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Effects of the Chemical Reaction on Unsteady MHD convective heat and mass transfer past a Semi-infinite vertical permeable moving plate with heat source absorption

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ABSTRACT: The problem of 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 a uniform transverse magnetic field and thermal and concentration buoyancy effects is considered. The plate is assumed to move with a constant velocity in the direction of fluid flow while the free stream velocity is assumed to follow the exponentially increasing small perturbation law. Time-dependent wall suction is assumed to occur at the permeable surface. The dimensionless governing equations for this investigation are solved analytically using two-term harmonic and non-harmonic functions. Graphical results for velocity, temperature and concentration pro-files of both phases based on the analytical solutions are presented and discussed.

Keywords: MHD, Chemical reaction, Porous medium, vertical plate, Radiation, Skin friction, Free convection, Heat and mass transfer, Heat source, Mass diffusion and absorption.

1. Introduction

Simultaneous heat and mass transfer from deferent geometries embedded in porous media has many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors, and underground energy transport. Cheng and Minkowycz [1] have presented similarity solutions for free thermal convection from a vertical plate in a fluid-saturated porous medium. The problem of combined thermal convection from a semi-infinite vertical plate in the presence or absence of a porous medium has been studied by many authors (see, for example [2-5]). Nakayama and Koyama[4] have studied pure, combined and forced convection in Darcian and non-Darcian porous media. Lai and Kulacki [6] have investigated coupled heat and mass transfer by mixed convection from an isothermal vertical plate in a porous medium. Hsieh et al [5]. has presented non-similar solutions for combined convection in porous media. Chamkha [7] has investigated hydromagnetic natural convection from a iso-thermal inclined surface adjacent to a thermally stratified porous medium.

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects. 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 reaction. Due to the fast growth of electronic technology, effective cooling of electronic equipment has become warranted and cooling of electronic equipment ranges from individual transistors to main frame computers and from energy suppliers to telephone switch boards and thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight.

At high operating temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. Bestman [8] examined the natural convection boundary layer with suction and mass transfer in a porous medium. His results confirmed the hypothesis that suction stabilises the boundary layer and affords the most efficient method in boundary layer control yet known. Abdus Sattar and Hamid Kalim [9] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Makinde [10] examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate. Recently, Ibrahim et al. [11] have studied non classical thermal effects in Stokes' second problem for micro polar fluids by used perturbation method. Muthucumaraswamy and Ganesan [12] studied effect of the chemical reaction and injection on flow charac-teristics in an unsteady upward motion of an isothermal plate. Deka et al. [13] studied the effect of the first-order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer. Chamkha [7] studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction. Soundalgekar and Patti [14] studied the problem of the flow past an impulsively started isothermal infinite vertical plate with mass transfer effects. The effect of foreign mass on the free-convection flow past a semi-infinite vertical plate were studied. Chamkha [15] assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. Raptis [16] investigate the steady flow of a viscous fluid through a very porous medium bounded by a porous plate subjected to a constant suction velocity by the presence of thermal radiation. Raptis and Perdikis [17] studied the unsteady free convection flow of water near 4 C in the laminar boundary layer over a vertical moving porous plate.

The spite of all these studies, the unsteady MHD free convection heat and mass transfer for a heat generating fluid with radiation absorption has received little attention. Hence, the main objective of the present investigation is to study the effects of radiation absorption, mass diffusion, chemical reaction and heat source parameter of heat generating fluid past a vertical porous plate subjected to variable suction. It is assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. It is also assumed that temperature over which are superimposed an exponentially varying with time.

The objective of this paper is to 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, magnetic field effects, and absorption effects. Most of previous works assumed that the semi-infinite plate is at rest. In the present work, it is assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. It is also assumed that the free stream to consist of a mean velocity and temperature over which are superimposed an exponentially varying with time.

2. Problem formulation

Consider unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting and heat absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects .

It is assumed that there is no applied voltage which implies the absence of an electrical field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible [18]. A consequence of the small magnetic Reynolds number is the uncoupling of the Navier-Stokes equations from Maxwell s equations [18]. The governing equations for this investigation are based on the balances of mass, linear momentum, energy and concentration species. Taking into consideration the assumptions made above, these equations can be written in Cartesian frame of reference, as follows

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

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

$$\frac{\partial T}{\partial t^*} + v^* \frac{\partial T}{\partial y^*} = \alpha \frac{\partial^2 T}{\partial y^{*2}} - \frac{Q_0}{\rho c_p}(T - T_\infty) \quad (3)$$

$$\frac{\partial c}{\partial t^*} + v^* \frac{\partial c}{\partial y^*} = D \frac{\partial^2 c}{\partial y^{*2}} - K(c - c_\infty) \quad (4)$$

where x*, y*, and t* are the dimensional distances along and perpendicular to the plate and dimensional time, respectively. U* and v^* are the components of dimensional velocities along x* and y* directions, respectively, ρ is the fluid density, υ is the kinematic viscosity, c_p is the specific heat at constant pressure, σ is the fluid electrical conductivity, B_0 is the magnetic induction, K* is the permeability of the porous medium, T is the dimensional temperature, Q_0 is the dimensional heat absorption coefficient, c is the dimensional concentration, α is the fluid thermal diffusivity, D is the mass diffusivity, g is the gravitational acceleration, and β_T and β_c are the thermal and concentration expansion coefficients, respectively. The magnetic and viscous dissipations are neglected in this study. The third and fourth terms on the RHS of the momentum Eq. (2) denote the thermal and concentration buoyancy effects, respectively. Also, the last term of the energy Eq. (3) rep-resents the heat absorption effects. It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow, and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time.

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are

$u^* = u_p^*,\ T = T_w + \varepsilon(T_w - T_\infty)e^{n^* t^*},\ c = c_w + \varepsilon(c_w - c_\infty)e^{n^* t^*}$ at $y^* = 0$ (5)

$u^* \to U^*_\infty = U_0(1 + \varepsilon e^{n^* t^*}),\ T \to T_\infty,\ c \to c_\infty$ as $y^* \to \infty$ (6)

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:

$$v^* = -V_0 (1 + \varepsilon A e^{n^* t^*}) \quad (7)$$

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

$$-\frac{1}{\rho}\frac{d\rho^*}{dx^*} = \frac{dU^*_\infty}{dt^*} + \frac{\upsilon}{K^*} U^*_\infty + \frac{\sigma}{\rho} B_0^2 U^*_\infty \quad (8)$$

It is convenient to employ the following dimensionless variables:

$$u = \frac{u^*}{U_0},\ v = \frac{v^*}{V_0},\ \eta = \frac{V_0 y^*}{\upsilon},\ U_\infty = \frac{U^*_\infty}{U_0},\ U_p = \frac{u_p^*}{U_0},$$

$$t = \frac{t^* V_0^2}{\upsilon},\ \theta = \frac{T - T_\infty}{T_w - T_\infty},\ C = \frac{c - c_\infty}{c_w - c_\infty},\ n = \frac{n^* \upsilon}{V_0^2},$$

$$K = \frac{K^* V_0{}^2}{\upsilon^2},\ P_r = \frac{\upsilon\rho C_p}{k} = \frac{\upsilon}{\alpha},\ S_c = \frac{\upsilon}{D},\ M = \frac{\sigma B_0{}^2 \upsilon}{\rho V_0{}^2}, \quad (9)$$

$$G_T = \frac{\upsilon \beta_T g\,(T_W - T_\infty)}{U_0 V_0{}^2},\ G_c = \frac{\upsilon \beta_C g\,(c_W - c_\infty)}{U_0 V_0{}^2},\ \emptyset = \frac{\upsilon Q_0}{\rho c_\rho V_0^2},\ K_r = \frac{K\upsilon}{V_0^2}$$

In view of Eqs. (7)-(9), Eqs. (2) -(4) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial u}{\partial \eta} = \frac{d\,U_\infty}{dt} + \frac{\partial^2 u}{\partial\,\eta^2} + G_T\theta + G_c C + N\,(U_\infty - u) \quad (10)$$

$$\frac{\partial \theta}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial \eta} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial\,\eta^2} - \emptyset\theta \quad (11)$$

$$\frac{\partial C}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial C}{\partial \eta} = \frac{1}{Sc}\frac{\partial^2 \theta}{\partial\,\eta^2} - K_r C \qquad Where\ \ N = (M + \frac{1}{K}) \quad (12)$$

and G_c, G_T, Pr, $\emptyset$ and Sc are the solutal Grashof number, thermal Grashof number, Prandtl number, dimensionless heat absorption coeﬃcient the Schmidt number, respectively. By setting Kr equal to zero Eqs. (12) reduce to those reported by Chamka [19]

The dimensionless form of the boundary conditions (5) and (6) become

$u = U_p,\ \ \theta = 1 + \varepsilon e^{nt},\ \ C = 1 + \varepsilon e^{nt}$ at $\eta = 0$ (13)

$u \to U_\infty,\ \ \theta \to 0,\ \ C \to 0$ as $\eta \to \infty$ (14)

3. Problem solution

Eqs. (10)– (12) represent a set of partial deferential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary deferential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as

$$u = f_0(\eta) + \varepsilon e^{nt} f_1(\eta) + O(\varepsilon^2) + \ldots\ldots.. \quad (15)$$

$$\theta = g_0(\eta) + \varepsilon e^{nt} g_1(\eta) + O(\varepsilon^2) + \ldots\ldots.. \quad (16)$$

$$C = h_0(\eta) + \varepsilon e^{nt} h_1(\eta) + O(\varepsilon^2) + \ldots\ldots.. \quad (17)$$

Substituting Eqs. (15)–(17) into Eqs. (10)–(12), equating the harmonic and non-harmonic terms, and neglecting the higher-order terms of $O(\varepsilon^2)$, one obtains the following pairs of equations for (f_0, g_0, h_0) and (f_1,g_1,h_1)

$$f_0'' + f_0' - N f_0 = -N - G_T\, g_0 - G_c\, h_0 \quad (18)$$

$$f_1'' + f_1' - N f_1 - n\, f_1 = -A f_0' - G_T g_1 - G_c h_1 - (N + n) \quad (19)$$

$$g_0'' + g_0' P_r - \emptyset P_r\, g_0 = 0 \quad (20)$$

$$g_1'' + P_r\, g_1' - n\, g_1 P_r - \emptyset P_r\, g_1 = -A\, P_r\, g_0' \quad (21)$$

$$h_0'' + S_C\, h_0' - S_C K_r h_0 = 0 \quad (22)$$

$$h_1'' + S_C\, h_1' - S_C\,(Kr + n) h_1 = -A\, S_C\, h_0' \quad (23)$$

where a prime denotes ordinary differentiation with respect to g. The corresponding boundary conditions can be written as

$$f_0 = U_{p_{p,}} f_1 = 0, g_0 = 1, g_1 = 1,\ h_0 = 1,\ h_1 = 1 \qquad \text{at } \eta = 0 \quad (24)$$

$$f_0 = 1,\ f_1 = 1,\ g_0 \to 0,\ g_1 \to 0,\ h_0 \to 0,\ h_1 \to 0 \text{ as } \eta \to \infty \quad (25)$$

Without going into detail, the solutions of Eqs. (18)–(23) subject to Eqs. (24) and (25) can be shown to be

$$f_0 = 1 + C_2 e^{-\lambda 1\eta} + A_3 e^{-m5\eta} + A_4 e^{-m1\eta} \quad (26)$$

$$f_1 = 1 + C_4 e^{-\lambda 3\eta} + A_5 e^{-\lambda 1\eta} + A_5 e^{-\lambda 1\eta} + A_6 e^{-m5\eta} + A_7 e^{-m1\eta} + A_8 e^{-m7\eta} + A_9 e^{-m3\eta} \quad (27)$$

$$g_0 = e^{-m5\eta} \quad (28)$$

$$g_1 = e^{-m7\eta} + A_2 [e^{-m5\eta} - e^{-m7\eta}] \quad (29)$$

$$h_0 = e^{-m1\eta} \quad (30)$$

$$h_1 = e^{-m3\eta} + A_1 [e^{-m1\eta} - e^{-m3\eta}] \quad (31)$$

Where

$$m_1 = \frac{S_c + \sqrt{S_c^2 + 4k_r s_c}}{2} \quad (32)$$

$$m_3 = \frac{S_c + \sqrt{S_c + 4s_c(k_r + n)}}{2} \quad (33)$$

$$m_5 = \frac{p_r + \sqrt{p_r^2 + 4\emptyset p_r}}{2} \quad (34)$$

$$m_7 = \frac{P_r + \sqrt{Pr^2 + 4p_r(n + \emptyset)}}{2} \quad (35)$$

$$\lambda_1 = \frac{1 + \sqrt{1 + 4N}}{2} \quad (36)$$

$$\lambda_3 = \frac{1 + \sqrt{1 + 4(N + n)}}{2} \quad (37)$$

And $$A_1 = \frac{AS_c m_1}{m_1^2 - S_c (m_1 + k_r + n)} \quad (38)$$

$$A_2 = \frac{Ap_r m_5}{m_5^2 - m_5 p_r - p_r(n + \emptyset)} \quad (39)$$

$$A_3 = \frac{G_T}{-m_5^2 + m_5 + N} \quad (40)$$

$$A_4 = \frac{G_c}{-m_1^2 + m_1 + N} \quad (41)$$

$$c_2 = u_\rho - 1 - A_3 - A_4 \quad (42)$$

$$A_5 = \frac{A \lambda_1 c_2}{\lambda_1^2 - \lambda_1 - (N + n)} \quad (43)$$

$$A_6 = \frac{(A A_3 m_5 - A_2 G_T)}{m_5^2 - m_5 - (N + n)} \quad (46)$$

$$A_7 = \frac{A A_4 m_1 - G_c A_1}{m_1^2 - m_1 - (N + n)} \quad (47)$$

$$A_8 = \frac{(-G_T + G_T A_2)}{m_7^2 - m_7 - (N + n)} \quad (48)$$

$$A_9 = \frac{(-G_c + G_c A_1)}{m_3^2 - m_3 - (N + n)} \quad (45)$$

$$c_4 = -(1 + A_5 + A_6 + A_7 + A_8 + A_9) \qquad (46)$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$u(\eta,t) = \left(1 + C_2 e^{-\lambda 1\eta} + A_3 e^{-m_5\eta} + A_4 e^{-m_1\eta}\right) + \varepsilon e^{nt}\left(C_4 e^{-\lambda_3\eta} + A_5 e^{-\lambda_1\eta} + A_6 e^{-m_5\eta} + A_7 e^{-m_1\eta} + A_8 e^{-m_7\eta} + A_9 e^{-m_3\eta} + 1\right) \qquad (47)$$

$$\theta(\eta,t) = e^{-m_5\eta} + \varepsilon e^{nt} e^{-m_7\eta} + A_2\,[\,e^{-m_5\eta} - e^{-m_7\eta}\,] \qquad (48)$$

$$C(\eta,t) = e^{-m_1\eta} + \varepsilon e^{nt} e^{-m_3\eta} + A_1\,[\,e^{-m_1\eta} - e^{-m_3\eta}\,] \qquad (49)$$

The skin-friction coefficient, the Nusselt number and the Sherwood number are important physical parameters for this type of boundary-layer flow. These parameters can be defined and determined as follows:

$$C_f = \frac{\tau_w^*}{\rho U_0 V_0} = \frac{\partial u}{\partial \eta}\Big| \text{ at } \eta=0$$

$$C_f = (-C_2\lambda_1 - m_5A_3 - m_1A_4) + \varepsilon e^{nt}(-\lambda_3C_4 - \lambda_1A_5 - m_5A_6 - m_1A_7 - m_7A_8 - m_3A_9)$$

$$N_u = x\frac{\partial T/\partial y^*|}{T_w - T_\infty} \text{ at } y^* = 0 \qquad (50)$$

$$\frac{N_u}{Re_x} = \frac{\partial \theta}{\partial \eta}\Big| \quad \text{ at } \eta=0$$

$$N_u = -m_5 + \varepsilon e^{nt}\,(m_7 - A_2\,m_5 + m_7A_2\,) \qquad (51)$$

$$S_h = x\frac{\partial C/\partial y^*|}{C_w - C_\infty} \text{ at } y^* = 0$$

$$\frac{S_h}{Re_x} = \frac{\partial c}{\partial \eta}\Big| \text{ at } \eta=0 \quad S_h = -m_1 + \varepsilon e^{nt}\,(-m_3 - m_1A_1 + A_1\,m_3) \qquad (52)$$

where $Re_x = V_0 x/v$ is the local Reynolds number. It should be mentioned that in the absence of the concentration buoyancy and heat absorption effects, all of the flow and heat transfer solutions reported above are consistent with those reported earlier by chamka [19].

4. Results and discussion

Numerical evaluation of the analytical results reported in the previous section was performed and a representative set of results is reported graphically in Figs. 1–12. These results are obtained to illustrate the influence of the chemical reaction parameter K_r, the Schmidt number Sc, the heat absorption coefficient , the magnetic field parameter M and permeability parameter K on the velocity, temperature and the concentration profiles, while the values of the physical parameters are fixed at real constants, A = 0.5, ε = 0.2, the frequency of oscillations n = 0.1, scale of free stream velocity $u_p = 0.5$, Prandtl number Pr = 0.7 and t = 0.5. Figs. 1–3 display results for the velocity, temperature and concentration distributions, spectively. It is seen, that the velocity, temperature and concentration increases with decreasing the chemical reaction parameter c, Also, we observe that the magnitude of the stream wise velocity increases and the inflection point for the velocity distribution moves further away from the surface.

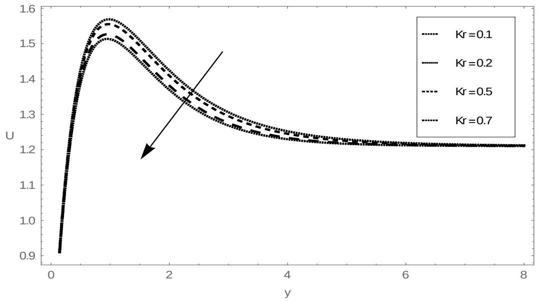

Fig. 1 Velocity profile against span wise coordinate y for different values of the chemical reaction parameter Kr with G_T=2, G_c=1, S_c=0.6, K=0.5, M= 0.0, Ø=1

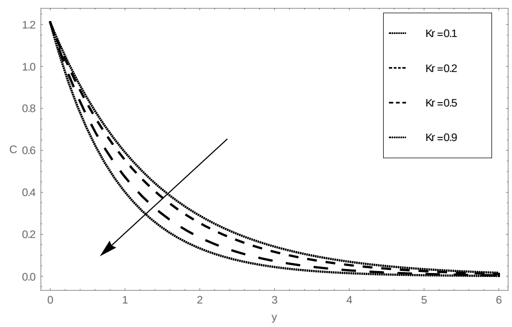

Fig. 2 Concentration profile against span wise coordinate y for different values of the chemical reaction parameter Kr with G_T=2, G_c=1, S_c=0.6, K=0.5, M= 0.0, Ø=1

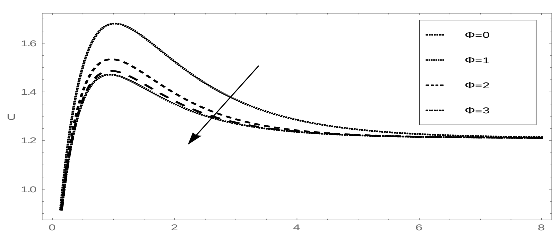

Fig. 3 Velocity profile against span wise coordinate y for different values of the heat absorption parameter Ø with G_T=2, G_c=1, S_c=0.6, K=0.5, M= 0.0, Kr = 0.2

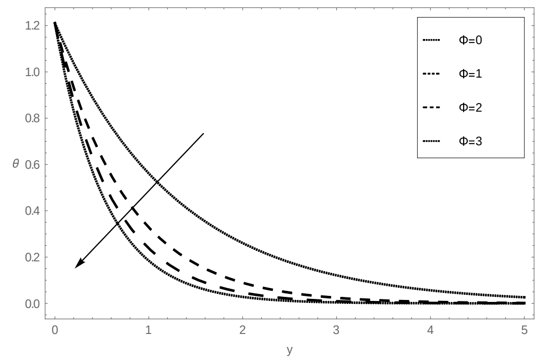

Fig. 4 Tempature profile against span wise coordinate y for different values of the heat absorption parameter Ø with G_T=2, G_c=1, S_c=0.6, K=0.5, M= 0.0, Kr=0.2

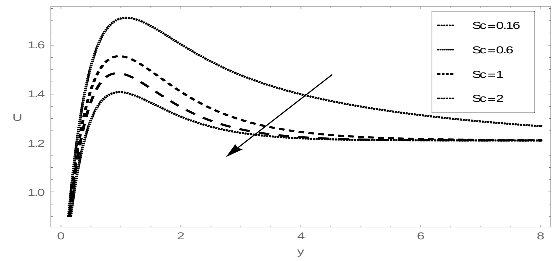

Fig. 5 Velocity profile against span wise coordinate y for different values of the Schmidt Number Sc with G_T=2, G_c=1,, K=0.5, M= 0.0, Ø=1, Kr= 0.2

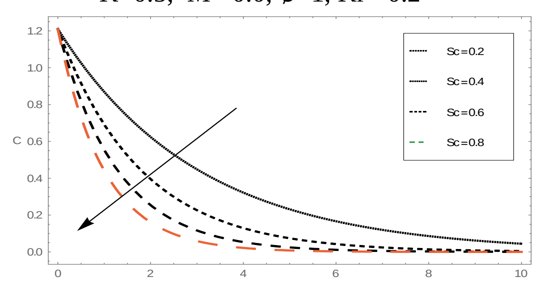

Fig.6 Concentration profile against span wise coordinate y for different values of the Schmidt Number Sc with G_T=2, G_c=1, K=0.5, M= 0.0, Ø=1, Kr = 0.2.

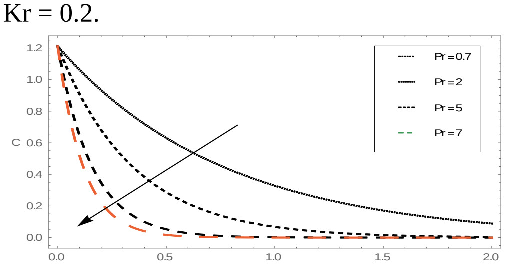

Fig. 7 Effects of Pr on concentration profiles

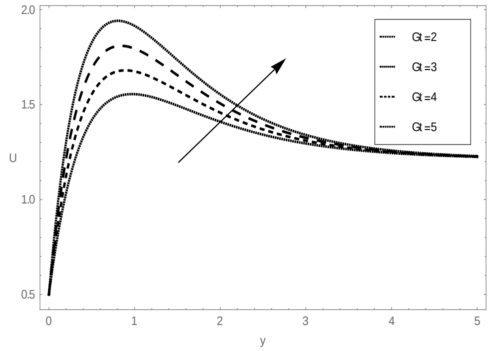

Fig. 8 Effects of Gt on Velocity profiles

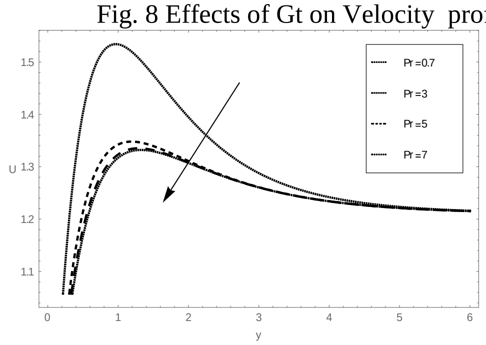

Fig. 9 Effects of Pr on Velocity profiles

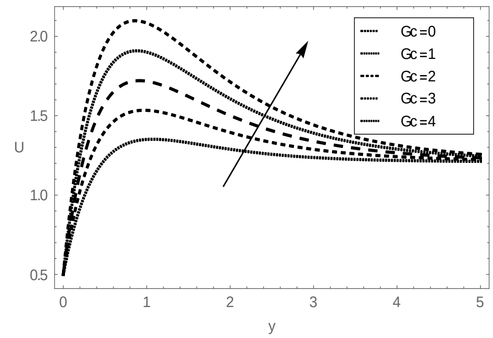

Fig. 10 Effects of Gc on Velocity profiles

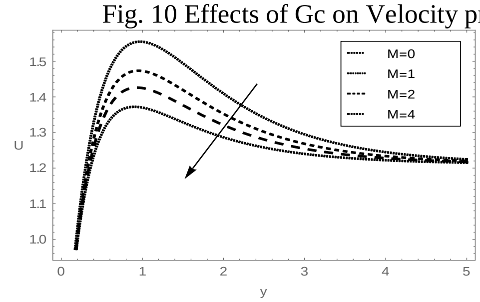

Fig. 11 Effects of M on Velocity profiles

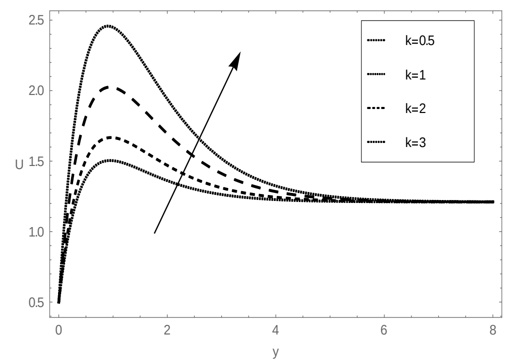

Fig. 12 Effects of K on Velocity profiles

Table 1. Effects of G_c on C_f, Nu/Re_x,Sh/Re_x, for the reference values in fig.10

Gc	Cf	Nu/Re_x	Sh/Re_x
0	**2.71514**	**-1.57909**	**-0.799572**
1	**3.47075**	**-1.57909**	**-0.799572**
2	**4.22637**	**-1.57909**	**-0.799572**
3	**4.98199**	**-1.57909**	**-0.799572**
4	**5.50062**	**-1.57909**	**-0.799572**

Table 2. Effects of ∅on C_f, Nu/Re_x,Sh/Re_x, for the reference values in fig. 3

∅	*Cf*	Nu/Re_x	Sh/Re_x
0	***3.73515***	***-0.931147***	***-0.799572***
1	***3.47075***	***-1.57909***	***-0.799572***
2	***3.40528***	***-1.96951***	***-0.799572***
3	***3.5271***	***-2.27782***	***-0.799572***

Table 3. Effects of S_c on C_f, Nu/Re_x,Sh/Re_x, for the reference values in fig. 5

Sc	Cf	Nu/Re_x	Sh/Re_x
0.16	**3.70936**	**-1.57909**	**-0.220006**
0.6	**3.47075**	**-1.57909**	**-0.799572**
1	**3.34831**	**-1.57909**	**-1.32582**
2	**3.06866**	**-1.57909**	**-2.64125**

5. Conclusions

The plate velocity was maintained at a constant value and the flow was subjected to a transverse magnetic field. The resulting partial differential equations were transformed into a set of ordinary differential equations using two-term series and solved in closed-form. Numerical evaluations of the closed-form results were per-formed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some of the physical parameters. It was found that the velocity profiles increased due to decreases in chemical reaction parameter, the Schmidt number, heat absorption coefficient and magnetic field. Whereas an increase in chemical reaction parameter c, the Schmidt number Sc and heat absorption coefficient / led to a decrease in the temperature profile on cooling. Also, it was found that the concentration profile decreased due to increases in the chemical reaction parameter Kr and the Schmidt number Sc.

Nomenclature

A suction velocity parameter
B_0 magnetic induction
c concentration
c_p specific heat at constant pressure
C dimensionless concentration
C_f skin-friction coefficient
D mass diffusion coefficient
G_c solutal Grashof number
G_T thermal Grashof number
g acceleration due to gravity
K permeability of the porous medium
k thermal conductivity
M magnetic field parameter
N dimensionless material parameter
n dimensionless exponential index
Nu Nusselt number
Pr Prandtl number
Q_0 heat absorption coefficient
Re_x local Reynolds number
Sc Schmidt number
Sh Sherwood number
T temperature
t dimensionless time
U_0 scale of free stream velocity
u, v components of velocities along and perpendicular to the plate, respectively
V_0 scale of suction velocity
x, y distances along and perpendicular to the plate, respectively

Greek symbols
a fluid thermal diffusivity
b_c coefficient of volumetric concentration expansion
b_T coefficient of volumetric thermal expansion
e scalar constant (_1)

g dimensionless normal distance
/ dimensionless heat absorption coefficient
r fluid electrical conductivity

q fluid density

l fluid dynamic viscosity

m fluid kinematic viscosity

s friction coefficient
h dimensionless temperature

Superscripts
0 differentiation with respect to y
* dimensional properties

Subscripts
p plate
w wall condition
∞ free stream condition

References

[1]. P. Cheng, W.J. Minkowycz, J. Geophys. 82 (1977) 2040.
[2]. W.J. Minkowycz, P. Cheng, C.H. Chang, Numer. Heat Transfer 8 (1985) 349.
[3]. P. Ranganathan, R. Viskanta, Numer. Heat Transfer 7 (1984) 305.
[4]. A. Nakayama, H. Koyama, J. Heat Transfer 109 (1987) 1041.
[5]. J.C. Hsieh, T.S. Chen, B.F. Armaly, Int. J. Heat Mass Transfer 36 (1985) 1485.
[6]. F.C. Lai, F.A. Kulacki, Int. J. Heat Mass Transfer 113 (1991) 252.
[7]. A.J. Chamkha, Int. J. Eng. Sci. 35 (1997) 975.
[8]. Bestman AR. Natural convection boundary layer with suction and mass transfer in a porous medium. Int J Energy Res 1990;14:389–96.
[9]. Abdus Sattar MD, Hamid Kalim MD. Unsteady free-convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. J Math Phys Sci 1996;30:25–37.
[10]. Makinde OD. Free convection flow with thermal radiation and mass transfer past amoving vertical porous plate. Int Comm Heat Mass Transfer 2005;32:1411–9.
[11]. Ibrihem FS, Hassanien IA, Bakr AA. Nonclassical thermal effects in stokes' second problem for micropolar fluids. ASME J Appl Mech 2005;72:468–74.
[12]. Muthucumaraswamy R, Ganesan P. Effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate. J Appl Mech Tech Phys 2001;42:665–71.
[13]. Deka R, Das UN, Soundalgekar VM. Effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. Forschung im Ingenieurwesen 1994;60:284–7.
[14]. Soundalgekar VM, Patti MR. Stokes problem for a vertical plate with constant heat flux. Astrophys Space Sci 1980;70:179–82
[15]. Chamkha AJ. Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Int J Eng Sci 2004;42:217–30.
[16]. Raptis A. Radiation and free convection flow through a porous medium. Int Comm Heat Mass Transfer 1998;25:289–95.
[17]. Raptis A, Perdikis C. Free convection flow of water near 4 LC past a moving plate. Forschung im Ingenieurwesen 2002;67:206–8.
[18]. K.R. Cramer, S.I. Pai, Magnetofluid Dynamics for Engineers and Applied Physicists, McGraw-Hill, New York, 1973.
[19]. Ali J Chamkha unsteady MHD convective heat and Mass transfer past a semi infinite vertical permeable moving plate with heat obsorption, International Journal of engineering Science 42 (2004) 217-230