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UNSTEADY FREE MHD CONVECTION FLOW PAST A VERTICAL POROUS PLATE IN SLIP-FLOW REGIME UNDER OSCILLATORY BOUNDARY CONDITIONS

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ABSTRACT

The unsteady free convective viscous incompressible flow past an infinite vertical porous flat plate with fluctuating heat and mass transfer in slip-flow regime is discussed. Assuming variable suction at the porous plate, nearly approximate solutions are obtained for velocity, skin-friction, and temperature and species concentration. The effects of Gr, Gc, Sc, A and ω for Pr = 0.71 (air) have been presented graphically and discussed qualitatively. It is noticed that as Grashof number increases, the velocity of the fluid medium decreases. Also, as modified Grashof number increases, in general the velocity increases. Further, it is seen that as Schmidt number increases, the velocity increases initially within the boundary layer region and thereafter it decreases. It is seen that the magnetic intensity suppresses fluid velocity. Also, increase of the pore size of the fluid bed and Prandtl No causes the fluid velocity to decrease. It is seen that the suction parameter influences temperature significantly and as the suction parameter increases, the temperature field decreases. Further, the concentration of the fluid medium decreases as the suction parameter increases. For a fixed magnetic intensity, as Grashof number increases, the skin friction is found to be increasing. Further, when Grashof number is varied, it is seen that, the skin friction decreases as the magnetic intensity increases. The influence of the amplitude on the velocity profiles is studied. It is noticed that, as the amplitude increases, the fluid velocity decreases and also at times a backward flow is noticed. Due to the percolation of the fluid into the boundary such a backward flow is noticed. However, as we move far away from the bounding surface, the effect of such backward flow is found to be negligible and the influence of amplitude is not seen. Also, it is seen that as B increases while holding Gr constant, the skin friction increases. The relation between skin friction and B is found to be almost linear.

Key words: *Free Convection, Incompressible Fluid, Heat and Mass Transfer.*

INTRODUCTION:

The phenomenon of free convection arises in situations when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. The examples that occur and can be felt are mostly, the atmospheric flow, which is mostly driven by temperature differences. The free-convection flow is enhanced by superimposing oscillating temperature on the mean plate temperature. In situations demanding efficient transfer of heat and mass transfer the, transient free convective flow occurs as such a flow acts as a cooling device. Further, free convection is of interest in the early stages of melting adjacent to a heated surface. There occurs several industrial and atmospheric applications where the transport processes occurring in nature due to temperature and chemical differences. Heat transfer in porous media is seen both in natural phenomena and in engineered processes. It is replete with the features that are influences of the thermal properties and volume fractions of the materials involved. These features are seen of course as responses to the causes that force the process in to action. For instance many biological materials, whose outermost skin is porous and pervious, saturated or semi saturated with fluids give out and take in heat from their surroundings. The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is the working medium. The applications are often found in situation the such as fiber and granules insulation, geothermal systems in the heating and cooling chamber, fossil fuel combustion, energy processes and Astro-physical flows. Further, the magneto convection place an important role in the control of mountain iron flow in the steady industrial liquid metal cooling in nuclear reactors and magnetic separation of molecular semi conducting materials. A classical example using the nuclear power stations is separation of Uranium U_{235} from U_{238} by gases diffusion. When mass transfer takes the place in a fluid rest, the mass is transformed purely by molecular diffusion a result identified from concentration gradient. The wide range of its technological and industrial applications has stimulated considerable amount of interest in the study of heat and mass transfer in convection flows.

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Ostrach [1], [2] and [3] studied extensively and more intensively the mathematical models of free convective flow past vertical plate. Siegel [4] examined the transient free convection from a vertical flat plate while, the results on the free convective heat transfer on a vertical semi-infinite plate has been presented in detail by Berezovsky *et al.* [5]. Subsequently, the laminar free convection from a vertical plate has been studied by Martynenko *et al.* [6]. The natural convection flows adjacent to both vertical and horizontal surface, which result from the combined buoyancy effects of thermal and mass diffusion, was first investigated by Gebhart and Pera [7] and Pera and Gebhart [8]. While, Soundalgekar [9] investigated the situation of unsteady free convective flows where in the effects of viscous dissipation on the flow past an infinite vertical porous plate was highlighted. In the course of analysis, it was assumed that the plate temperature oscillates in such a way that its amplitude is small. Later, Chen *et al* [10] studied the combined effect of buoyancy forces from thermal and mass diffusion on forced convection. Subsequently, Ramanaiah and Malarvizhi [11] investigated the free convection on a horizontal plate in a saturated porous medium with prescribed heat transfer coefficient. Vighnesam and Soundalgekar [12] presented the case of combined free and forced convection flow of water from a vertical plate with variable temperature. The transient free convection flow past an infinite vertical plate with periodic temperature variation was studied by Das *et al* [13]. In recent times, Hossain *et al.* [14] studied the influence of fluctuating surface temperature and concentration on natural convection flow from a vertical flat plate.

The present analysis discussed herein is based on the study as referred and suggested by Soundalgekar and Wavre [15] and [16]. Under the assumptions made by Sharma and Chaudhary [17] and Sharma and Sharma [18] have also discussed the free convection flow past a vertical plate in slip-flow regime. They had quoted several applications that occurs in several engineering applications wherein heat and mass transfer occurs at high degree of temperature differences.

In all above presentations, the plate was assumed to be maintained at a constant temperature, which is also the temperature of the surrounding stationary fluid. However, in many applications that occur in industrial situations are not those simple and at high temperatures, quite often the plate temperature starts oscillating about a non-zero mean temperature. In many practical applications, the particle adjacent to a solid surface no longer takes the velocity of the surface. The particles at the surface always possess a finite tangential velocity and it "slips" almost along the surface. Therefore, the flow regime is called the slip - flow regime and such an effect cannot be neglected. Hence, in the fitness of the industrial and scientific applications and to be more realistic the effect of periodic heat and mass transfer on unsteady free convection flow past a vertical flat porous plate under the influence of applied transverse magnetic field has been examined. The slip flow regime it is assumed that the suction velocity oscillates in time about a non-zero constant mean because in actual practice temperature, species concentration and suction velocity may not always be uniform.

MATHEMATICAL FORMULATION:

An unsteady free MHD convective flow of a viscous incompressible fluid past an infinite vertical porous flat plate in slip-flow regime, with periodic temperature and concentration when variable suction velocity distribution $\left[V^* = -V_0^*\left(1+\varepsilon A e^{i\omega^* t^*}\right)\right]$ is fluctuating with respect to time is considered. A co-ordinate system is employed with wall lying vertically in $x^* y^* -$ plane. The $x^* -$axis is taken in vertically upward direction along the vertical porous plate and $y^* -$axis is taken normal to the plate. Since the plate is considered infinite in the $x^* -$direction, hence all physical quantities will be independent of x^*. Under these assumption, the physical variables are purely the functions of y^* and t^* only. In the firntess of the realistic situation by neglecting viscous dissipation and then assuming variation of density in the body force term (Boussinesq's approximation) the problem can be governed by the following set of equations:

$$\frac{\partial u^*}{\partial t^*} - V_0^*\left(1+\varepsilon A e^{i\omega^* t^*}\right)\frac{\partial u^*}{\partial y^*} = g\beta\left(T^* - T_\infty^*\right) + g\beta^0\left(C^* - C_\infty^*\right) + \nu\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma\beta_0^2}{\rho}u^* - \frac{\nu}{K^*}u^* \tag{1}$$

$$\rho C_P\left[\frac{\partial T^*}{\partial t^*} - V_0^*\left(1+\varepsilon A e^{i\omega^* t^*}\right)\frac{\partial T^*}{\partial y^*}\right] = k\frac{\partial^2 T^*}{\partial y^{*2}} \tag{2}$$

$$\frac{\partial C^*}{\partial t^*} - V_0^*\left(1+\varepsilon A e^{i\omega^* t^*}\right)\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} \tag{3}$$

The boundary conditions of the problem are:

$$\left.\begin{aligned} &u^* = B^* e^{i\psi t}, \quad T^* = T_w^* + \varepsilon\left(T_w^* - T_\infty^*\right)e^{i\omega^* t^*}, \quad C^* = C_w^* + \varepsilon\left(C_w^* - C_\infty^*\right)e^{i\omega^* t^*} \quad \text{at } y^* = 0 \\ &u^* \to 0, \quad T^* \to T_\infty^*, \quad C^* \to C_\infty^* \quad \text{as } y^* \to \infty \end{aligned}\right\} \tag{4}$$

We now introduce the following non-dimensional quantities into Eqs. (1) to (4)

$$y=\frac{y^{*}V_{0}^{*}}{\nu},\quad t=\frac{t^{*}V_{0}^{*2}}{4\nu},\quad u=\frac{u^{*}}{V_{0}^{*}},\quad \omega=\frac{4\nu\omega^{*}}{V_{0}^{*2}},\quad \theta=\frac{T^{*}-T_{\infty}^{*}}{T_{w}^{*}-T_{\infty}^{*}},\quad C=\frac{C^{*}-C_{\infty}^{*}}{C_{w}^{*}-C_{\infty}^{*}}.$$

$$Gr=\frac{g\beta\nu\left(T_{w}^{*}-T_{\infty}^{*}\right)}{V_{0}^{*3}},\quad Gr=\frac{g\beta^{\circ}\nu\left(C_{w}^{*}-C_{\infty}^{*}\right)}{V_{0}^{*3}},\quad Pr=\frac{\mu C_{p}}{k}=\frac{\nu\rho C_{p}}{k},\quad Sc=\frac{\nu}{D},$$

$$M=\frac{\sigma\beta_{0}^{2}\nu}{\rho V_{0}^{*2}},\quad K=\frac{K^{*}V_{0}^{*2}}{\nu^{2}},\quad B=\frac{B^{*}}{V_{0}^{*}}.$$

All physical variables are defined in nomenclature. The $(*)$ stands for dimensional quantities. The subscript (∞) denotes the free stream condition. Then equations (1) to (3) reduce to the following non-dimensional form:

$$\frac{1}{4}\frac{\partial u}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial u}{\partial y}=Gr\,\theta+Gc\,C+\frac{\partial^{2}u}{\partial y^{2}}-Mu-\frac{u}{K} \tag{5}$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^{2}\theta}{\partial y^{2}} \tag{6}$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^{2}C}{\partial y^{2}} \tag{7}$$

The boundary conditions to the problem in the dimensionless form are:

$$\left.\begin{array}{l} u=Be^{i\psi t},\quad \theta=1+\varepsilon e^{i\omega t},\quad C=1+\varepsilon e^{i\omega t}\quad \text{at } y=0 \\ u\to 0,\quad \theta\to 0,\quad C\to 0\quad \text{as } y\to\infty \end{array}\right\} \tag{8}$$

METHOD OF SOLUTION:

Assuming the small amplitude oscillations ($\varepsilon << 1$), we can represent the velocity u, temperature θ and concentration C near the plate as follows:

$$u\left(y,t\right)=u_{0}\left(y\right)+\varepsilon u_{1}\left(y\right)e^{i\omega t} \tag{9}$$

$$\theta\left(y,t\right)=\theta_{0}\left(y\right)+\varepsilon\theta_{1}\left(y\right)e^{i\omega t} \tag{10}$$

$$C\left(y,t\right)=C_{0}\left(y\right)+\varepsilon C_{1}\left(y\right)e^{i\omega t} \tag{11}$$

Substituting (9) to (11) in (5) to (7), equating the coefficients of harmonic and non harmonic terms, neglecting the coefficients of ε^{2}, we get:

$$u_{0}''+u_{0}'-\left(M+\frac{1}{K}\right)u_{0}=-Gr\theta_{0}-GcC_{0} \tag{12}$$

$$u_1'' + u_1' - \left(M + \frac{1}{K} + \frac{i\omega}{4}\right)u_1 = -Gr\theta_1 - GcC_1 - Au_0' \tag{13}$$

$$\theta_0'' + \Pr\theta_0' = 0 \tag{14}$$

$$\theta_1'' + \Pr\theta_1' - \frac{i\omega\Pr\theta_1}{4} = -A\Pr\theta_0' \tag{15}$$

$$C_0'' + ScC_0' = 0 \tag{16}$$

$$C_1'' + ScC_1' - \frac{i\omega ScC_1}{4} = -AScC_0' \tag{17}$$

The corresponding boundary conditions reduce to:

$$\left.\begin{array}{l} u_0 = 0,\ \ u_1 = \dfrac{B}{\varepsilon}e^{i(\psi-\omega)t},\ \ \theta_0 = 1,\ \ \theta_1 = 1,\ \ C_0 = 1,\ \ C_1 = 1 \ \text{ at } \ y = 0 \\ u_0 = 0,\ \ u_1 = 0,\ \ \theta_0 = 0,\ \ \theta_1 = 0,\ \ C_0 = 0,\ \ C_1 = 0 \ \text{ as } \ y \to \infty \end{array}\right\} \tag{18}$$

where primes denote differentiation with respect to 'y'. Solving the Eqns. (12) to (17) under the boundary conditions (18) we get:

$$\theta_0(y) = e^{-\Pr y} \tag{19}$$

$$C_0(y) = e^{-Scy} \tag{20}$$

$$u_0(y) = m_1 e^{-m_2 y} + m_3 e^{-\Pr y} + m_4 e^{-Scy} \tag{21}$$

$$\theta_1(y) = m_5 e^{-m_6 y} + m_7 e^{-\Pr y} \tag{22}$$

$$C_1(y) = m_8 e^{-m_9 y} + m_{10} e^{-Scy} \tag{23}$$

$$u_1(y) = m_{11} e^{-m_{12} y} - m_{13} e^{-m_6 y} - m_{14} e^{-m_9 y} + m_{15} e^{-m_2 y} + m_{16} e^{-\Pr y} + m_{17} e^{-Scy} \tag{24}$$

where

$$M_1 = M + \frac{1}{K}, \qquad m_1 = -m_3 - m_4, \qquad m_2 = \frac{1+\sqrt{1+4M_1}}{2},$$

$$m_3 = -\frac{Gr}{\Pr^2 - \Pr - M_1},\ m_4 = -\frac{Gc}{Sc^2 - Sc - M_1}, \quad m_5 = 1 - \frac{4iA\Pr}{\omega}, \qquad m_6 = \frac{\Pr + \sqrt{\Pr^2 + i\omega\Pr}}{2},$$

$$m_7 = \frac{4iA\Pr}{\omega},$$

$$m_8 = 1 - \frac{4iASc}{\omega}, \qquad m_9 = \frac{Sc + \sqrt{Sc^2 + i\omega Sc}}{2},$$

$$m_{10} = \frac{4iASc}{\omega},\ m_{11} = \frac{B}{\varepsilon}e^{i(\psi-\omega)t} + m_{13} + m_{14} - m_{15} - m_{16} - m_{17},$$

$$m_{12} = \frac{1+\sqrt{1+4M_1+i\omega}}{2},\ m_{13} = \frac{m_5 Gr}{m_6^{\,2} - m_6 - \left(M_1 + i\omega/4\right)},$$

$$m_{14} = \frac{m_8 Gc}{m_9^{\,2} - m_9 - \left(M_1 + i\omega/4\right)},\ m_{15} = \frac{m_1 m_2 A}{m_2^{\,2} - m_2 - \left(M_1 + i\omega/4\right)},$$

$$m_{16} = \frac{m_3 A\,\Pr - m_7 Gr}{\Pr^2 - \Pr - \left(M_1 + i\omega/4\right)},\ m_{17} = \frac{m_4 ASc - m_{10} Gc}{Sc^2 - Sc - \left(M_1 + i\omega/4\right)}.$$

The important characteristics of the problem are the skin-friction and heat transfer at the plate.

Skin-friction: The dimensionless shearing stress on the surface of a body, due to a fluid motion, is known as skin-friction and is defined by the Newton's law of viscosity

$$\tau^* = \mu\left(\frac{\partial u^*}{\partial y^*}\right) \tag{25}$$

Substituting equations (21) and (24) into (9) we can calculate the shearing stress component in dimensionless form as

$$\tau = \frac{\tau^*}{\rho V_0^{*2}} = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{26}$$

$$= -m_1 m_2 - m_3 \Pr - m_4 Sc + \varepsilon e^{i\omega t}\left(-m_{11}m_{12} + m_6 m_{13} + m_9 m_{14} - m_2 m_{15} - m_{16}\Pr - m_{17} Sc\right)$$

RESULTS AND CONCLUSIONS:

1. The effect of Grashof number on velocity profiles is illustrated in Fig. – 1. It is noticed that increase in Grashof number contributes to the increase in velocity of the fluid. Further, it is noticed in the boundary layer region the velocity increases and thereafter, it decreases. Also, far away from the plate, not much of significant effect of Grashof number is noticed.

2. The variation of velocity with respect to Gc is noticed in Fig – 2. It is observed that as Gc increases, in general the velocity also increases. As was seen in earlier case, the rise in velocity is noticed in the boundary layer region and thereafter, it decreases.

3.The contribution of Schmidt number on the velocity profiles is noticed in Fig – 3. It is seen that as Schmidt number increases, the velocity decreases. It is seen that the contribution by Sc is not that significant at the boundary but as we move far away from the plate, the dispersion due to Sc is found to be more distinct and the effect of Sc could be noticed.

4. The contribution of the magnetic intensity over the velocity field is observed in Fig-4. It is observed that, as the magnetic intensity is increased, the fluid velocity decreases. Such an observation is in tune with the realistic situation that, as the magnetic intensity suppresses the fluid velocity.

5. The influence of the porosity of the fluid bed on the velocity profiles is shown in Fig -5. It is noted that, as the pore size of the fluid bed increases, the velocity decreases. This is in agreement with the real life situation. As the pore size of the fluid bed increases, the fluid over the bed gets trapped into the pores resulting in the decrease of the fluid velocity.

6. Variation in the velocity of the fluid medium with respect to suction parameter is illustrated in Fig – 6. It is noticed that as as the suction parameter is increased, the velocity of the fluid medium is found to be decreasing. At the boundary, the suction parameter does not show any influence. However, as we move far away from the plate the influence appears to be more predominant.

7. The influence of the amplitude on the velocity profiles is shown in Fig – 7. It is noticed that, as the amplitude increases, the fluid velocity decreases and also at times a backward flow is noticed. Due to the percolation of the fluid into the boundary such a

backward flow is noticed. However, as we move far away from the bounding surface, the effect of such backward flow is found to be negligible and the influence of amplitude is not seen.

8. The influence of prandtl number on the velocity profiles is illustrated in Fig – 8. It is observed that increase in Pr contributes to the decrease in the fluid velocity. The contribution by Pr is not that significant at the boundary. But the effect appears to be more significant as we move far away from the bounding surface.

9. Fig – 9 illustrates the influence of Prandtl number on the temperature field. It is observed that the prandtl number has significant contribution over the temperature field. From the illustrations it is seen that as the Prandtl No increases, the temperature decreases. Further, not much of significant contribution by the Prandtl No is noticed at the boundary and also as we move far away from the plate.

10. The influence of suction parameter on the temperature field is illustrated in Fig – 10. It is seen that as the suction parameter increases, the temperature field decreases. It is observed that the increase in the suction parameter contributes to the parabolic nature of the temperature profiles. Further, far away from the plate, it is noticed that the suction parameter tends to loose its significance.

11. Fig – 11 illustrates the effect of Sc on concentration profiles. It is seen that as Sc increases, the concentration is found to be decreasing. Further, increase in Sc contributes to the parabolic nature of the concentration profiles. Also, the dispersion in concentration is found to be more distinctive as we move far away from the bounding surface,

12.The influence of suction parameter on the concentraion of the fluid medium is shown in Fig – 12. It is observed that as the suction parameter increases, the concentration of the fluid medium decreases. Further, as we move far away from the plate, it is observed that the effect of such suction parameter to be diminishing rapidly.

13. The consolidated effected of Gr with respect to the magnetic intensity on the skin friction is observed in Fig – 13. In general, it is noticed that, as Gr increases, the skin friction on the bounding surface increases. Further, as the magnetic influence is increased over the system, the skin friction decreases. Also, it is noticed that the influence of Gr at higher values of the magnetic intensity reduces drastically. Also, for larger values of M and Gr – the skin friction on the boundary appears to be almost negligible.

14. The consolidated influence of Sc and the magnetic intensity over the skin friction is noticed in Fig – 14. It is seen that increase in Sc contributes to the decrease in skin friction. Further, for a constant value of Sc, as the magnetic intensity is increased, the skin friction decreases. An interesting observation is that, at larger values of Sc and magnetic intensity the skin friction almost remains constant.

15. The combined influence of Gr and suction parameter on the skin friction is shown in Fig – 15. In general it is observed that for a constant suction parameter as Gr increases, the skin friction is found to be increasing. Interestingly, the relation is found to be nearly linear.

16. The influence of suction parameter with respect to Schmidt number on the skin friction is illustrated in Fig – 16. It is seen that as Schmidt number increases, for a constant value of suction parameter the skin friction decreases. Further, the relation is found to inverse and is linear.

17. The influence of Gr with respect to B on the skin friction is noticed in Fig – 17. It is observed that as Gr increases, the skin friction is found to be increasing. Also, it is seen that as B increases while holding Gr constant, the skin friction increases. The relation between skin friction and B is found to be almost linear.

18. Fig – 18 illustrates the consolidated influence of Sc and B on skin friction. It is observed that as Sc increases, the skin friction on the boundary decreases. Further, the relationship between Sc and skin friction is positive and of course with a positive slope. Also, as B increases, the skin friction increases.

NOMENCLATURE:

ε = Amplitude (<<1),
β = Coefficient of thermal expansion,
β_0 = Coefficient of thermal expansion with concentration,
ω = Dimensionless frequency,
θ = Dimensionless temperature,
μ = Viscosity,
ν = Kinematics viscosity,
α = thermal diffusivity,
ω^* = Frequency,
ψ = Excitation constant
k = Thermal conductivity,
K^* = Permeability parameter,
K = Dimensionless permeability parameter,
ρ = Density,
τ = Dimensionless shearing stress,
τ^* = Shearing stress,

A = Suction parameter,
B = Amplitude of excitation of boundary
C = Dimensionless species concentration,
C^* = Species concentration,
C_P = Specific heat at constant pressure,
C^*_∞ = Concentration in free stream,
C^*_w = Concentration at the wall,
D = Molecular diffusivity of the species,
g = Gravity,
Gc = Modified Grashof number,
Gr = Grashof number,
M = Magnetic intensity,
$\Pr$ = Prandtl number,
q^*_w = Heat flux at the wall,
Sc = Schmidt number,
t = Dimensionless time,
T^* = Temperature,
T^*_∞ = Temperature of fluid in free stream,
T^*_w = Temperature of wall,
t^* = Time,
u = Dimensionless velocity component,
u^* = Velocity component,
V = Suction velocity,
V^*_0 = Constant mean suction velocit

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FIGURES:

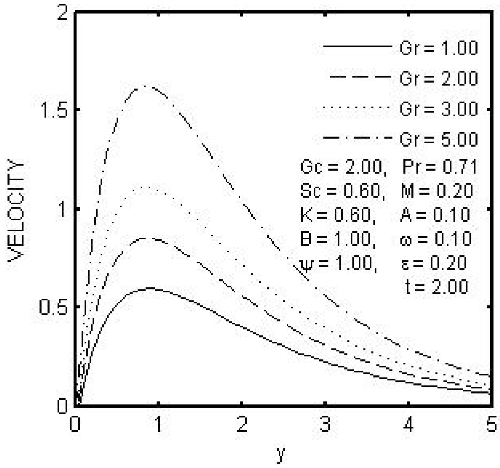

Fig.1:- Effect of Gr on velocity profiles

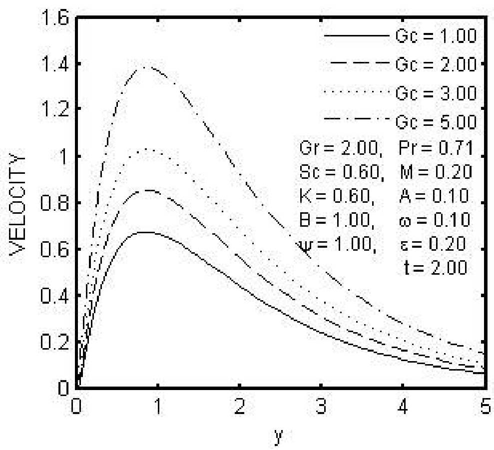

Fig. 2:- Effect of Gc on velocity profiles

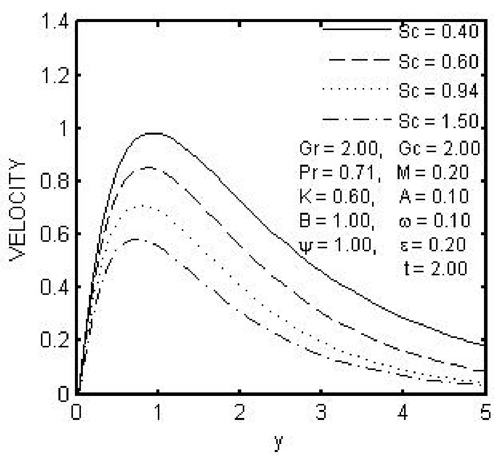

Fig. 3:- Effect of Sc on velocity profiles

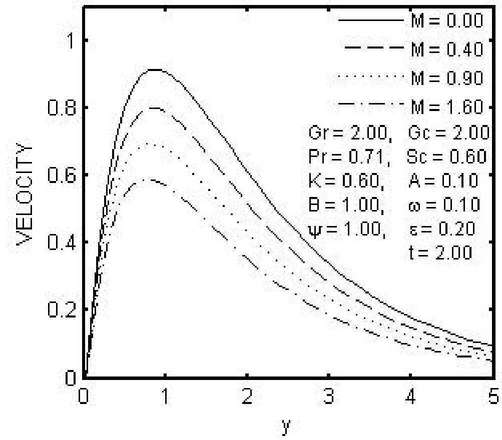

Fig. 4:- Effect of Magnetic field on velocity

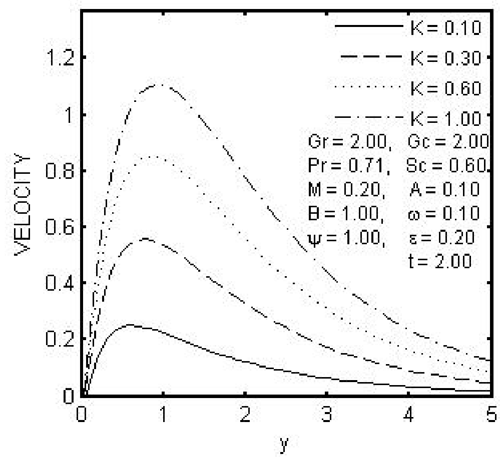

Fig. 5:- Effect of Permeability parameter on velocity

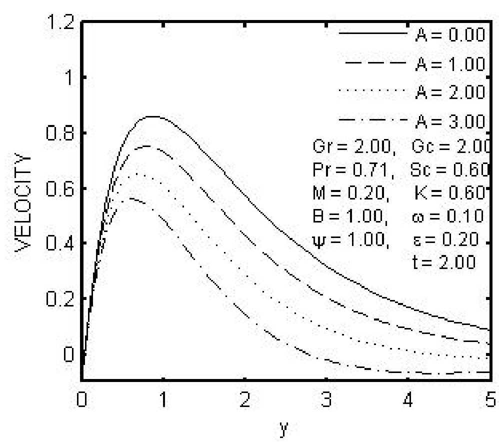

Fig. 6:- Effect of Suction parameter on velocity

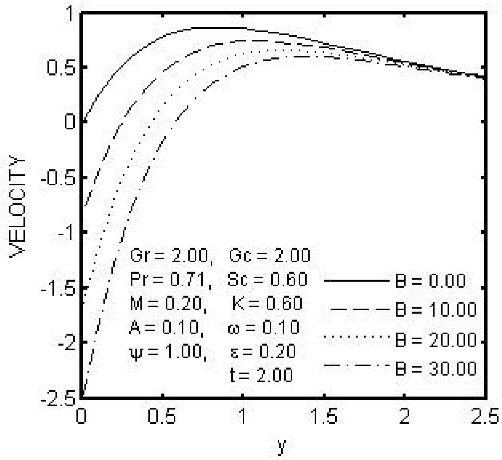

Fig. 7:- Effect of B on velocity

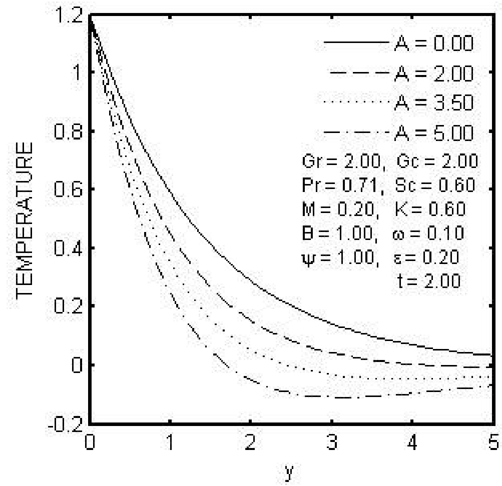

Fig. 10:- Effect of Suction parameter on temperature

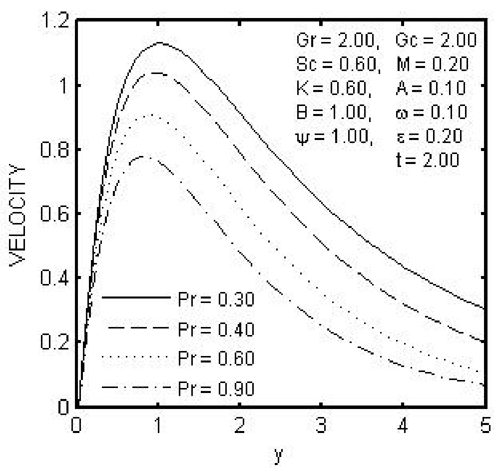

Fig. 8:- Effect of Pr on velocity profiles

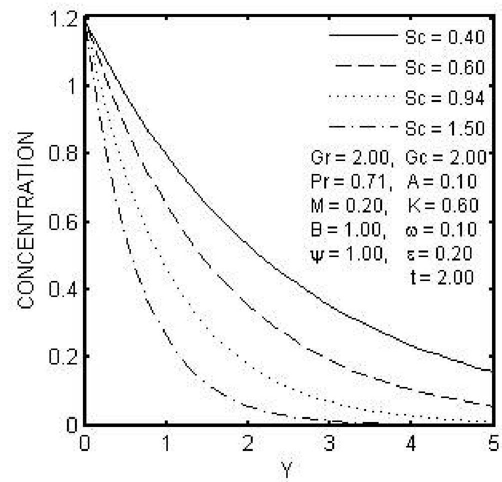

Fig.11:- Effect of Sc on concentration

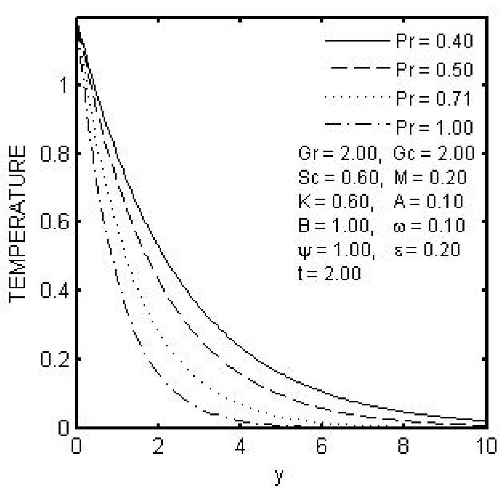

Fig. 9 :- Effect of Pr on temperature profiles

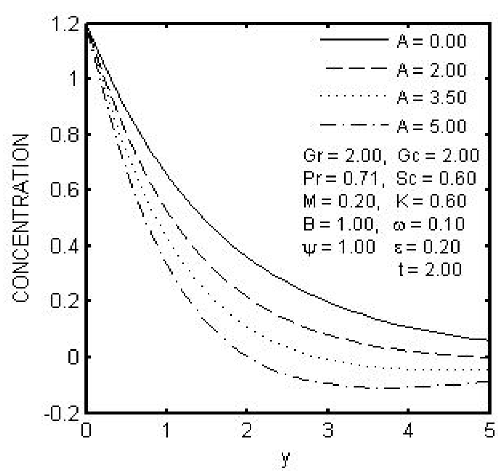

Fig.12:- Effect of Suction parameter on concentration

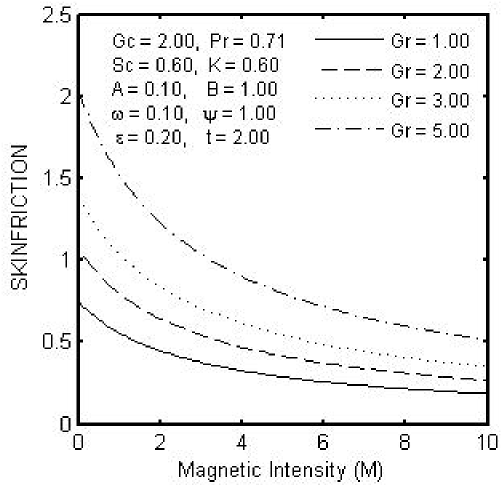

Fig.13:- Effect of Gr on skin friction

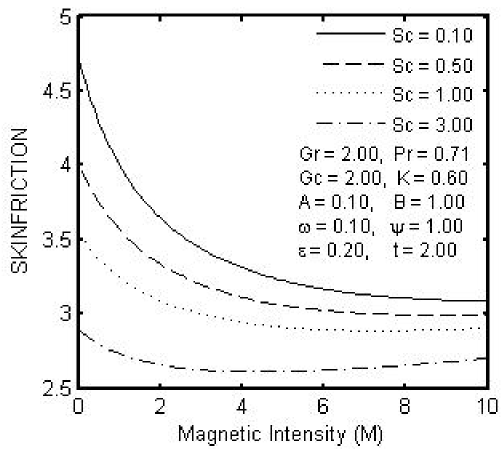

Fig.14:- Effect of Sc on skin friction

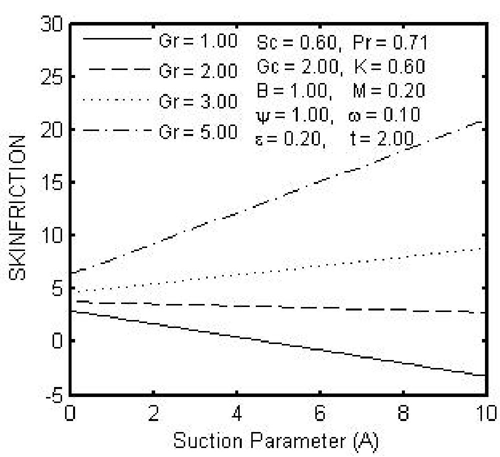

Fig.15:- Effect of Gr on skin friction

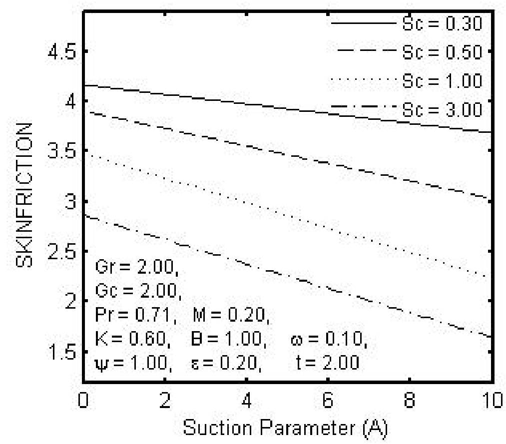

Fig.16:- Effect of Sc on skin friction

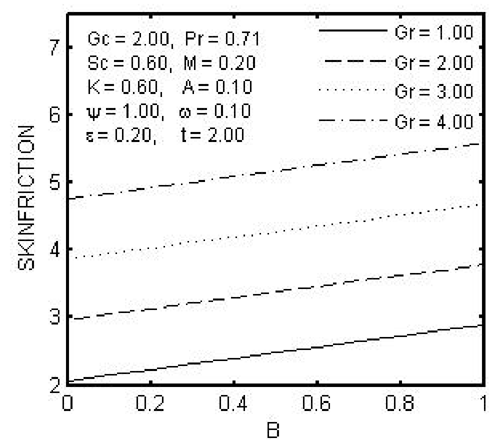

Fig.17:- Effect of Gr on skin friction

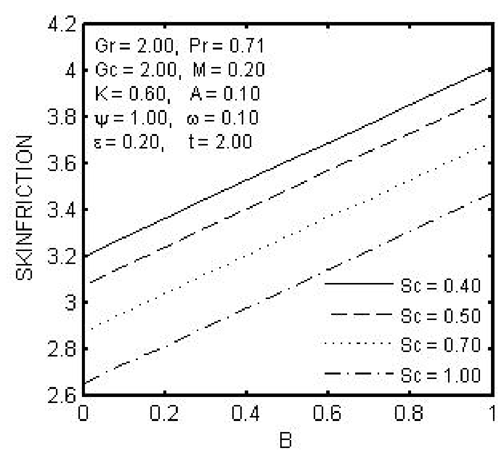

Fig.18:- Effect of Sc on skin friction