UNSTEADY MHD FREE CONVECTIVE MASS TRANSFER FLOW PAST AN INFINITE VERTICAL POROUS PLATE WITH VARIABLE SUCTION AND SORET EFFECT

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Abstract: *The MHD effects on the unsteady heat convective mass transfer flow past an infinite vertical porous plate with variable suction, where the plate temperature oscillates with the same frequency as that of variable suction velocity with the Soret effects. The governing equations of motion are solved to best possible classical solution by assuming at suitable trial solution. The flow phenomenon has been characterized with the help of flow parameters such as velocity, temperature and concentration profiles for different parameters such as Grashof number (Gr), modified Grashof number (Gm), Schmidt number (Sc), Prandtl number (Pr), Soret number (S0), Magnetic field (M) and variable suction parameter (A). The velocity, temperature and concentration profiles and ski-friction are shown graphically.*

Keywords: *MHD flow, Porous plate, Schmidt number, Viscous Dissipation, Skin-friction.*

1. Introduction

Convective heat transfer in a porous media is a topic of rapidly growing interest due to its application to geophysics, geothermal reservoirs, thermal insulation engineering, exploration of petroleum and gas fields, water movements in geothermal reservoirs, etc. The study of convective heat transfer mechanisms through porous media in relation to the applications to the above areas has been made by Nield and Bejan [1]. Several researchers are investigated to the unsteady free convective flow past infinite or semi-vertical plates due to its important technological applications. As presence of suction being more important and appropriate from the technological point of view, Nanda and Sarma [2], Schetz and Eichhorn [3], Soundalgekar [4], [5] and Kafousias [6] have studied unsteady free convective flow past vertical plates with suction. Hossain and Begum [7] have discussed unsteady free convective mass transfer flow past vertical porous plates. MHD convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption was studied by Rahman and Sattar [8]. Recently, the study of free convective mass transfer flow has become the object of extensive research as the effects of heat transfer along with mass transfer effects are dominant features in many engineering applications such as rocket nozzles, cooling of nuclear reactors, high sinks in turbine blades, high speed aircrafts and their atmospheric reentry, chemical devices and process equipments. Soundalgekar[9]. Soundalgekar [10] was examined by free convection flow past a semi-infinite vertical plate with mass transfer. Unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system studied by Sharma [11]. But in all these papers thermal diffusion effects have been neglected, whereas in a convective fluid when the flow of mass is caused by a temperature difference, thermal diffusion effects cannot be neglected. In view of the importance of this diffusion-thermo effect, Jha and Singh [12] presented an analytical study for free convection and mass transfer flow past an infinite vertical plate moving impulsively in its own plane taking Soret effects into account. In all the above studies, the effect of the viscous dissipative heat was ignored in free-convection flow. However, Gebhart [13], Gebhart and Mollendorf [14] have shown that when the temperature difference is

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small or in high Prandtl number fluids or when the gravitational field is of high intensity, viscous dissipative heat should be taken into account in free convection flow past a semi-infinite vertical plate. The unsteady free convection flow of a viscous incompressible fluid past an infinite vertical plate with constant heat flux is considered on taking into account viscous dissipative heat, under the influence of a transverse magnetic field studied by Srihari. K *et al* [15]. RamanaKumari and Bhaskara Reddy [16] have studied a two-dimensional unsteady MHD free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous plate with variable suction. Suneetha [17] examined the problem of radiation and mass transfer effects on MHD free convection flow past an impulsively started isothermal vertical plate with dissipation. The effect of temperature dependent viscosity and thermal conductivity on unsteady MHD convective heat transfer past a semi-infinite vertical porous plate has studied Seddek and Salama [18]. In recent years, progress has been considerably made in the study of heat and mass transfer in magneto hydrodynamic flows due to its application in many devices, like the MHD power generator and Hall accelerator. The influence of magnetic field on the flow of an electrically conducting viscous fluid with mass transfer and radiation absorption is also useful in planetary atmosphere research. Kinyanjui *et al*. [19] presented simultaneous heat and mass transfer in unsteady free convection flow with radiation absorption past an impulsively started infinite vertical porous plate subjected to a strong magnetic field. Yih [20] numerically analyzed the effect of transpiration velocity on the heat and mass transfer characteristics of mixed convection about a permeable vertical plate embedded in a saturated porous medium under the coupled effects of thermal and mass diffusion. Elbashbeshy [21] studied the effect of surface mass flux on mixed convection along a vertical plate embedded in porous medium. Chin *et al.* [22] obtained numerical results for the steady mixed convection boundary layer flow over a vertical impermeable surface embedded in a porous medium when the viscosity of the fluid varies inversely as a linear function of the temperature. Pal and Talukdar [23] analyzed the combined effect of mixed convection with thermal radiation and chemical reaction on MHD flow of viscous and electrically conducting fluid past a vertical permeable surface embedded in a porous medium is analyzed. Mukhopadhyay [24] performed an analysis to investigate the effects of thermal radiation on unsteady mixed convection flow and heat transfer over a porous stretching surface in porous medium. Hayat *et al.* [25] analyzed a mathematical model in order to study the heat and mass transfer characteristics in mixed convection boundary layer flow about a linearly stretching vertical surface in a porous medium filled with a visco-elastic fluid, by taking into account the diffusion thermo (Dufour) and thermal-diffusion (Soret) effects.

The object of the present paper is to study the MHD effects as well as Soret effects on the unsteady free convective mass transfer flow past an infinite vertical plate with variable suction, where the plate temperature oscillates with the same frequency as that of variable suction velocity. The governing equations of motion are solved to best possible classical solution by assuming at suitable trial solution.

2. Formation of the Problem

Unsteady flow of an incompressible, electrically conducting viscous fluid past an infinite vertical porous plate under the influence of a uniform transverse magnetic field is considered. Here the origin of the co-ordinate system is taken to be at any point of the plate. Let the components of velocity along x' and y' axes be u', v', and which are chosen in the upward direction along the plate and normal to the plate respectively. The polarization effects are assumed to be negligible and hence the electric field is also negligible. Hence the governing equations of the problem are:

$$\frac{\partial \rho'}{\partial t'} + \frac{\partial(\rho' u')}{\partial x'} + \frac{\partial(\rho' u')}{\partial y'} = 0 \quad \cdots\cdots \quad (1)$$

$$\rho'\left(\frac{\partial u'}{\partial t'}+u'\frac{\partial u'}{\partial x'}+v'\frac{\partial u'}{\partial y'}\right) = -\frac{\partial p'}{\partial x'} + \rho' g\beta\left(T'-T'_{\infty}\right) + \rho' g\beta^{*}\left(C'-C'_{\infty}\right) + \quad \cdots \quad (2)$$

$$\frac{\partial}{\partial x'}\left(2\mu\frac{\partial u'}{\partial x'}\right) + \frac{\partial}{\partial y'}\left\{\mu\left(\frac{\partial u'}{\partial y'}+\frac{\partial v'}{\partial x'}\right)\right\} - \frac{\mu}{K'}u' - \sigma B_0^2 u'$$

$$\rho' Cp'\left(\frac{\partial T'}{\partial t'}+u'\frac{\partial T'}{\partial x'}+v'\frac{\partial T'}{\partial y'}\right) = K_T\left(\frac{\partial^2 T'}{\partial x'^2}+\frac{\partial^2 T'}{\partial y'^2}\right) \quad \cdots\cdots \quad (3)$$

$$\rho'\left(\frac{\partial C'}{\partial t'}+u'\frac{\partial C'}{\partial x'}+v'\frac{\partial C'}{\partial y'}\right)=\rho' D\left(\frac{\partial^2 C'}{\partial x'^2}+\frac{\partial^2 C'}{\partial y'^2}\right)+\rho' D_1\left(\frac{\partial^2 T'}{\partial x'^2}+\frac{\partial^2 T'}{\partial y'^2}\right) \quad \ldots\ldots(4)$$

Here, the status of an equation of state is that of equation ρ' = constant. This means that the density variations produced by the pressure, temperature and concentration variations are sufficiently small to be unimportant. Variations of all fluid properties other than the variations of density except in so far as they give rise to a body force, are ignored completely (Boussinesq approximation). All the physical variables are functions of y' and t' only as the plate are infinite. It is also assumed that the variation of expansion coefficient is negligibly small and the pressure and influence of the pressure on the density are negligible. In a convective fluid the flow of mass is caused by a temperature difference, the thermal diffusion (Soret effect) cannot be neglected. With in the framework of above assumptions the governing equations reduce to

$$\frac{\partial v'}{\partial y'}=0 \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$\frac{\partial u'}{\partial t'}+v'\frac{\partial u'}{\partial y'}=g\beta(T'-T'_\infty)+g\beta^*(C'-C'_\infty)+\upsilon\frac{\partial^2 u'}{\partial y'^2}-\frac{\upsilon}{K'}u'-\frac{\sigma B_0^2}{\rho}u' \quad \ldots (6)$$

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\frac{K_T}{\rho' C_p'}\frac{\partial^2 T'}{\partial y'^2} \quad \ldots\ldots(7)$$

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}+D_1\frac{\partial^2 T'}{\partial y'^2} \quad \ldots\ldots(8)$$

and the corresponding boundary conditions are

$$\begin{aligned} &t>0, u'=0, \quad T'=T'_w=1+\varepsilon e^{i\omega' t'}, C'=C'_w \quad \text{at} \quad y'=0 \\ &u'\to 0, \quad T'\to T'_\infty, \quad C'\to C'_\infty \quad \text{as} \quad y'\to\infty \end{aligned} \quad \ldots\ldots(9)$$

From the continuity equation, it can be seen that v' is either a constant or a function of time. So, assuming suction velocity to be oscillatory about a non-zero constant mean, one can write

$$v'=-v_0(1+\varepsilon A e^{i\omega' t'}) \quad \ldots\ldots \quad (10)$$

where v_0 is the mean suction velocity and ε, A are small such that ε A<<1. The negative sign indicates that the suction velocity is directed towards the plate.

In order to write the governing equations and the boundary conditions in dimensional following non-dimensional quantities are introduced.

$$y=\frac{v_0 y'}{\nu},\quad u=\frac{u'}{v_0}, t=\frac{t' v_0^2}{4\nu},\quad T=\frac{T'-T'_\infty}{T'_w-T'_\infty},$$

$$C=\frac{C'-C'_\infty}{C'_w-C'_\infty},$$

$$Gr=\frac{g\beta\upsilon(T'_w-T'_\infty)}{v_0^3},$$

$$Gc=\frac{g\beta^*\upsilon(C'_w-C'_\infty)}{v_0^3}, Sc=\frac{\upsilon}{D}, \nu=\frac{\nu'}{v_0}$$

$$\omega=\frac{4\nu\omega'}{v_0^2}, M=\frac{\sigma B_0^2\nu}{\rho v_0}, K=\frac{K'\nu}{v_0^2},$$

$$So=\frac{D_1(T_w-T_\infty)}{\upsilon(C_w-C_\infty)}, \Pr=\frac{\mu C_p}{K_T} \quad \ldots\ldots(11)$$

Hence, using the above non-dimensional quantities, the equations (6) - (9) in the non-dimensional form can be written as

$$\frac{1}{4}\frac{\partial u}{\partial t}-\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y}=GrT+GcC+\frac{\partial^2 u}{\partial y^2}-\left(M+\frac{1}{K}\right)u \quad \ldots\ldots(12)$$

$$\frac{1}{4}\frac{\partial T}{\partial t}-\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial T}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2} \quad \ldots\ldots(13)$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}+ScSo\frac{\partial^2 T}{\partial y^2} \quad \ldots\ldots(14)$$

and the corresponding boundary conditions are

$$\begin{aligned} &t>0, u=0, \quad T=T_w=1+\varepsilon e^{i\omega t}, C=1 \quad \text{at} \quad y=0 \\ &u\to 0, \quad T\to 0, \quad C\to 0 \quad \text{as} \quad y\to\infty \end{aligned} \quad \ldots\ldots(15)$$

Here, t' is the time, g the acceleration due to gravity, ß the coefficient of volume expansion, ß* the coefficient of thermal expansion with concentration, T ' temperature of the fluid, T'_∞ the temperature of the fluid far away from the plate, C ' the species concentration, C'_∞ the species concentration of the fluid far away from the plate, T'_w the plate temperature, C'_w the species concentration near the plate, ν the kinematic viscosity, ρ the density, Cp the specific heat at constant pressure, K_T the thermal conductivity, D the chemical molecular diffusivity, μ the coefficient of viscosity, M the magnetic field parameter, *So* the Soret number, Sc the Schmidt number and all the physical quantities have their usual meaning.

3. Solution of the Problem

In order to reduce the above system of partial differential equation to a system of ordinary differential equations, the velocity, temperature and concentration in the neighborhood of the porous plate are taken as

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{i\omega t} + o(\varepsilon^2) + \ldots\ldots$$
$$T(y,t) = T_0(y) + \varepsilon T_1(y)e^{i\omega t} + o(\varepsilon^2) + \ldots\ldots \quad \ldots(16)$$
$$C(y,t) = C_0(y) + \varepsilon C_1(y)e^{i\omega t} + o(\varepsilon^2) + \ldots\ldots$$

Substituting equation (16) in equations (12) to (14) and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of $o(\varepsilon^2)$, we obtain

$$u_0'' + Lu_0' - (M + 1/K)u_0 + (GrT_0 + GcC_0) = 0 \ \ldots\ldots (17)$$
$$u_1'' + Lu_1' - (M + 1/K + i\omega/4)u_1 + (GrT_1 + GcC_1) = 0 \ \ldots\ldots (18)$$
$$T_0'' + \Pr LT_0' = 0 \quad \ldots\ldots \quad (19)$$
$$T_1'' + \Pr LT_1' - (i\omega \Pr/4)T_1 = 0 \ldots\ldots \quad (20)$$
$$C_0'' + LScC_0' + ScS0T_0'' = 0 \ldots\ldots \quad (21)$$
$$C_1'' + LScC_1' - (i\omega/4)C_1 + ScSoT_1'' = 0 \ldots\ldots (22)$$

and the corresponding boundary conditions are

$$t>0,\ u_0 = u_1 = 0,\ T_0 = T_1 = 1,\ C_0 = 1,\ C_1 = 0 \quad \text{at} \quad y = 0$$
$$u_0 = u_1 \to 0,\ T_0 = T_1 \to 0,\ C_0 = C_1 \to 0 \quad \text{as} \quad y \to \infty \quad (23)$$

Solving the above equations (17) to (22) and using boundary conditions (23), the solution of equations are expressed as:

$$u(y,t) = m_{24}e^{(-m_{25}y)} - m_{23}e^{(-L\Pr y)} - m_{21}e^{(-LScy)} + \varepsilon\left(m_{17}e^{(-m_{16}y)} + m_{12}e^{(-m_9 y)} - m_{15}e^{(-m_1 y)}\right)e^{i\omega t} \ldots\ldots (24)$$
$$T(y,t) = e^{(-L\Pr y)} + \varepsilon e^{(-m_1 y)}e^{i\omega t} \ldots\ldots (25)$$
$$C(y,t) = m_5 e^{(-LScy)} + m_4 e^{(-L\Pr y)} + \varepsilon m_8\left(e^{(-m_1 y)} - e^{(-m_9 y)}\right)e^{i\omega t} \ldots\ldots (26)$$

and skin-friction as

$$\left.\frac{\partial u}{\partial y}\right|_{y=0} = L\Pr m_{23} - m_{25}m_{24} + LScm_{21} + \varepsilon\left(m_{15}m_1 - m_{12}m_9 - m_{16}m_{17}\right)e^{i\omega t} \ldots\ldots (27)$$

where $L = 1 + \varepsilon A e^{i\omega t}$,

$N = M + 1/K + i\omega/4$,

$$m_1 = \frac{L\Pr + \sqrt{L^2\Pr^2 + i\omega\Pr}}{2}$$

$m_2 = -ScSoL^2\Pr^2$,

$m_3 = L^2\Pr(\Pr - Sc)$,

$m_4 = m_2/m_3$, $m_5 = 1 - m_4$

$m_6 = -ScSom_1^2$,

$$m_7 = m_1^2 - LScm_1 - \frac{i\omega Sc}{4},$$

$m_8 = m_6/m_8$,

$$m_9 = \frac{LSc + \sqrt{L^2Sc^2 + i\omega Sc}}{2}$$

$m_{10} = m_1^2 - m_1 L - N$,

$m_{11} = m_9^2 - m_9 L - N$,

$m_{12} = Gcm_8/m_{11}$,

$m_{13} = Gcm_8/m_{10}$

$m_{14} = Gr/m_{10}$, $m_{15} = m_{13} + m_{14}$,

$$m_{16} = \frac{L + \sqrt{L^2 + 4N}}{2},$$

$m_{17} = m_{15} - m_{12}$

$m_{18} = L^2\Pr - L^2\Pr - (M + 1/K)$,

$m_{19} = L^2Sc^2 - L^2Sc - (M + 1/K)$

$m_{20} = Gr/m_{18}$, $m_{21} = Grm_5/m_{19}$, $m_{22} = Gcm_4/m_{18}$,

$m_{23} = m_{20} + m_{22}$, $m_{24} = m_{23} + m_{21}$,

$$m_{25} = \frac{L + \sqrt{L^2 + 4(M + 1/K)}}{2}$$

4. Results and Discussions

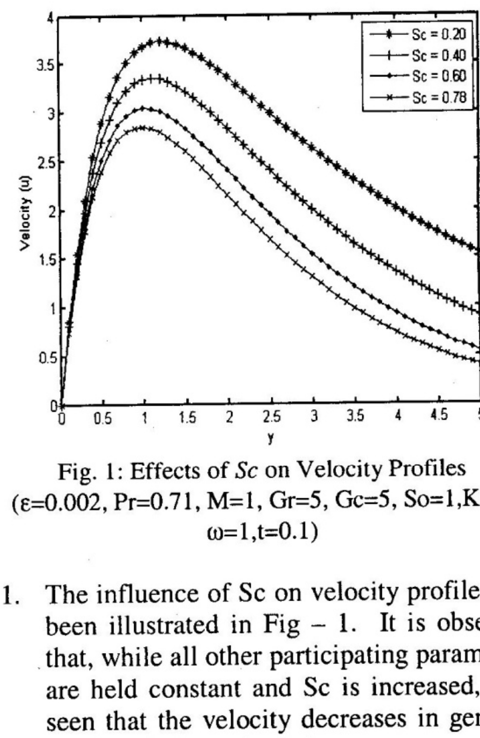

Fig. 1: Effects of Sc on Velocity Profiles (ε=0.002, Pr=0.71, M=1, Gr=5, Gc=5, So=1, K=5, ω=1, t=0.1)

1. The influence of Sc on velocity profiles has been illustrated in Fig – 1. It is observed that, while all other participating parameters are held constant and Sc is increased, it is seen that the velocity decreases in general. Further, it is noticed that as we move far away from the plate, the fluid velocity goes down.

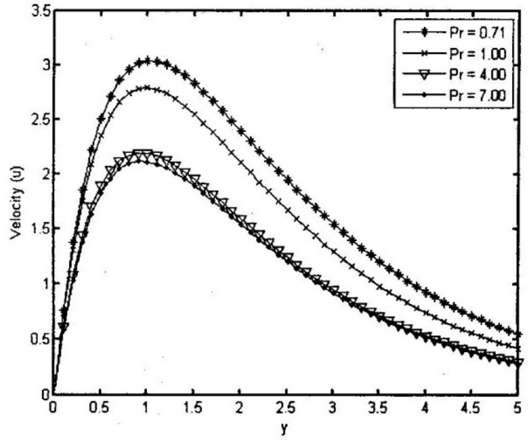

Fig. 2: Effects of *Pr* on Velocity Profiles (ε=0.002, Sc=0.60, M=1, Gr=5, Gc=5, So=1,K=5, ω=1,t=0.1)

2. The effect of Prandtl number on the velocity profiles has been illustrated in Fig – 2. It is observed that as the Prandtl number increases, the velocity decreases in general. The dispersion in the velocity profiles is found to be more significant for smaller values of Pr and not that significant at higher values of Pr.

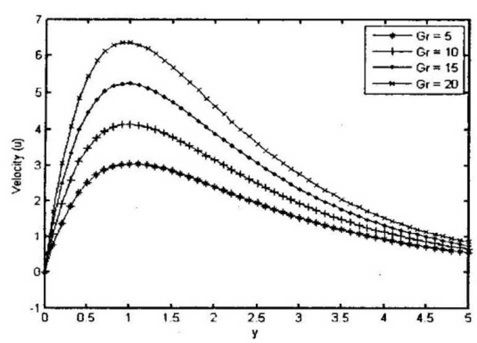

Fig. 3: Effects of *Gr* on Velocity Profiles (ε=0.002, Pr=0.71, M=1, Sc=0.60, Gc=5, So=1,K=5, ω=1,t=0.1)

3. The Effect of Gr on the velocity profiles is seen in Fig – 3. Increase in Gr contributes to the decrease in velocity when all other parameters that appear in the velocity field are held constant. Also it is noticed that as we move away from the plate the influence of Gr is not that significant.

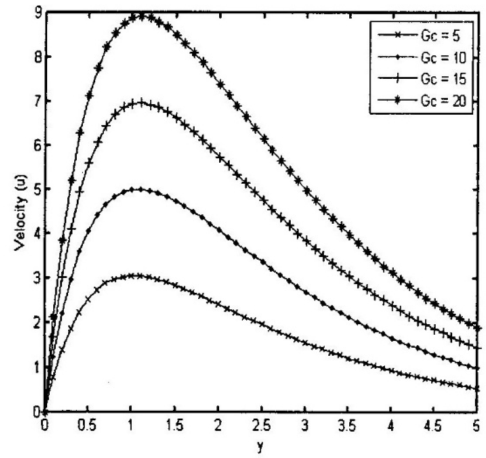

Fig. 4: Effects of *Gc* on Velocity Profiles (ε=0.002, Pr=0.71, M=1, Sc=0.60, Gr=5, So=1, K=5, ω=1,t=0.1)

4. The effect of Gc on the velocity profiles is observed in Fig -4. Increase in Gc is found to influence the velocity to increase. Also, it is seen that as we move far away from the plate it is seen that the effect of Gc is found to be not that significant.

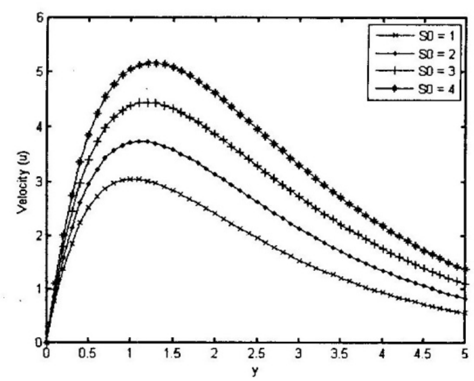

Fig. 5: Effects of *So* on Velocity Profiles (ε=0.002, Pr=0.71, M=1, Sc=0.60, Gc=5, Gr=5, K=5, ω=1,t=0.1)

5. The contribution of soret number on the velocity profiles is noticed in Fig – 5. The increase in sorect number contributes tp the increase in the velocity field. Further, it is noticed that the velocity decreases as we move away from the plate whuich is found to be independent of soret number.

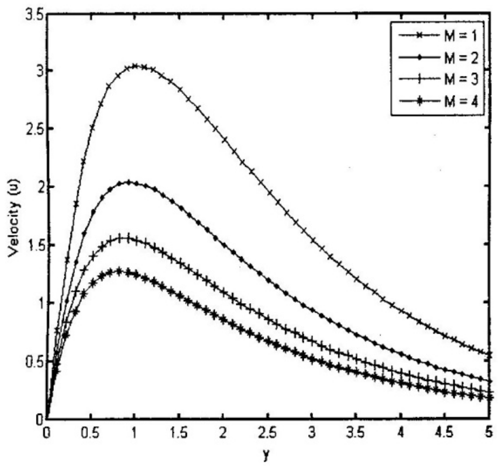

Fig. 6: Effects of *M* on Velocity Profiles
(ε=0.002, Pr=0.71, So=1, Sc=0.60, Gc=5, Gr=5, K=5, ω=1,t=0.1)

6. The influence of Magnetic field on the velocity profiles has been studied in Fig – 6. It is seen that the increase in the applied magnetic intensity contributes to the decrease in the velocity. Further, it is seen that the magnetic influence does not contribute significantly as we move away from the bounding surface.

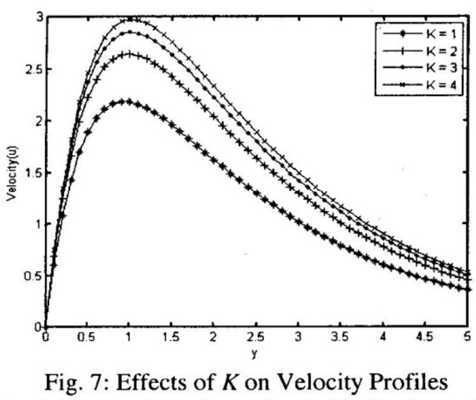

Fig. 7: Effects of *K* on Velocity Profiles
(ε=0.002, Pr=0.71, So=1, Sc=0.60, Gc=5, Gr=5, M=1,ω=1,t=0.1)

7. The influence of the porosity of the boundary on the velocity of the fluid medium has been shown in Fig – 7. It is seen that as the porosity of the fluid bed increases, the velocity decreases which is in tune with the realistic situation. Further, the porosity of the boundary do not influence the fluid motion as we move far away from the bounding surface.

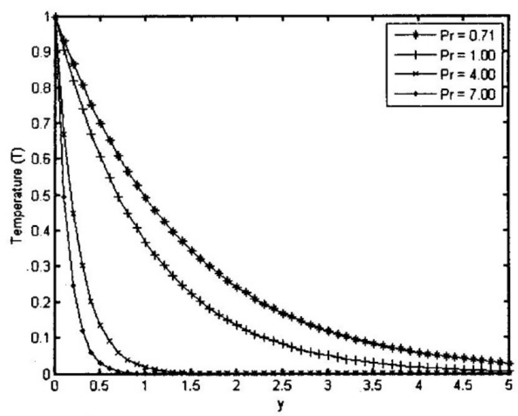

Fig. 8: Effects of *Pr* on Temperature Profiles
(ε=0.002, A=0.4,ω=1,t=π/2)

8. The Effect of Prandtl number on the temperature field has been illustrated in Fig - 8. It is observed that as the Prandtl number increases, the temperature in the fluid medium decreases. Also, as we move away from the boundary, the Prandtl number has not much of significant influence on the temperature. The dispersion is not found to be significant.

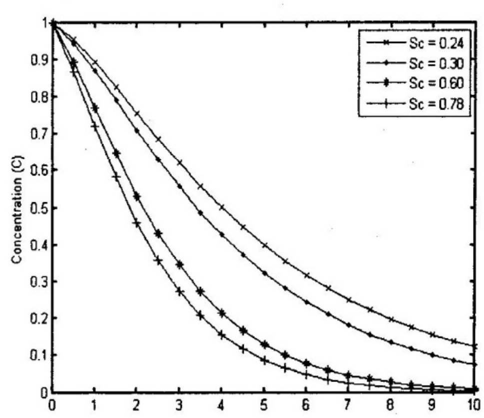

Fig. 9: Effects of *Sc* on concentration profiles
(ε=0.002, So=1, t=0.1,ω=1,A=0.4,Pr=0.71)

9. The influence of Sc on the concentration is illustrated in Fig – 9. It is observed that increase in Sc contributes to decrease of concentration of the fluid medium. Further,

it is seen that Sc does not contributes much to the concentration field as we move far away from the bounding surface.

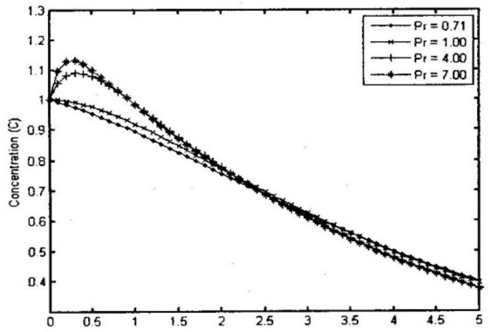

Fig. 10: Effects of *Pr* on concentration profiles (ε=0.002, So=1, t=0.1,ω=1,A=0.4,Sc=0.24)

10. The influence of Prandtl number on the concentration field is seen in Fig. 10. It is noticed that the increase in the Prandtl number though increases the concentration of the fluid medium in the initial stages; the effect is not predominant as we move away from the plate. However, it is noticed that as we move far away from the plate, irrespective of the Prandtl number, the concentration decreases.

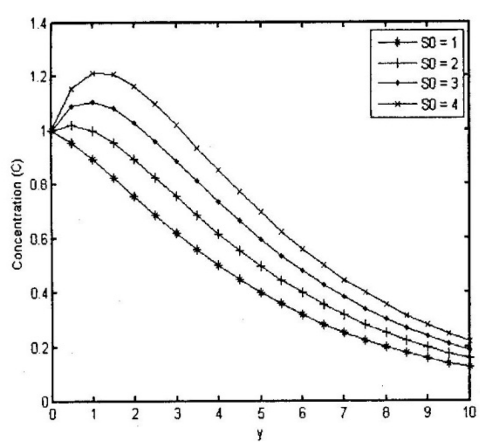

Fig. 11: Effects of *So* on concentration profiles (ε=0.002, Sc=0.24, t=0.1,ω=1,A=0.4,Pr=0.71)

11. The influence of So on the concentration of the fluid medium is seen in Fig. 11. In general it is noted that increase in Sorret number contributes to increase in concentration of the fluid medium. Further, the effect is found to be diminishing as we move away from the plate,

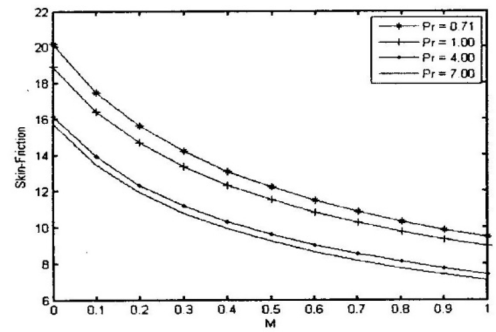

Fig. 12: Effects of Pr on concentration profiles (ε=0.002, Sc=0.24, t=pi/2, K=5, Gr= 5, Gc=5, ω=1,A=0.4, So=1)

12. The combined effect of Prandtl number and the magnetic influence on the skin friction is illustrated in Fig. 12. It is observed that the magnetic intensity influences the skin friction and is seen that as the magnetic intensity increases, the skin friction reduces drastically. Also, it is noted that for a constant magnetic field, as the Prandtl number increases and the magnetic influence is held constant, it is seen that the skin friction decreases. Also, for a constant Prandtl number, the increase in the magnetic intensity decreases the skin friction

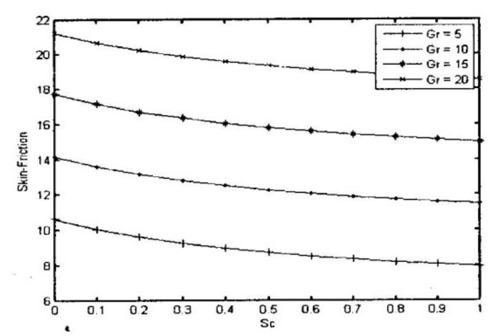

Fig. 13: Effects of Sc on concentration profiles (ε=0.002, M=1, t=pi/2, K=5, So=1, Gr= 5, Gc=5, ω=1, A=0.4,Pr=0.71)

13. The consolidated influence of Gr with respect to Sc over skin friction is seen in Fig. 14. It is seen that in general, increase in Gr contributes to increase of skin friction.

and is found to be independent of Sc. Further, for a constant Gr, as Sc increases the skin friction remains almost constant.

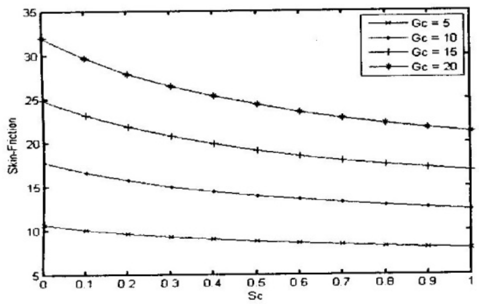

Fig. 14: Effects of Sc on concentration profiles (ε=0.002, M=1, t=pi/2, K=5, Gr= 5, So=1, ω=1, A=0.4,Pr=0.71)

14. The influence of Gc with respect to Sc on the skin friction is shown in Fig – 15. It is seen that for higher values of Gc, within the boundary layer the effect appears to be significant. In general it is seen that increase in Gc contributes to the decrease in the skin friction. For a constant value of Gc, as Sc increase, the skin friction almost remains constant. When the Sc is held constant and Gc is increased, the skin friction is found to be increasing.

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