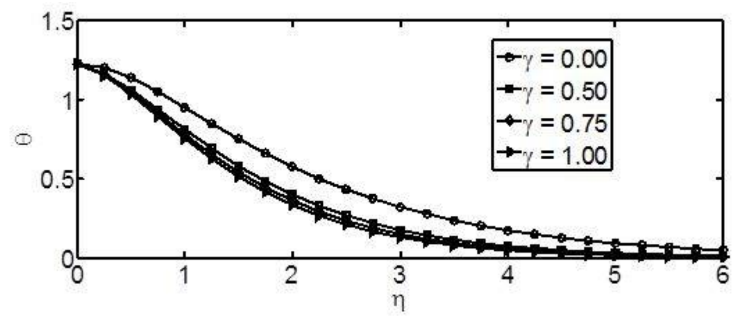

Fig. 6 Effects of γ on temperature profiles

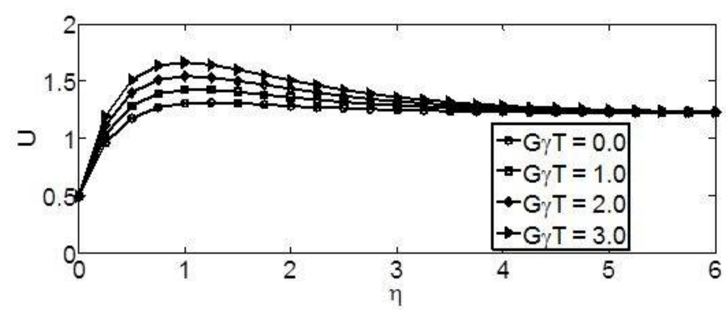

Fig. 7 Effects of Gr_T on velocity

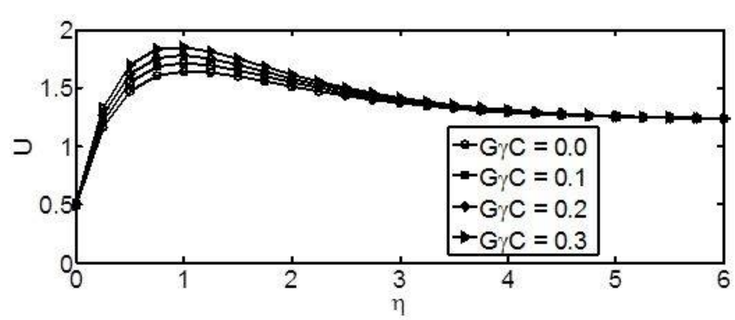

Fig. 8 Effects of Gr_c on velocity profiles

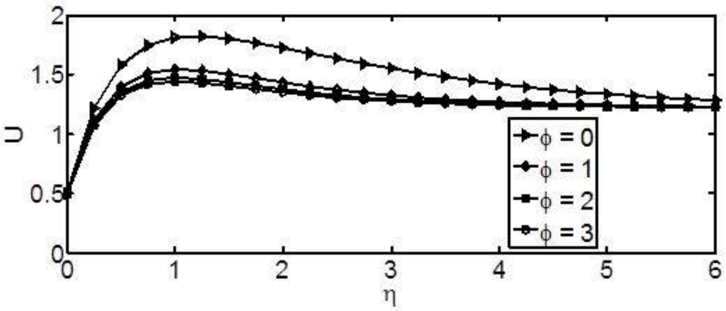

Fig. 9 Effects of ϕ on velocity profiles

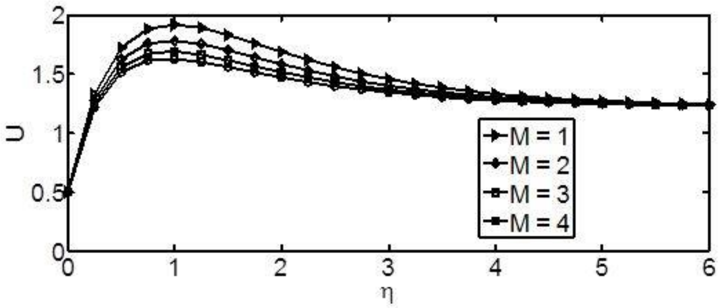

Fig. 10 Effects of M on velocity profiles

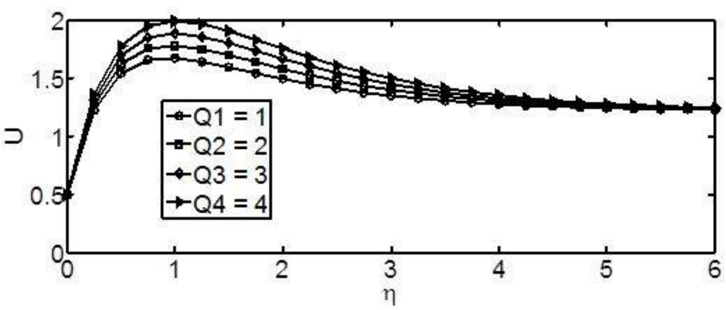

Fig. 11 Effects of Q_1 on velocity profiles

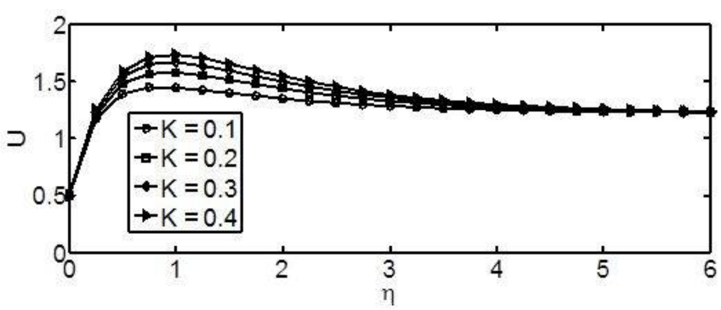

Fig. 12 Effects of K on velocity profiles

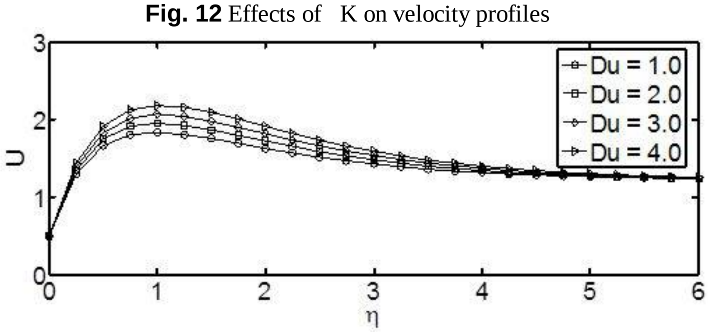

Fig.13 Effects of Du on velocity profiles

Fig.2 illustrate the concentration profiles for different values of chemical reaction γ. From this figure, it is observed that the concentration with increasing values of γ. The temperature profiles for different values of heat absorption parameter are depicted in Fig 3. It is

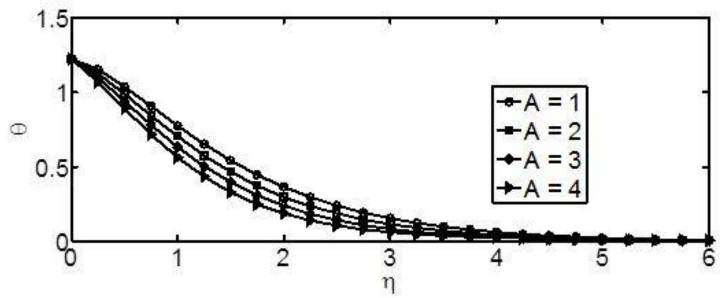

Fig. 14 Effects of A on temperature profiles

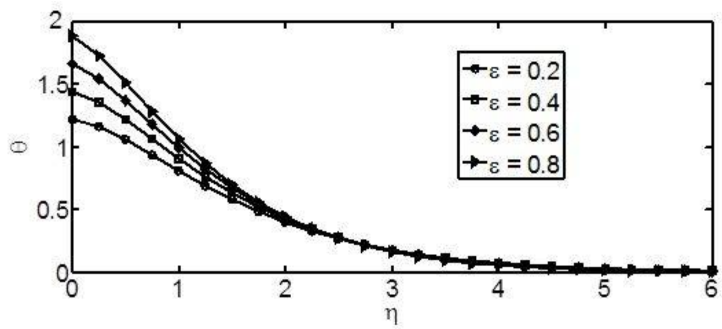

Fig. 15 Effects of ε on temperature profiles

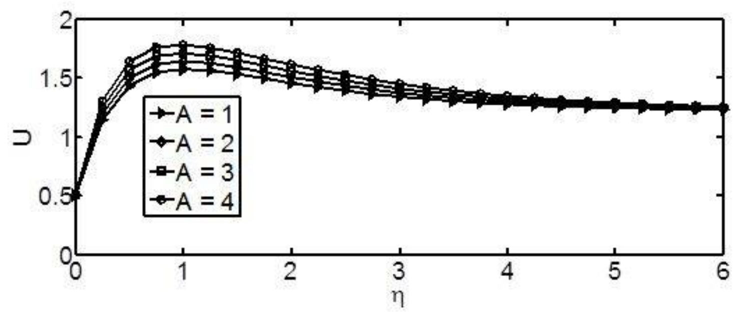

Fig. 16 Effects of A on velocity profiles

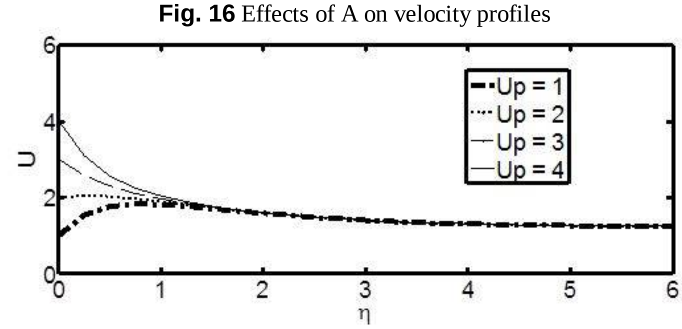

Fig. 17 Effects of Up on velocity profiles

noticed that the temperature decreases significantly with the increasing values of ϕ because when heat is absorbed, the buoyancy force decreases the temperature profiles. It is seen from Fig.4 that increasing by radiation parameter Q_1 causes to increase the fluid temperature and hence the maximum peak value is attained at the porous plate. It is seen from this figure that the effect of absorption of radiation is to increase temperature in the boundary layer as the radiated heat is absorbed by the fluid which in turn increases the temperature of the fluid very close to the porous boundary layer and its effect diminishes far away from the boundary layer. Fig.5 has been plotted to depict the temperature profiles against y for different values of Du and hence the thermal buoyancy layer thickness can be increases with increasing values of Du. From Fig.6, it is appear that the temperature profiles decreases as γ increases. The effect of chemical reaction parameter is to increase the thermal boundary layer. From this figure an increasing Du causes a distinct rise in the temperature throughout the boundary layer. Velocity distribution for various values Gr_T and solutal buoyancy force parameter Gr_C are plotted in Figs.7 & 8. As seen from this figures that the maximum peak value is observed in the absence of buoyancy force, this is due to fact that buoyancy force enhances fluid velocity and increase the buoyancy layer thickness with increase in the values of Gr_T and Gr_C. It is also observed that the significance of the velocity is maximum near the plate and there after it decreases and reaches to the stationary position at the other side of the plate. Fig.9 represents the decrease in fluid velocity when the heat absorption parameter ϕ is increased, it is clear that the hydro magnetic boundary layer decreases as the heat absorption effect increase also observed that in the absence of heat absorption the velocity attains maximum peak value. As expected due to the fact that when heat is absorbed the buoyancy force decreases which retard the flow rate and thereby giving rise to decrease in the velocity profiles. Fig. 10 demonstrates the effect of magnetic parameter M on the dimensionless velocity field. From this figure, it is observed that with increase in the magnetic parameter M, i.e. ratio of electromagnetic force to the viscous force, the velocity field decreases. The Lorentz force is stronger corresponding to larger magnetic parameter due to which higher temperature and thicker thermal boundary layer thickness. As the values of magnetic parameter M increases, the retarding force increases and consequently the velocity decreases. Fig.11 displays the velocity profiles for various values of radiation parameter Q_1. From this figure it is obvious that the velocity increases as Q_1 increases and the velocity starts from minimum value of zero at the surface and increases till attain the peak value. We observe in this figure that increasing the value of the absorption of the radiation parameter due to increase in the buoyancy force accelerates the flow rate. The influence of the permeability parameter K on velocity is shown in Fig. 12, as seen from this figure that maximum peak value attains for K = 0.4 and minimum peak value is observed for K = 0.1,also it is clear that the velocity increases significantly with the increasing values of K. With increase of K the velocity along the plate increases and consequently the momentum boundary layer thickness decreases. Fig.13 illustrates the effect of Dufour on velocity; from this figure an increasing Du causes a distinct rise in the velocity throughout the boundary layer. Fig. 14 & 16 deploys the profiles for temperature and velocity for A. with the increasing values of A, temperature is decreasing and velocity is increasing. Fig. 15 shows the variation of boundary-layer with the perturbation parameter (ε). It is observed that the thermal boundary layer thickness increases with an increase in the perturbation parameter. The effect of ε is to accelerate the temperature and its influence is highly dominant near the plate where as it remains uniform as we move far away from the plate. Fig.17 presents the variation of the velocity distribution across the boundary layer for different values of the plate velocity *Up* in the direction of the fluid flow. Although we have different initial plate velocities, the velocity increases to the constant value for given material parameters.

Table 1 Numerical values of Skin-friction coefficient for various flow quantities:

Sc	$G\gamma_T$	$G\gamma_C$	ϕ	M	Q_1	K	Pr	Du	C_f
0.60	0	2	1	2	2	0.5	0.7	0.5	2.5970
0.60	1	2	1	2	2	0.5	0.7	0.5	3.0354
0.60	2	2	1	2	2	0.5	0.7	0.5	3.4738
0.60	3	2	1	2	2	0.5	0.7	0.5	3.9122
0.60	2	0	1	2	2	0.5	0.7	0.5	2.7786
0.60	2	1	1	2	2	0.5	0.7	0.5	3.1262
0.60	2	3	1	2	2	0.5	0.7	0.5	3.8214
0.60	2	2	0	2	2	0.5	0.7	0.5	3.9226
0.60	2	2	2	2	2	0.5	0.7	0.5	3.3479
0.60	2	2	3	2	2	0.5	0.7	0.5	3.2845
0.60	2	2	1	0.5	2	0.5	0.7	0.5	3.5691
0.60	2	2	1	1	2	0.5	0.7	0.5	3.5167
0.60	2	2	1	1.5	2	0.5	0.7	0.5	3.4873
0.60	2	2	1	3	2	0.5	0.7	0.5	3.4779
0.60	2	2	1	2	1	0.5	0.7	0.5	3.3757
0.60	2	2	1	2	3	0.5	0.7	0.5	3.5719
0.60	2	2	1	2	4	0.5	0.7	0.5	3.6701
0.60	2	2	1	2	2	0.1	0.7	0.5	3.8491
0.60	2	2	1	2	2	0.2	0.7	0.5	3.5509
0.60	2	2	1	2	2	0.3	0.7	0.5	3.4856
0.60	2	2	1	2	2	0.4	0.7	0.5	3.4717
0.60	2	2	1	2	2	0.5	0.71	0.5	3.4724
0.60	2	2	1	2	2	0.5	1.0	0.5	3.4435
0.60	2	2	1	2	2	0.5	7.0	0.5	3.4151
0.60	2	2	1	2	2	0.5	0.7	1.0	3.5254
0.60	2	2	1	2	2	0.5	0.7	2.0	3.6286
0.60	2	2	1	2	2	0.5	0.7	3.0	3.7319
0.60	2	2	1	2	2	0.5	0.7	4.0	3.8351
0.16	2	2	1	2	2	0.5	0.7	0.5	3.8076
0.60	2	2	1	2	2	0.5	0.7	0.5	3.4738
1.00	2	2	1	2	2	0.5	0.7	0.5	3.3371
2.00	2	2	1	2	2	0.5	0.7	0.5	3.1116

Table 2 Numerical values of Nusslet number for various flow quantities:

Sc	ϕ	Du	γ	$G\gamma_T$	$G\gamma_C$	Nu
0.16	1	0.5	0.5	4	2	0.333
0.60	1	0.5	0.5	4	2	-0.094
1.00	1	0.5	0.5	4	2	-0.100
0.60	0	0.5	0.5	4	2	1.384
0.60	2	0.5	0.5	4	2	-0.094
0.60	3	0.5	0.5	4	2	-0.752
0.60	1	0.5	0.5	4	2	-1.214
0.60	1	1	0.5	4	2	0.291
0.60	1	2	0.5	4	2	1.062
0.60	1	3	0.5	4	2	1.834
0.60	1	0.5	0.0	4	2	0.038
0.60	1	0.5	0.75	4	2	-0.111
0.60	1	0.5	1.0	4	2	-0.118
0.60	1	0.5	0.5	1	2	-0.094
0.60	1	0.5	0.5	2	2	-0.094
0.60	1	0.5	0.5	3	2	-0.094
0.60	1	0.5	0.5	4	0	-0.094
0.60	1	0.5	0.5	4	1	-0.094
0.60	1	0.5	0.5	4	3	-0.094

Table 1 depicts the influence of various physical parameters such as Gr_T, Gr_C, Q_1, Du, ϕ, M, Pr and Sc on skin-friction coefficient. It is clear that an increasing values of $G\gamma_T, G\gamma_C, Q_1, Du$ enhances Skin friction coefficient. But an increasing value of $\phi, M, K, \mathrm{Pr}, Sc$ Skin friction coefficient is decreasing. Table 2 depicts the influence of various physical parameters on Nusselt number. This table establishes the result of enhancement of the rate of heat transfer of the plate under the influence of Dufour number. The same table clearly shows that the rate of heat transfer is continuously reduced due to ϕ, Sc and γ. But no effect on Nusselt number due to of $G\gamma_T$ and $G\gamma_C$. Table 3 shows the influence of Sc and γ on Sherwood number. It is evident that a rise in Schmidt number and chemical reaction parameter depreciates the mass transfer rate. Hence, chemical reaction parameter has more significant effect on Sherwood number than it does on Nusselt number. There is increase in both the heat and mass transfer rates with increase in the buoyancy ratio.

Table 3 Numerical values of Sherwood number for various flow quantities:

Sc	γ	Sh
0.16	1.0	-0.6127
0.6	1.0	-1.4428
1.0	1.0	-2.0821
2.0	1.0	-3.5600
0.60	0.0	-0.8227
0.60	0.50	-1.1974
0.60	0.75	-1.3284

5. CONCLUSIONS

In this paper we have studied the Diffusion-thermo and radiation absorption effects on an unsteady MHD free convective heat and mass transfer flow past a semi-infinite moving plate. From the present investigation the following conclusions can be drawn.

1. There is a considerable effect of heat absorption parameter Q on the velocity.
2. It is found that on introducing the generative chemical reaction species concentration and Temperature are decreases significantly.
3. An increasing Dufour number causes a distinct rise in the temperature and velocity throughout the boundary layer.
4. The concentration decreases with an increase in the values of Sc. The velocity decelerated under the effect of magnetic parameter.
5. The rate of mass transfer reduces due to Schmidt number and chemical reaction parameter.
6. The Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic and concentration boundary layers. Increase in the values of γ implies more interaction of species concentration with the momentum boundary layer and less interaction with the thermal boundary layer.

NOMENCLATURE

x^*, y^*	dimensional distances along to the plate(m)
u^*, v^*	components of dimensional velocities along x^*, y^* directions(m/s)
g	gravitational acceleration(m/s^2)
T^*	dimensional temperature of the fluid near the plate(K)
T_∞	stream dimensional temperature(K)
C^*	dimensional concentration
C_∞	stream dimensional concentration
β_T	thermal expansion coefficient
B_C	concentration expansion coefficient
P^*	pressure
Cp	specific heat of constant pressure(J/kg.K)
B_0	magnetic field coefficient
q_r^*	radiative heat flux
P	density
K	thermal conductivity(W/mK)
σ	density magnetic permeability of the fluid
υ	kinematic viscosity(m^2/s)
D	molecular diffusivity(J/kg.K)
Q_0	dimensional heat absorption coefficient
Q_1^*	coefficient of proportionality of the absorption of the radiation
Sc	Schmidt number
T	dimensional time(s)
M	magnetic parameter(A/m)
Up	wall dimensional velocity
T_w	wall dimensional temperature
C_w	wall dimensional concentration
U_∞^*	free stream velocity
T_∞	free stream temperature
C_∞	free stream concentration

Greek Symbols

μ	viscosity of the fluid (kg/ms)
θ	dimensionless temperature (k)
η	similarity variable
ϕ	heat absorption parameter
γ	chemical reaction parameter

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