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Heat and Mass Transfer Flow Over an Inclined Plate with Time Dependent Suction.

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ABSTRACT

This paper investigates the effects of hall current, heat source and radiation on unsteady MHD two dimensional, laminar, boundary layer flow of a viscous, incompressible, electrically conducting fluid along a semi-infinite inclined plate in the presence of thermal and concentration buoyancy effects. A time dependent is assumed and the radiative flux is described using the differential approximation for radiation. Asymtotic series expansion about a small parameter ε is performed to obtain the flow fields. The velocity of the porous plate increases exponentially with time and a variable suction velocity is applied normal to the plate. The governing equations of the flow field are solved using perturbation technique and the expressions are obtained for velocity, temperature and concentration fields. The observations show good agreement with the previous results.
Keywords: Heat Source, Radiation, Unsteady, MHD.

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INTRODUCTION

Natural convection flow over inclined plate immersed in porous media has paramount importance because of its potential applications in soil physics, geo-hydrology, and filtration of solids from liquids, chemical engineering and biological systems. Magneto convection assumes an essential part in farming, petroleum ventures, geophysics and in astronomy. Radiated heat and mass transfer knowledge gives the solution of complex physicochemical problems such as chemical engineering, mechanical engineering, aeronautical engineering, and fuel technology, as well as in physics and chemistry. Combined heat and mass transfer from different processes with porous media has a wide range Engineering and Industrial applications such as enhanced oil recovery, underground energy transport, geothermal reservoirs, cooling of nuclear reactors, drying of porous solids, packed-bed catalytic reactors and thermal insulation. Magneto hydrodynamics (MHD) is the branch of continuum mechanics which deals with the flow of electrically conducting fluids in electric and magnetic fields. In recent years, progress has been considerably made in the study of heat and mass transfer in magneto hydrodynamics (MHD) flows due to its application in many devices, like the MHD power generators and Hall accelerators. Kafousias and Georgantopoulos [1] studied the transverse magnetic effects on the free convective flow of an incompressible, electrically conducting fluid past a non-conducting and non-magnetic, vertical limiting surface, the governing equations were solved by the usual Laplace transform technique. Raptis and Soundalgekar [2] determined the effects of mass transfer on the flow of an electrically conducting fluid past a steadily moving infinite vertical porous plate under the action of a transverse magnetic field. Raptis and Soundalgekar [3] considered the problem of flow of an electrically conducting fluid past a steadily moving vertical infinite plate in presence of constant heat flux and constant suction at the plate and induced magnetic field is also taken into account. England and Emery [4] have studied the radiation effects of an optically thin gray gas bounded by a stationary plate. Raptis and Massalas [5] investigated the effects of radiation on the oscillatory flow of a gray gas, absorbing-emitting in presence induced magnetic field and analytical solutions were obtained with help of perturbation technique. Mansour et al. [6] investigated the effects of chemical reaction, thermal stratification, Soret and Dufour numbers on MHD free convective heat and mass transfer of a viscous, incompressible and electrically conducting fluid on a vertical stretching surface embedded in a saturated porous medium. Gupta [7] considered unsteady magneto-convection under buoyancy forces. Chamkha [8] has analyzed the unsteady MHD free three-dimensional convection over an inclined permeable surface with heat generation/absorption. Radiation magneto hydrodynamic convection flows are also important in astrophysical and geophysical regimes. Raptis and Massalas [9] considered induced magnetic field effects in their study of unsteady hydro magnetic-radiative free convection. Different researches have been forwarded to analyze the effects of thermal radiation on different flows [10-14]. Baby Rani et al., [15] have been studied the effects of chemical reaction and radiation on unsteady case. Baby Rani et al., [17] have been analyzed Chemically Reactive Flow past a Porous Inclined Plate with Radiation. The aim of the present paper is to investigate the effect of various parameters like parameter for Thermal Radiation, Chemical Reaction, hall current, inclined angle, Prandtl number, Schmidt number, heat source, thermal Grashof number, mass Grashof number, etc on convective heat transfer along an inclined plate in porous medium. The governing non-linear partial differential equations are first transformed into a dimensionless form and thus resulting non-similar set of equations has been solved using the perturbation technique.

Mathematical Analysis

Let us consider a problem of unsteady two-dimensional, laminar, boundary layer flow of a viscous, incompressible, electrically conducting fluid along a semi-infinite vertical plate in the presence of thermal and concentration buoyancy effects. A variable time -dependent suction velocity $v' = -V_0(1+\in Ae^{n't'})$ is considered normal to the flow. The plate is taken along x'-axis in vertical upward direction against to the gravitational field and y'-axis is taken normal to the flow in the direction of applied traverse magnetic field. Further, due to semi-infinite plate surface assumption the flow variables are the functions of y' and t' only. Then under the usual Boussinesq's approximation the flow is governed by the following set of equations.

Continuity equation:

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

Momentum equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} + g\cos\alpha\,\beta(T - T_\infty) + g\cos\alpha\,\beta^*(C - C_\infty) - \frac{m}{1+m^2}\frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{k'}u' \quad (2)$$

Energy equation:

$$\frac{\partial T}{\partial t'} + v'\frac{\partial T}{\partial y'} = \nu\frac{\partial^2 T}{\partial y'^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y'} + Q_0(T - T_\infty) \quad (3)$$

Concentration equation:

$$\frac{\partial C}{\partial t'} + v'\frac{\partial C}{\partial y'} = \nu\frac{\partial^2 C}{\partial y'^2} - k_r'^2(C - C_\infty) \quad (4)$$

By using Rosselant approximation as in Rapits[17], Ogulu[18] and Makinde[19], we can write the raduative flux q_r as:

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y'} \quad (5)$$

All the variables defined in the nomenclature. It is assumed that the temperature differences within the flows are sufficiently small so that T^4 can be expanded in aTaylor series about the free stream temperatureT_∞ so that after rejecting higher order terms:

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \quad (6)$$

The equation of energy after submission of equations (5) and (6) can now be written as

$$\frac{\partial T}{\partial t'} + v'\frac{\partial T}{\partial y'} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y'^2} + \frac{16\sigma^* T_\infty^3}{3\rho c_p k^*}\frac{\partial^2 T}{\partial y'^2} \quad (7)$$

From equation (1), we have $\frac{\partial v'}{\partial y'} = 0 \Longrightarrow v' = f(t)$

Here we can see that the suction velocity is a function of time t' only. So, it is assumed in the form Cookey et al., [22];

$$v' = f(t) = -V_0(1+\varepsilon A e^{n't'}) \quad (8)$$

Where A is the suction parameter and εA << 1. Here the minus sign indicates that the suction is towards the plate. Now, for convenience, let us introduce the following non-dimensional parameters in equations (2), (4) and (7) to get dimensionless form.

$$u = \frac{u'}{U_0},\ y = \frac{U_0 y'}{\nu},\ t = \frac{U_0^2 t'}{\nu},\ P_r = \frac{\rho c_p \nu}{k},\ S_c = \frac{\nu}{D},\ \theta = \frac{T-T_\infty}{T-T_W},\ \phi = \frac{C-C_\infty}{C-C_W},\ G_r = \frac{g\beta\nu(T-Tw)}{U_0^3},$$
$$G_m = \frac{g\beta^*\nu(C-Cw)}{U_0^3},\ n = \frac{\nu n'}{U_0^2},\ k = \frac{k' U_0^2}{\nu^2},\ Q = \frac{Q_0\nu}{U_0^2},\ M = \frac{\sigma\beta_0^2\nu}{\rho U_0^2},\ k_r^2 = \frac{k_r'^2}{U_0^2},\ N_r = \frac{16\sigma^* T_\infty^3}{3k^* k} \quad (9)$$

On introducing equation (9) into equations (2), (4) and (7), we obtain the following governing equations in dimensionless form:

$$\frac{\partial u}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + G_{r1}\theta + G_{m1}\phi - (M + \frac{1}{K})u \quad (10)$$

$$\frac{\partial \theta}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial y} = (\frac{1+N_r}{P_r})\frac{\partial^2 \theta}{\partial y^2} + Q\theta \quad (11)$$

$$\frac{\partial \phi}{\partial t} - (1+\varepsilon A e^{nt}) \frac{\partial \phi}{\partial y} = \frac{1}{S_c} \frac{\partial^2 \phi}{\partial y^2} - k_r^2 \phi \quad (12)$$

The corresponding boundary conditions are

$$u = 1+\varepsilon e^{nt}, \theta = 1+\varepsilon e^{nt}, \phi = 1+\varepsilon e^{nt} \text{ on } y = 0$$
$$u \to 0, \theta \to 0, \phi \to 0, \text{ as } y \to \infty \quad (13)$$

Method of Solution:

From equations (10) – (12) are coupled non-linear partial differential equations whose solutions in closed-form are difficult to obtain, is possible. To solve, these coupled non linear partial differential equations, we assume, the following Soundalgekar [23], that the unsteady flow is superimposed on the mean study flow, so that in the neighbourhood of the plate, we have:

$$u = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2)$$
$$\theta = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + O(\varepsilon^2)$$
$$\phi = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + O(\varepsilon^2) \quad (14)$$

The final form of the velocity, temperature and concentration distributions in the boundary layer can be expressed as:

$$u(y,t) = (B_7 e^{-m_5 y} - B_5 e^{-m_3 y} - B_6 e^{-m_1 y}) + \varepsilon[(1+B_8+B_9+B_{10}+B_{11}-B_{12})e^{-m_6 y} - B_8 e^{-m_1 y} - B_9 e^{-m_2 y} - B_{10} e^{-m_3 y} - B_{11} e^{-m_4 y} + B_{12} e^{-m_5 y}]e^{nt} \quad (15)$$

$$\theta(y,t) = e^{-m_3 y} + \varepsilon (B_3 e^{-m_3 y} + B_4 e^{-m_4 y}) e^{nt} \quad (16)$$

$$\phi(y,t) = e^{-m_1 y} + \varepsilon (B_1 e^{-m_1 y} + B_2 e^{-m_2 y}) e^{nt} \quad (17)$$

Skin-friction

Skin-friction co-efficient (τ) at the plate is given by

$$\tau = \left[\frac{du}{dy}\right]_{y=0} \quad (18)$$

Using the equations (28) and (31), we obtain skin-friction as follows:

$$\tau = (m_1 B_6 + m_3 B_5 - m_5 B_7) + \varepsilon e^{nt} [(m_1 B_8 + m_2 B_9 + m_3 B_{10} + m_4 B_{11} - m_5 B_{11}) - m_6 (1 + B_8 + B_9 + B_{10} + B_{11} - B_{12})]. \quad (19)$$

Nusselt number

The rate of heat transfer coefficient (Nu) at the plate is given by

$$Nu = -\left[\frac{d\theta}{dy}\right]_{y=0} \quad (20)$$

Using the equations (29) and (33), Nusselt number (Nu) is derived as:

$$Nu = -m_3 + \varepsilon(-m_3 B_3 - m_4 B_4) e^{nt} \quad (21)$$

Sherwood number

The rate of mass transfer coefficient (Sh) at the plate is given by

$$Sh = -\left[\frac{d\phi}{dy}\right]_{y=0} \quad (22)$$

From equations (30) and (35), we obtain Sherwood number (Sh) as follows:

$$Sh = -m_1 + \varepsilon\,(-\,m_1 B_1 - m_2 B_2)\,e^{nt}. \qquad (23)$$

RESULTS AND DISCUSSIONS

In order to get a physical insight into the problem, some numerical computations are carried out for the non-dimensional velocity u, temperature θ, concentration ϕ, Skin-friction, Nusselt number and Sherwood number in terms of the parameters m, α, P_r , S_c , M , Q , k , N_r, k_r , A , G_m and G_r respectively. The values of Prandtl number are chosen such that for air (Pr = 0.71), electrolytic solution (Pr = 1.00), water (Pr = 7.0) and water at 4^o c (Pr = 11.4). The values of Schmidt number are chosen so that for hydrozen (Sc = 0.22), water-vapour (Sc = 0. 60), Ammonia (Sc = 0.78), menthanol (Sc = 1.0) and propyl benzene (Sc = 2.62). In the present study following default parameter values are adopted for computations: Sc = 0.60, Kr = 1, n = 0.5, A = 0.1, ε = 0.01, t = 1.0, Pr = 0.71, Nr = 0.1, Q = 0.1, M = 0.5, k =1.0, Gr = 10, Gm = 5, m = 0.1, α = $^{\pi}/_{3}$. Therefore all the graphs and tables are corresponding to these values unless specifically indicated on the appropriate graph or table. The velocity profiles for an inclined surface are presented in below figures.

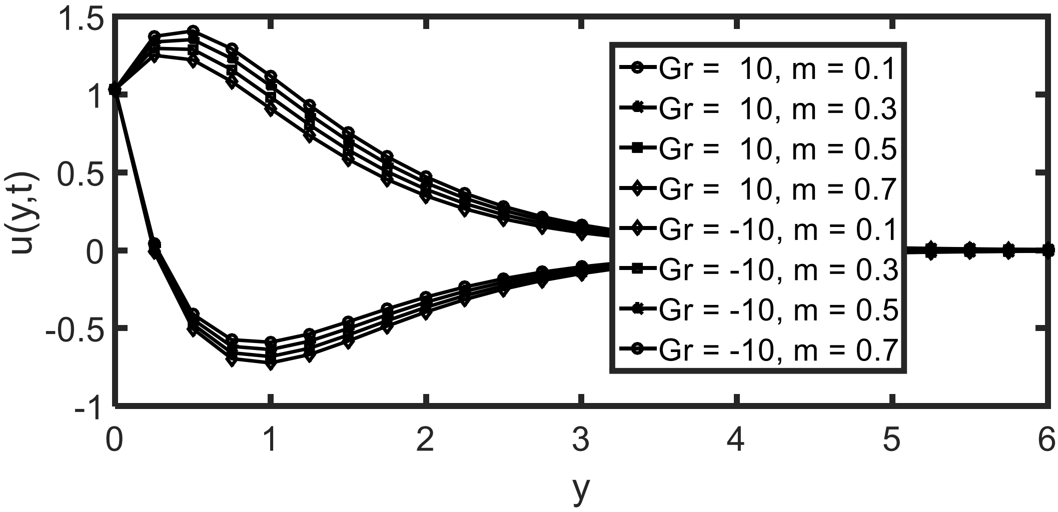

Fig 1: Velocity profiles for various values of m.

Figure 1 reveals that the effect of hall current on fluid velocity and it is observed that an increase in m, the velocity decreases in case of cooling of the plate and a reverse effect it is noticed that in case of heating of the plate. From Fig. 2, we observe that velocity decreases with the increases of α in case of cooling of the plate and the trend is just reversed in the case of heating of the plate. The influence of Nr on fluid velocity is illustrated in Fig. 3. From this figure it is observed that as Nr increases, the fluid velocity is increases in case of cooling of the plate and that is reversed in case of heating. From the Fig. 6, it is observed that the plate velocity decreases in both cases of cooling and heating of the plate with an increase in Kr. Fig. 5 reveals the velocity increases with the increases of Q in case of cooling of the plate and the trend is just reversed in case of heating of the plate. Figures 6-8 display the effects of Pr, Nr and Q on temperature distribution respectively. Increase in Pr is observed to lead to decrease in temperature boundary layer while increase in Nr or Q results in an increase in the thermal boundary layer. Figures 9 and 10 depict the effect of the Sc and Kr on the species concentration. It is observed that an increase in Sc or Kr decrease in concentration and concentration boundary layer.

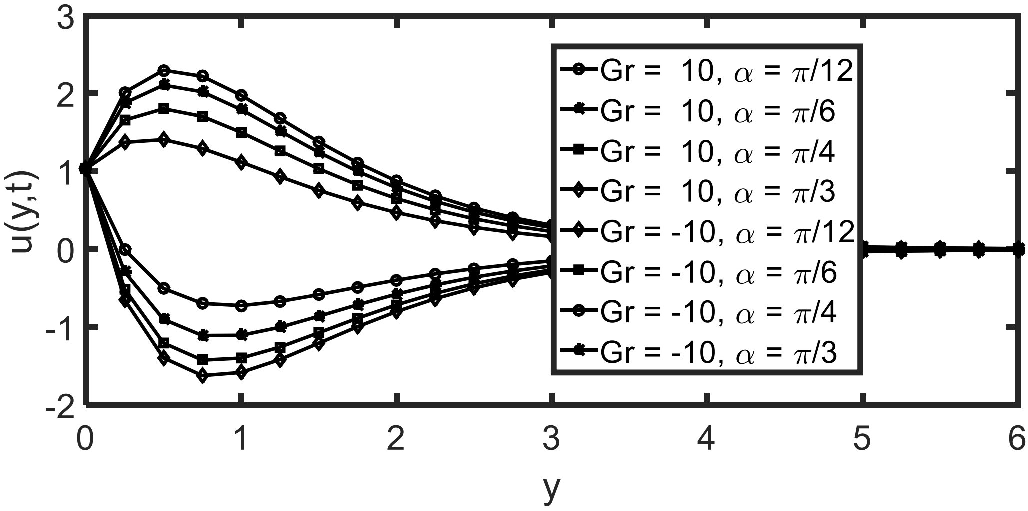

Fig 2: Velocity profiles for various values of α.

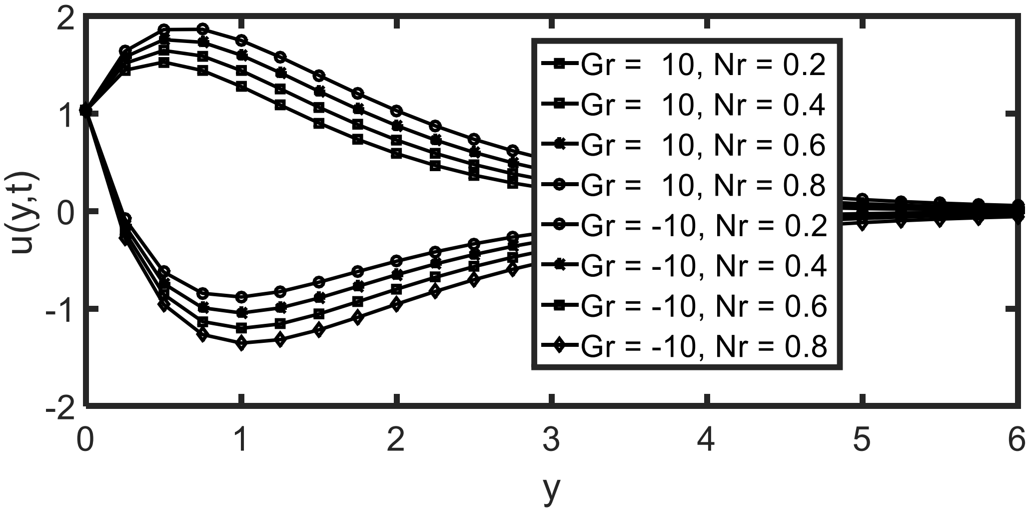

Fig 3: Velocity profiles for various values of Nr.

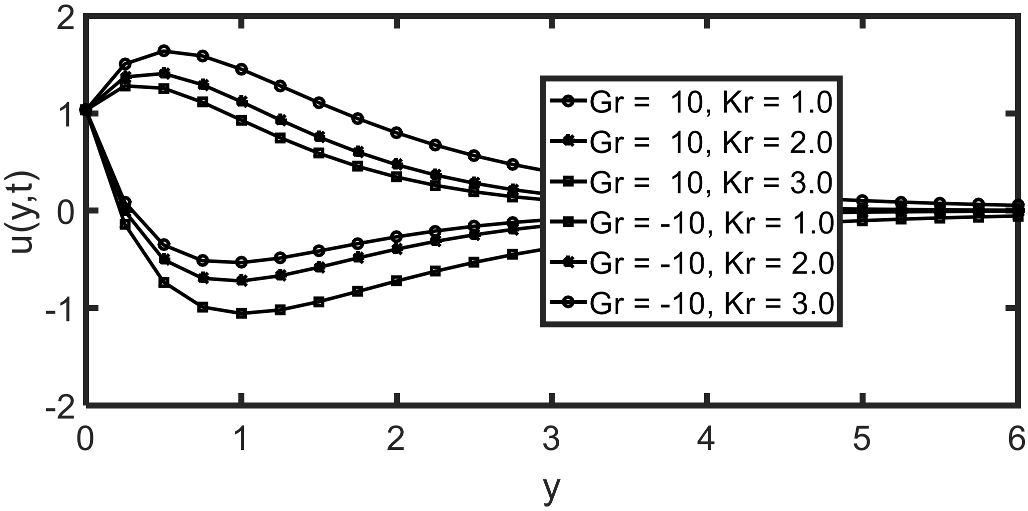

Fig 4: Velocity profiles for various values of Kr.

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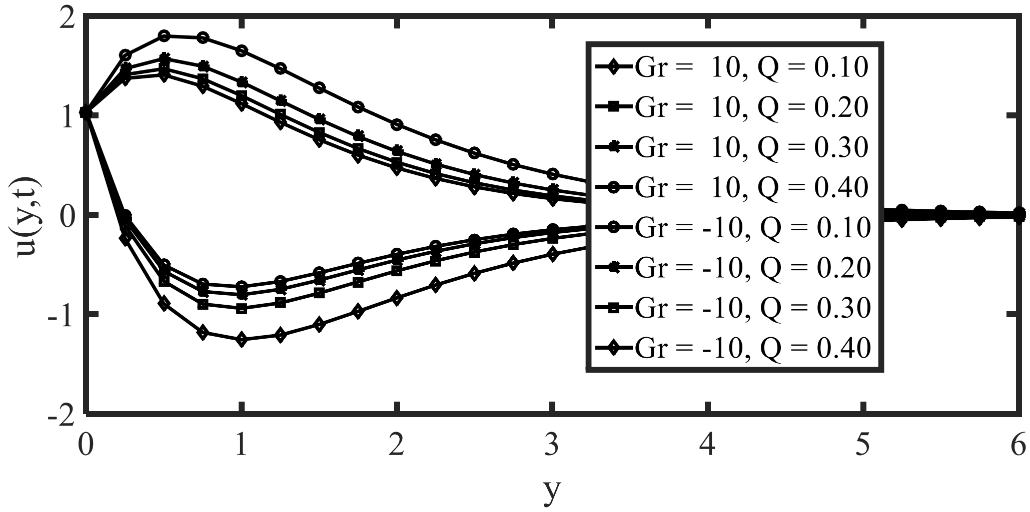

Fig 5: Velocity profiles for various values of Q.

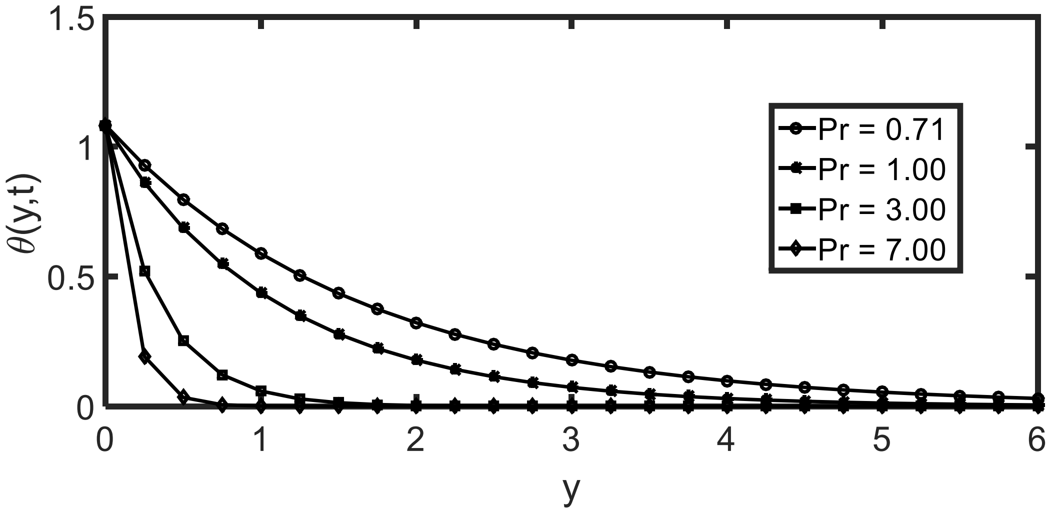

Fig 6: Temperature profiles for various values of Pr.

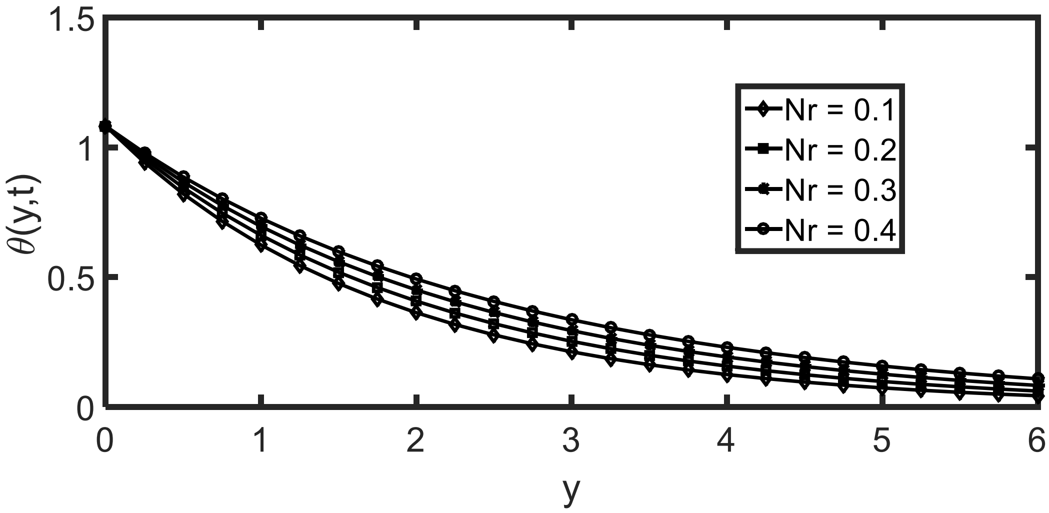

Fig 7: Temperature profiles for various values of Nr.

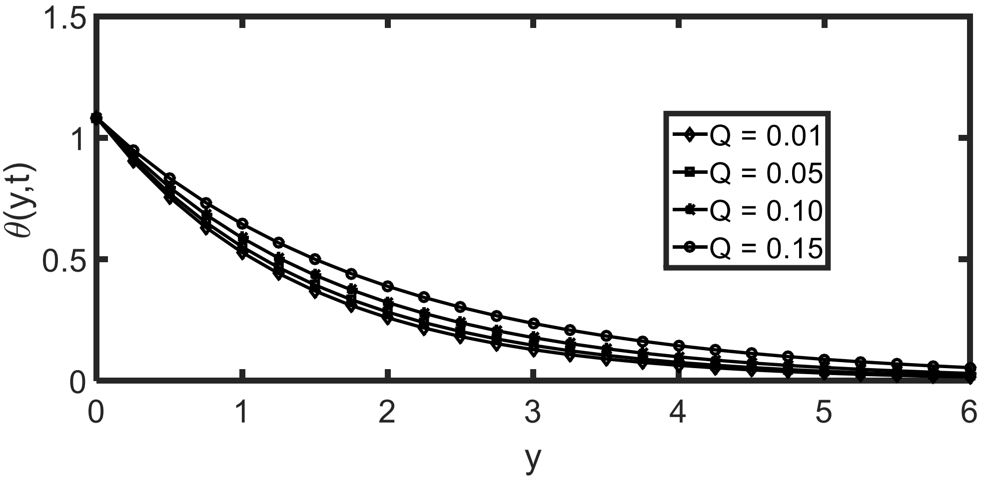

Fig 8: Temperature profiles for various values of Q.

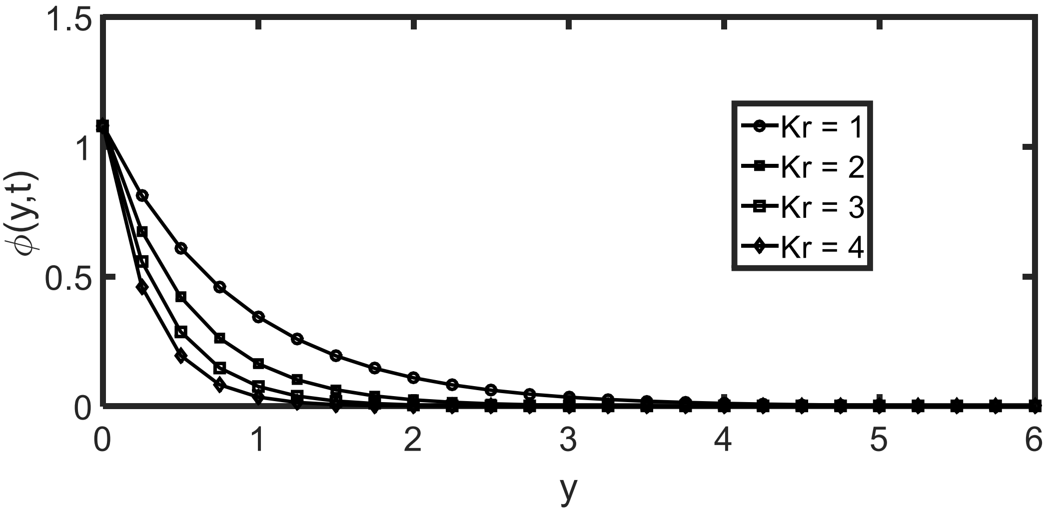

Fig 9: Concentration profiles for various values of Kr.

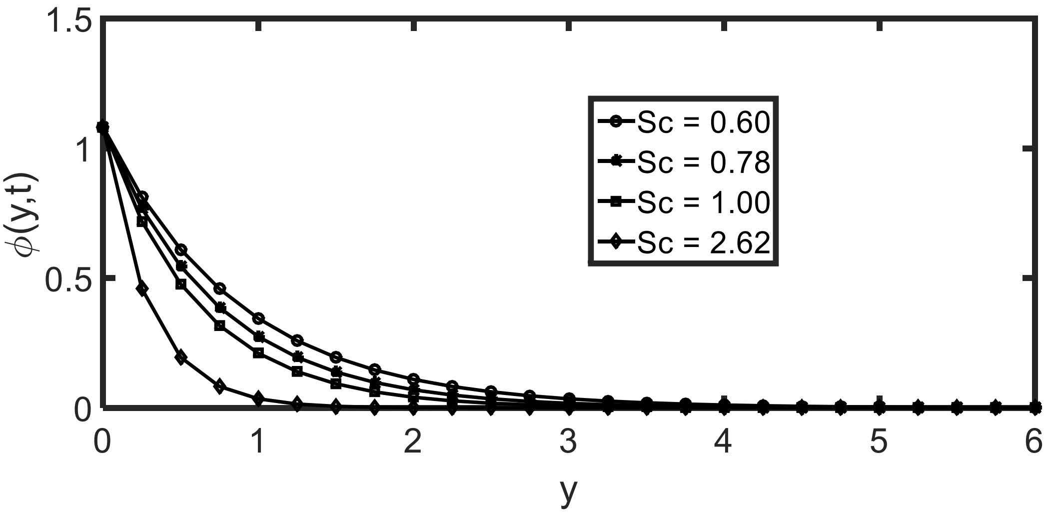

Fig 10: Concentration profiles for various values of Sc.

Table 1: Skin-friction for cooling and heating of the plate for m

m	Sk with Gr > 0	Sk with Gr < 0
0.1	2.2789	- 2.7923
0.2	2.1931	- 2.8091
0.3	2.0985	- 2.8283
0.4	1.9964	- 2.8499

Table 2: Skin-friction for cooling and heating of the plate for α

α	Sk with Gr > 0	Sk with Gr < 0
π/12	5.9916	- 3.8052
π/6	5.1956	- 3.5880
π/4	3.9292	- 3.2425
π/3	2.2789	- 2.7923

Table 3: Skin-friction for cooling and heating of the plate for Pr

Pr	Sk with Gr > 0	Sk with Gr < 0
0.71	3.9165	- 4.4299
1.00	3.1096	- 3.6230
7.00	0.4311	- 0.9445
11.4	0.1780	- 0.6914

Table 4: Skin-friction for cooling and heating of the plate for Sc

Sc	Sk with Gr > 0	Sk with Gr < 0
0.60	2.2789	- 2.7923
0.78	2.1161	- 2.9551
1.00	1.9668	- 3.1043
2.62	1.4674	- 3.6038

Table 5: Skin-friction for cooling and heating of the plate for Nr

Nr	Sk with Gr > 0	Sk with Gr < 0
0.1	2.4418	- 2.9551
0.2	2.6145	- 3.1279
0.3	2.7793	- 3.2927
0.4	2.9368	- 3.4502

Table 6: Skin-friction for cooling and heating of the plate for Kr

Kr	Sk with Gr > 0	Sk with Gr < 0
1	1.8515	- 3.2197
2	1.6144	- 3.4567
3	1.4659	- 3.6053
4	1.3645	- 3.7067

Table 7: Skin-friction for cooling and heating of the plate for M

M	Sk with Gr > 0	Sk with Gr < 0
0.1	2.3392	- 2.7808
0.2	2.3239	- 2.7837
0.3	2.3088	- 2.7866
0.4	2.2938	- 2.7894

Table 8: Skin-friction for cooling and heating of the plate for Q

Q	Sk with Gr > 0	Sk with Gr < 0
0.1	2.4512	- 2.9646
0.2	2.7298	- 3.2432
0.3	3.3399	- 3.8533
0.4	3.0930	- 3.6064

Table 9: Skin-friction for cooling and heating of the plate for Gm

Gm	Sk with Gr > 0	Sk with Gr < 0
10	3.7275	- 1.3436
15	5.1762	0.1050
20	6.6248	1.5536
25	8.0735	3.0023

Table 10: Nusselt number

Pr	Nr	Q	Nu
0.71			0.5993
1.00			0.8998
3.00			2.9259
7.00			6.9606
	0.1		0.5377
	0.2		0.4791
	0.3		0.4283
	0.4		0.3833
		0.2	0.3675
		0.3	0.3666
		0.4	0.3656
		0.5	0.3642

Table 11: Sherwood number

Kr	Sc	Sh
0.1		0.6897
0.2		0.7186
0.3		0.7623
0.4		0.8167
	0.60	1.2405
	0.78	1.4865
	1.00	1.7738
	2.62	3.7126

Tables 1-11, shows the influences of variation of skin-friction, non-dimensional heat and mass transfer coefficients for various values such as hall current(m), inclined angle(α), prandtl number(Pr), Schmidt(Sc), Thermal radiation parameter(Nr), Chemical reaction parameter(Kr), magnetic parameter(M), heat source parameter(Q) and mass Grashof number(Gm) with Thermal Grashof number (Gr) as cooling of the plate(>0) and heating of the plate(<0).

From Table1, it is clear that the skin-friction decreases in case of cooling and heating of the plate with increases of hall current. From Table 2, we observe that the skin-friction decreases in case of cooling and reverse effect are observed in case of heating with increases of inclined angle. From Table 3, it is seen that the skin-friction decreases in case of cooling and reverse effect are observed in case of heating with increases of Prandtal number. From Table 4, it is observed that the skin-friction decreases in case of cooling and heating of the plate with increases of Schmidt number. From Table 5, we observe that the skin-friction increases in case of cooling and reverse effect are observed in case of heating with increases of Thermal radiation parameter. Table6 illustrate the variation in skin-friction for different values of chemical reaction parameter. It is observed that the skin-friction decreases in case of cooling and heating of the plate with increases of chemical reaction parameter. Table7 demonstrates the influences of magnetic parameter. It is observed that the skin-friction decreases in case of cooling and heating of the plate with increases of magnetic parameter. Influence of heat source parameter on skin-friction is displayed in Table8. It depicts that the skin-friction increases in case of cooling and reverse effect are observed in case of heating with increases of heat source parameter. From Table9, it is observed that the skin-friction increases in case of cooling and heating of the plate with increases of mass Grashof number. Nusselt number which measures the rate of heat transfer at the plate y=0, is shown in Table10 for different values of Prandtl number, heat source parameter and thermal radiation respectively. It is found that an increase in the in the Prandtl number leads to increase in the rate of heat transfer while it decreases as heat source parameter or thermal radiation decreases. Sherwood number which measures the rate of mass transfer at the plate y = 0, is shown in Table 11 for different values of Schmidt number or chemical reaction rate constant, respectively. It is observed that Sherwood number increases with increasing values of Schmidt number or chemical reaction rate constant.

CONCLUSIONS

This paper investigates the effects of heat source, hall current and radiation on unsteady MHD two dimensional, laminar, boundary layer flow of a viscous, incompressible, electrically conducting fluid along a semi-infinite inclined plate in the presence of thermal and concentration buoyancy effects. A perturbation technique is employed to solve the resulting coupled partial differential equations. The obtained results work compared with previous work Shankar et al., [20] and were found to be good in agreement.

- It is observed that an increase in Schmidt number or chemical reaction rate constant increase in concentration and concentration boundary layer.
- An increase in the Prandtl number is observed to lead to increase in temperature boundary layer.
- Increase in the thermal radiation parameter or heat source parameter results in decrease in the temperature boundary layer.

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