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**Advances in Applied Science Research, 2011, 2 (6):460-469**

**ISSN: 0976-8610**
**CODEN (USA): AASRFC**

# Viscous Dissipation Effects on Unsteady free convection and Mass Transfer Flow past an Accelerated Vertical Porous Plate with Suction

**Bala Siddulu Malga* and Naikoti Kishan****

**Department of Mathematics, Holy Mary Institute Technology & Science, Keesara, Hyderabad*
***Department of Mathematics, University College of Science, Osmania University, Hyderabad*

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## ABSTRACT

*The unsteady free convection and mass transfer boundary layer flow past an accelerated infinite vertical porous plate with suction by taking into account the viscous dissipation is considered when the plate accelerates in its own plane. The governing equations were solved numerically by using Galerkin Finite element method. The flow phenomenon has been characterized with the help of flow parameters such as suction parameter (a), porosity parameter (α), Grashof number (Gr, Gc), Schmidt number (Sc) and Prandtl number (Pr), Eckert number (Ec). The effects of these parameters on the velocity field, temperature field and concentration distribution have been studied and the results are presented graphically and discussed quantitatively.*

**Keywords:** Free convection, mass transfer, porosity, suction, viscous dissipation, unsteady, finite element method.

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## INTRODUCTON

Free convection flow is often encountered in cooling of nuclear reactors or in the study of structure of stars and planets. Along with the free convection flow the phenomenon of mass transfer is also very common in the theories of stellar structure. The study of convective flow with mass transfer along a vertical porous plate is receiving considerable attention of many researchers because of its varied applications in the field of cosmical and geophysical sciences. Permeable porous plates are used in the filtration processes and also for a heated body to keep its temperature constant and to make the heat insulation of the surface more effective. The study of stellar structure on the solar surface is connected with mass transfer phenomena. Its origin is attributed to difference in temperature caused by the non homogeneous production of heat, which in many cases can rest not only in the formation of convective currents but also in violent explosions. Mass transfer certainly occurs within the mantle and cores of planets of the size of or larger than the earth. It is therefore interesting to investigate this phenomenon and to study in particular, the case of mass transfer on the free convection flow.

Several workers have studied the problem of free convection flow with mass transfer. Gupta *et al* [1] have studied Heat and mass transfer on a stretching sheet with suction or blowing. Raptis *et al* [2] have analyzed Free Convection and Mass Transfer Flow through Porous Medium bounded by an infinite Vertical limiting Surface with Constant Suction. Sattar [3] has discussed the free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with time dependent temperature and concentration. Singh *et al* [4] have investigated Free Convection Heat and Mass Transfer along a Vertical Surface in a Porous Medium. Das *et al* [5] have studied Numerical Solution of Mass Transfer Effects on Unsteady Flow past an Accelerated Vertical Porous Plate with Suction. Das *et al* [6] have discussed Mass Transfer effects on MHD Flow and Heat Transfer Past a Vertical Porous Plate through Porous Medium Under Oscillatory Suction and Heat Source. In all the investigations mentioned above, viscous dissipation is neglected. Such effects are important in geophysical flows and also in certain industrial operations and are usually characterized by the Eckret number. Gebhart B *et al* [7] have analyzed Viscous dissipation in external natural convection flows. Soundalgekar [8] has studied Viscous dissipative effects on unsteady free convective flow past a vertical porous plate with constant suction. Vajravelu [9] has studied the natural convection at a heated semi-infinite vertical plate with internal heat generation. Pop and Soundalgekar [10] have investigated the free convection flow past an accelerated infinite plate. Singh [11] has analyzed the MHD free convective flow past an accelerated vertical porous plate by finite difference method. Raptis *et al.* [12] have studied the unsteady free convective flow through a porous medium adjacent to a semi-infinite vertical plate using finite difference scheme. Singh and Soundalgekar [13] have investigated the problem of transient free convection in cold water past an infinite vertical porous plate. Jha [14] has reported the effects of applied magnetic field on transient convective flow in a vertical channel. Chandran *et al*. [15] have discussed the unsteady free convection flow with heat flux and accelerated motion. Soundalgekar *et al.* [16] have analyzed the transient free convection flow of a viscous dissipative fluid past a semi-infinite vertical plate. Kim [17] has investigated the problem of unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Postelnica *et al* [18] have discussed Free convection boundary-layer over a vertical permeable flat plate in a porous medium with internal heat generation. Israel-Cookey *et al*. [19] have studied the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. Mohameda *et al* [20] have analyzed Finite element analysis of hydromagnetic flow and heat transfer of a heat generation fluid over a surface embedded in a non-Darcian porous medium in the presence of chemical reaction.

Recently, Das *et al* [5] have studied Numerical Solution of Mass Transfer Effects on Unsteady Flow past an Accelerated Vertical Porous Plate with Suction. The present study is extension of work; here we considered the effects of viscous dissipation on unsteady free convection and mass transfer boundary layer flow past an accelerated infinite vertical porous flat plate with suction. In their paper they converted the governing equations which are in partial differential equations to ordinary differential equations by introducing similarity variables and then solved the governing equations by finite difference scheme. In the study we have solved the governing partial differential equations only by using the Galerkin finite element method. The effects of the flow parameters on the velocity, temperature and the concentration distribution of the flow field have been studied with the help of graphs. This type of problem has some significant relevance to geophysical and astrophysical studies.

**Mathematical Formulation**

Consider the unsteady flow of an incompressible viscous fluid past an accelerating vertical porous plate. Let the *x*-axis be directed upward along the plate and the y-axis normal to the plate. Let *u* and *v* be the velocity components along the *x*- and *y*- axes respectively. Let us assume that the plate is accelerating with a velocity $u = Ut$ in its own plane at time $t \geq 0$. Then the unsteady boundary layer equations in the Boussinesq's approximation, together with Brinkman's empirical modification of Darcy's law, are

$$\frac{\partial V'}{\partial y'} = 0 \tag{1}$$

$$\frac{\partial u'}{\partial t'} + V'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{k^*}u + g\beta(T - T_\infty) + g\beta^*(C' - C'_\infty) \tag{2}$$

$$\frac{\partial T}{\partial t'} + V'\frac{\partial T}{\partial y'} = k\frac{\partial^2 T}{\partial y'^2} + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3}$$

$$\frac{\partial C'}{\partial t'} + V'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

where $k$ is the thermal diffusivity, $\nu$ is the kinematic viscosity, $k^*$ is the permeability coefficient, β is the volumetric expansion coefficient for heat transfer, $\beta^*$ is the volumetric expansion coefficient for mass transfer, ρ is the density, *g* is the acceleration due to gravity, *T* is the temperature, $T_\infty$ is the temperature of the fluid far away from the plate, *C* is the concentration, $C_\infty$ is the concentration far away from the plate and *D* is the molecular diffusivity.

The necessary boundary conditions are

$$\left.\begin{array}{l} u' = U_0 t,\ \ T = T_w,\ \ C' = C_w \ \ at\ y = 0 \\ u' = 0,\ \ T = T_\infty,\ C' = C_\infty \ \ as\ \ y \to \infty \end{array}\right\} for\ \ t > 0 \tag{5}$$

We introduce the similarity variables and dimensionless quantities

$$\left.\begin{array}{c} t = \frac{t' U_0^2}{\nu},\ \ y = \frac{y' U_0}{\nu},\ \ (u, V, w) = \frac{(u', V', w')}{U_0}, \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)}, \\ C = \frac{(C' - C_\infty)}{(C_w - C_\infty)}, P_r = \frac{\nu}{k}\ \text{Prandtl number}, \mathrm{Ec} = \frac{U_0^2}{Cp(T_w - T_\infty)}\ \text{Eckert number} \\ \mathrm{Sc} = \frac{\nu}{D}, \text{Schmidth number}, \alpha = \frac{\nu^2}{k^* U_0^2}\ \ \text{Porosity parameter}, \\ G_r = \frac{\nu g\beta(T_w - T_\infty)}{U_0^3},\ \ \text{Modified Grashof number for heat transfer} \\ G_c = \frac{\nu g\beta^*(C_w - C_\infty)}{U_0^3}, \text{Modified Grashof number for mass transfer} \end{array}\right\} \tag{6}$$

Following Singh and Soundalgekar [13], we choose

$$V = -a\left(\frac{\nu}{t}\right)^{1/2} \tag{7}$$

where a > 0, the suction parameter, using equations (6) and (7), equations (1), (2), (3) and (4) become

$$\frac{\partial V}{\partial y} = 0 \tag{7}$$

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \alpha u + G_r\theta + G_c C \tag{8}$$

$$\frac{\partial \theta}{\partial t} + V\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} + \mathrm{Ec}\left(\frac{\partial u}{\partial y}\right)^2 \tag{9}$$

$$\frac{\partial C}{\partial t} + V\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} \tag{10}$$

and the boundary conditions (equation (5)) in the non-dimensional form are

$$\left.\begin{array}{l} u = 1,\ \theta = 1,\ C = 1 \text{ at } y = 0 \\ u = 0,\ \theta = 0,\ C = 0 \text{ at } y \to \infty \end{array}\right\} for\ t > 0 \qquad (12)$$

**Method of solution**

In order to investigate the numerical solution of the problem. The governing equations (8), (9) and (10) are coupled with boundary conditions (5). The numerical values of the dependent variables like velocity u, temperature θ and concentration C are obtained at the interesting points which are called degrees of freedom. The weak formulations of the non-dimensional governing equations are derived. The set of independent test functions to consist of the velocity, the temperature and the concentration are prescribed. The governing equations are multiplied by independent weighting functions and then are integrated over the spatial domain with the boundary. Applying integration by parts and making use of the divergence theorem reduce the order of the spatial derivatives and allows for the application of the boundary conditions. The same shape functions are defined piecewise on the elements. Using the Galerkin procedure, the unknown field's u, θ and C and the corresponding weighting functions are approximated by the same shape functions. The last step towards the finite element discretization is to choose the element type and the associated shape functions.

By applying the Galerkin finite element method for equation (8) over a typical two-noded linear element $(e)$ $(\, y_j \le y \le y_k\,)$ is

$$\int_{y_j}^{y_k} N^T\left[\frac{\partial^2 u}{\partial y^2} - \frac{\partial u}{\partial t} - V\frac{\partial u}{\partial y} - \alpha u + G_r\theta + G_c C\right] dy \qquad (13)$$

$$\int_{y_j}^{y_k}\left[\frac{\partial N}{\partial y}.\frac{\partial u^{(e)}}{\partial y} - N^T\left(-V\frac{\partial u^{(e)}}{\partial y} - \frac{\partial u^{(e)}}{\partial t} - \alpha u^{(e)} + R\right)\right] dy = 0 \qquad (14)$$

$$where\quad R = (G_r\theta + G_c C),\quad N = [N_j\,, N_k],\quad \emptyset^{(e)} = \begin{bmatrix} u_j \\ u_k \end{bmatrix},$$

$$u^{(e)} = N.\emptyset^{(e)},\ N_j = \frac{y_k - y}{l^{(e)}},\ N_k = \frac{y - y_j}{l^{(e)}},\ l^{(e)} = y_k - y_j = h$$

The element equation given by

$$\int_{y_j}^{y_k}\begin{bmatrix} N_j'N_j' & N_j'N_k' \\ N_k'N_j' & N_k'N_k' \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} dy + V\begin{bmatrix} N_jN_j' & N_jN_k' \\ N_kN_j' & N_kN_k' \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} dy + \begin{bmatrix} N_jN_j & N_jN_k \\ N_kN_j & N_kN_k \end{bmatrix}\begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix} dy +$$

$$\alpha\begin{bmatrix} N_jN_j & N_jN_k \\ N_kN_j & N_kN_k \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} dy - R\begin{bmatrix} N_j \\ N_k \end{bmatrix} dy = 0 \qquad (15)$$

$$\int_{y_j}^{y_k}\left(S^{(e)} + A^{(e)} + R\right) dy = 0 \qquad (16)$$

where $S^{(e)} = \begin{bmatrix} N_j'N_j' & N_j'N_k' \\ N_k'N_j' & N_k'N_k' \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + V\begin{bmatrix} N_jN_j' & N_jN_k' \\ N_kN_j' & N_kN_k' \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \alpha\begin{bmatrix} N_jN_j & N_jN_k \\ N_kN_j & N_kN_k \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix}$

$$A^{(e)} = \begin{bmatrix} N_jN_j & N_jN_k \\ N_kN_j & N_kN_k \end{bmatrix}\begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix}\quad and\ R^* = R\begin{bmatrix} N_j \\ N_k \end{bmatrix}$$

Here the prime and dot denote differentiation with respect to y and t. we obtain

$$S^{(e)} = \frac{1}{l^{(e)}}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \frac{V}{2}\begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \alpha\frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix}$$

$$A^{(e)} = \frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix}\quad and\ R^* = R\frac{l^{(e)}}{2}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

We write the element equation for the elements $y_{i-1} \leq y \leq y_i$ and $y_i \leq y \leq y_{i+1}$. Assembling these element equations, we get

$$\frac{1}{l^{(e)}}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{V}{2}\begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \alpha\frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} \dot{u}_{i+1} \\ \dot{u}_i \\ \dot{u}_{i+1} \end{bmatrix} = R\frac{l^{(e)}}{2}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \quad (17)$$

Now put row corresponding to the node i to zero, from equation (21) the difference schemes with $l^{(e)} = h$ is

$$\frac{h}{6}(\dot{u}_{i-1} + 4\dot{u}_i + \dot{u}_{i+1}) + \left(\alpha\frac{h}{6} + \frac{V}{2} - \frac{1}{h}\right)u_{i-1} + \left(\frac{2}{h} - 2\alpha\frac{h}{3}\right)u_i + \left(\alpha\frac{h}{6} - \frac{V}{2} - \frac{1}{h}\right)u_{i+1} = R^* \quad (18)$$

here $R^* = R\frac{l^{(e)}}{2}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$

Using the Cranck-Nicolson method to the equation (18), we obtain:

$$A_1u_{i-1}^{j+1} + A_2u_i^{j+1} + A_3u_{i+1}^{j+1} = A_4u_{i-1}^{j} + A_5u_i^{j} + A_6u_{i+1}^{j} + R^* \quad (19)$$

Similarly, the equations (9), (10) are becoming as follows:

$$B_1\theta_{i-1}^{j+1} + B_2\theta_i^{j+1} + B_3\theta_{i+1}^{j+1} += B_4\theta_{i-1}^{j} + B_5\theta_i^{j} + B_6\theta_{i+1}^{j} + R^{**} \quad (20)$$

$$C_1c_{i-1}^{j+1} + C_2c_i^{j+1} + C_3c_{i+1}^{j+1} + C_4c_{i-1}^{j} + C_5c_i^{j} + C_6c_{i+1}^{j} = 0 \quad (21)$$

The initial and boundary conditions (5) reduce to

$$\left.\begin{array}{l} u(i,0) = 0, \theta(i,0) = 0, C(i,0) = 0 \quad for\ all\ i \\ \left.\begin{array}{l} u(0,j) = 1, = 0, \theta(0,j) = 1, C(0,j) = 1 \\ u(100,j) = 0,\ \theta(100,j) = 0, C(100,j) = 0 \end{array}\right\} \quad for\ \ all\ j \end{array}\right\} \quad (22)$$

$A_1 = (1 - 6r + 3pV + k\alpha),\ A_2 = (4 + 12r + 4k\alpha), A_3 = (1 - 6r - 3pV + k\alpha),$
$A_4 = (1 + 6r - 3pV - k\alpha),\ A_5 = (4 - 12r - 4k\alpha), A_6 = (1 + 6r + 3pV - k\alpha),$
$B_1 = \left(1 - 6r\frac{1}{P_r} + 3pV\right),\ B_2 = \left(4 + 12r\frac{1}{P_r}\right), B_3 = \left(1 - 6r\frac{1}{P_r} - 3pV\right),$
$B_4 = \left(1 + 6r\frac{1}{P_r} - 3pV\right), B_5 = \left(4 - 12r\frac{1}{P_r}\right),\ B_6 = \left(1 + 6r\frac{1}{P_r} + 3pV\right),$
$C_1 = \left(1 - 6r\frac{1}{S_c} + 3pV\right),\ C_2 = \left(4 + 12r\frac{1}{S_c}\right), C_3 = \left(1 - 6r\frac{1}{S_c} - 3pV\right),$
$C_4 = \left(1 + 6r\frac{1}{S_c} - 3pV\right), C_5 = \left(4 - 12r\frac{1}{S_c}\right), C_6 = \left(1 + 6r\frac{1}{S_c} + 3pV\right),$
$R^{**} = \mathrm{Ec}\left(\frac{\partial \mathrm{u}}{\partial \mathrm{y}}\right)^2,$

Here $r = \frac{K}{h^2}$ where k, h is mesh sizes along y direction and time direction respectively. Index i refers to space and j refers to time. The mesh system consists of h=0.5 for velocity profiles and concentration profiles and k=0.25 has been considered for computations. In equation (19)-(21), taking i=1(1) n and using initial and boundary conditions (5), the following system of equation are obtained.

$$A_i X_i = B_i\ ,\ i = 1,2,3 \ldots. \quad (23)$$

Where $A_i$'s are matrices of order n and $X_i\ and\ B_i's$ are column matrices having n-components. The solution of above system of equations are obtained using Thomas algorithm for velocity, temperature and concentration. Also, numerical solutions for these equations are obtained by Mat lab-program. In order to prove the convergence and stability of Galerkin finite element method, the same Mat lab-program was run with slightly changed values of h and k and no significant change was observed in the values of $u, \theta, C$. Hence, the Galerkin finite element method is stable and convergent.

## RESULTS AND DISCUSSION

The velocity, temperature and concentration profiles have been computed by using the Galerkin finite element method. The numerical calculations are carried out for the effect of the flow parameters such as Suction parameter (a), Prandtl number (Pr), Schmidth number (Sc), Modified Grashof number for heat transfer (Gr), Modified Grashof number for mass transfer (Gc), Porosity parameter $(\alpha)$, Eckert number (Ec) on the velocity, temperature and concentration distribution of the flow fields are presented graphically in figure 1-6.

**1. Effect of suction parameter (a):-** Figure 1(a) shows the velocity profiles against y for several values of the suction parameter (a). The suction parameter is found to retard the velocity of the flow field at all points. The reduction in velocity at any point of the flow field is more as the suction parameter becomes larger.
Figure 5(a) depicts the temperature profiles for different values of suction parameter (a). The temperature profiles decreases with the increase of suction parameter (a). It is also noticed that from figure 6(c) concentration profiles also decreases with the increase of suction parameter $(a)$. One interesting inference of this finding is more suction leads to a faster decrease in the velocity, temperature and concentration profiles.

**2. Effect of porosity parameter (α):-** Figure 1(b) depicts the effect of porosity parameter $(\alpha)$ on the velocity of the flow field. The porosity parameter is to decelerate the velocity of the flow field at all points.

**3. Effect of Grashof numbers for heat and mass transfer (Gr, Gc):-** Figure 1(c) it can be seen that the velocity of the flow field is increase with the increase of Grashof numbers for heat transfer (*Gr*) and mass transfer (*Gc*) along with Eckert number (Ec).

**4. Effect of Schmidt number (Sc):-** The nature of velocity profiles in presence of foreign pecies such as $H_2$ ($Sc$ = 0.22), $CO_2$ ($Sc$ = 0.30) and $NH_3$ ($Sc$ = 0.78) is shown in figure 1(d). The velocity profiles decreases with the increase of Schmidt number (Sc). The concentration profiles decrease with the increase of Schmidt number (Sc) shown in fig 6(a).

**5. Effect of Prandtl number (Pr):-**The effect of Prandtl number (*Pr*) figure 5(c). It is observed from the figure that the temperature of the flow field decreases in magnitude as Prandtl number *(Pr)* increases.

**6. Eckert number (Ec): -** The effect of Eckert number (Ec) on the velocity profiles are shown in figure 2, 3, 4 for different values of Suction parameter (a), Prandtl number (Pr), Schmidth number (Sc), Modified Grashof number for heat transfer (Gr), Modified Grashof number for mass transfer (Gc), Porosity parameter $(\alpha)$. The effect of Eckert number (Ec) is to increases the velocity flow filed is observed from the figures. It is cleared from the figures the Eckert number (Ec) effect is negligible for larger values of suction parameter (a) or for the larger suction parameter (a=2). It is also noticed that the temperature profiles are shown in figure 5, for different values of Ec. It is evident from that effect Eckert number (Ec) is to lead to increase the temperature of the flow field at all the points.

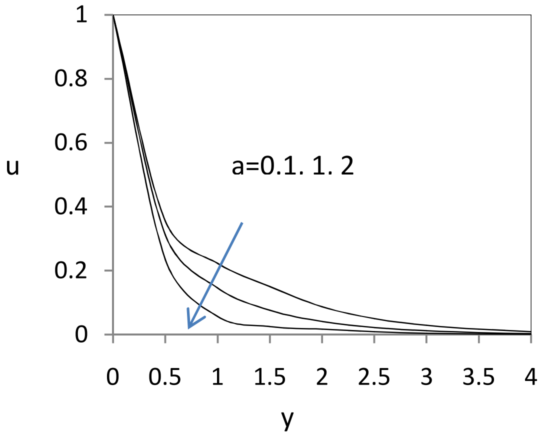


Fig.1 (a): Velocity profiles for different values of **a** with α=1,Gr=1,Gc=1, Pr=0.71, Sc=0.22,. t=0.5

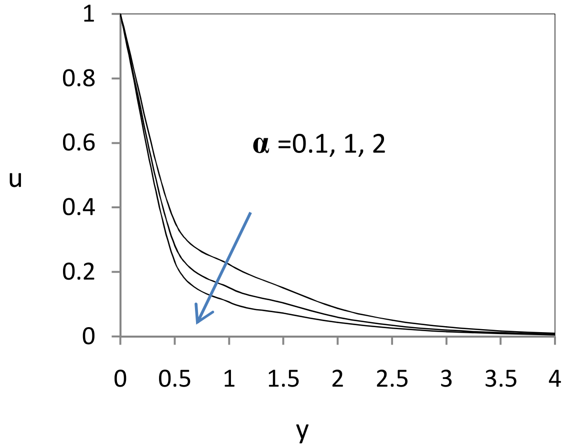


Fig.1(b): Velocity profiles for different values of **α** with a=0.1,Gr=1, Gc=1, Pr=0.71, Sc=0.22, t=0.5

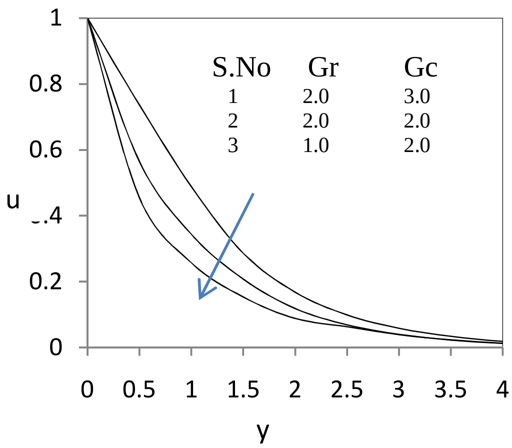


Fig.1 (c): Velocity profiles for different values of **Gr and Gc** with α=1, a=0.1, Pr=0.71, Sc=0.22. t=0.5

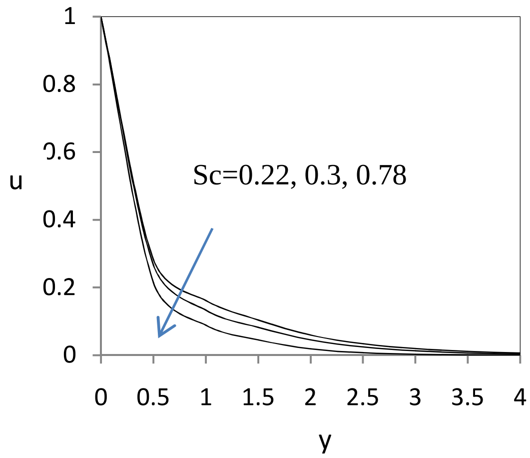


Fig.1 (d): Velocity profiles for different values of **Sc** with α=1, a=0.1, Gr=1, Gc=1, Pr=0.71, t=0.5

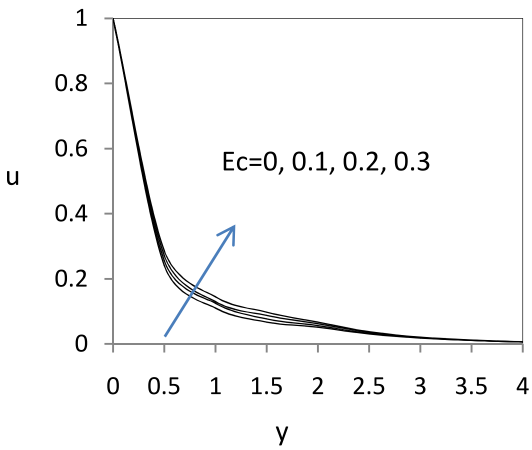


Fig 2(a): Velocity profiles for different values of **Ec** with **a=0.1**, Pr=0.71, Sc=0.22, Gr=1.0, Gc=1.0, α=1. t=0.5

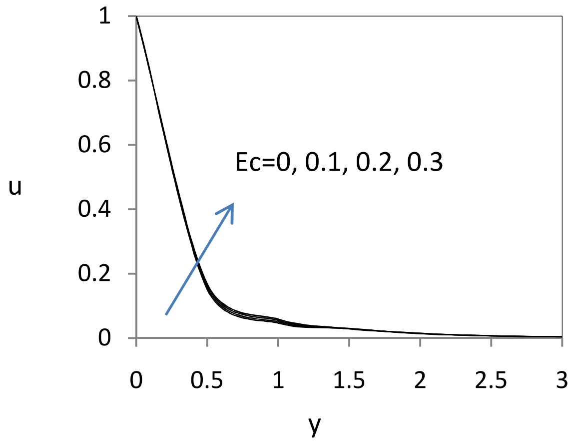


Fig 2(b): Velocity profiles for different values of **Ec** with **a=2.0,** Pr=0.71, Sc=0.22, Gr=1.0, Gc=1.0, α=1, t=0.5

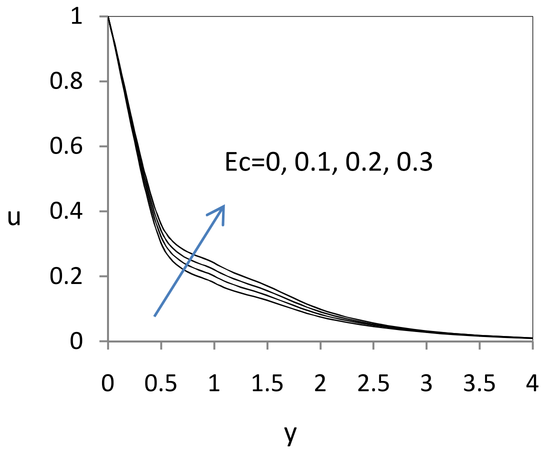


Fig 3(a): Velocity profiles for different values of **Ec** with **α=0.1,** t=0.5, a=0.1 Pr=0.71, Sc=0.22, Gr=1.0, Gc= 1.

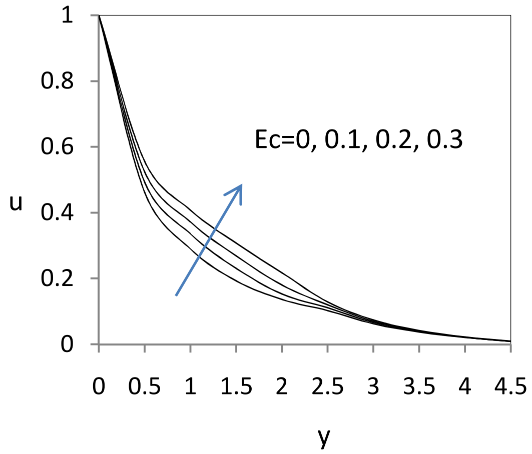


Fig 3(b): Velocity profiles for different values of **Ec** with **α= -1,** a=0.1,.0, Pr=0.71, Sc=0.22, Gr=1.0, Gc=1.0, t=0.5

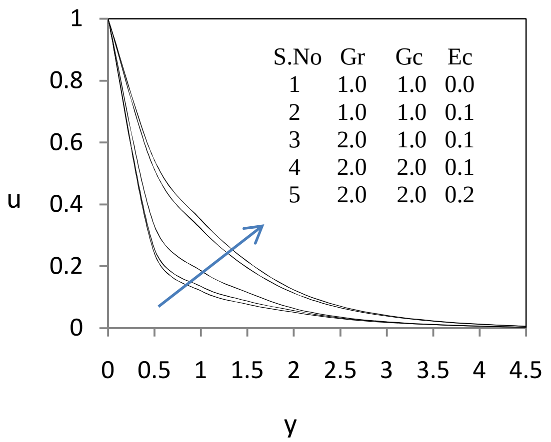


Fig 4(a): Velocity profiles for different values of **Ec , Gr &Gc** with α=1, Pr=0.71,Sc=0.22, a=0.1, t=0.5

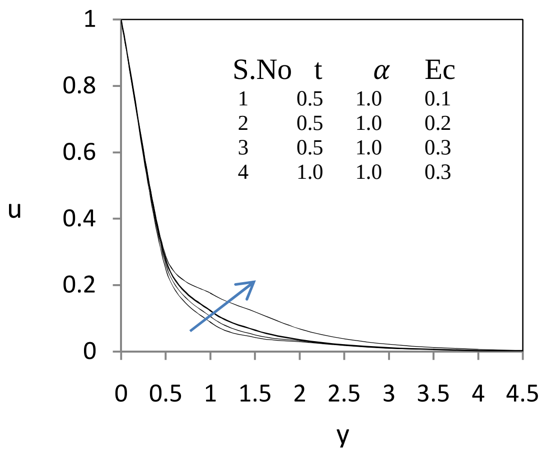


Fig 4(b): Velocity profiles for different values of **Ec, & α, t,** with Gr=1 & Gc=1**,** Pr=0.71, Sc=0.22, a=0.1.

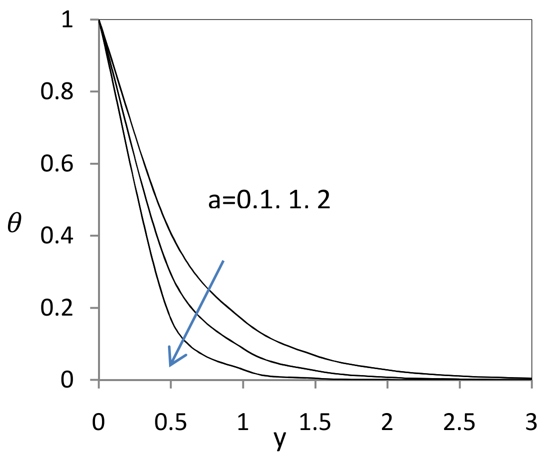


Fig.5 (a): Temparature profiles for different values of **a** with Pr=0.71. t=0.5

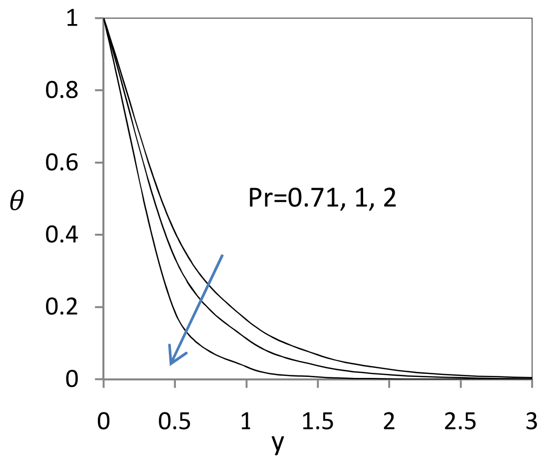


Fig.5 (b): Temparature profiles for different values of **Pr** with a=0.1, t=0.5

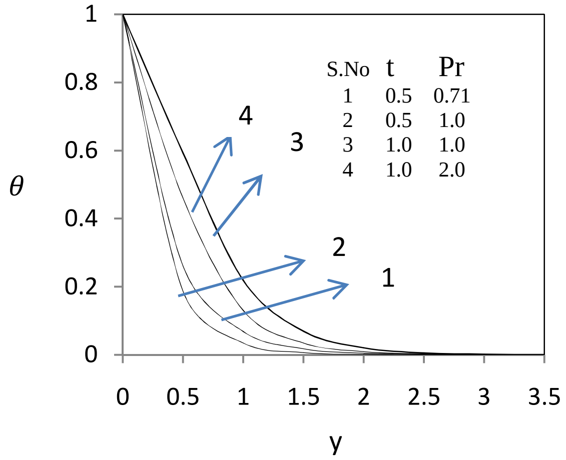


Fig 5(c): Temperature profiles for different values of **Pr & t** with a=0.1.

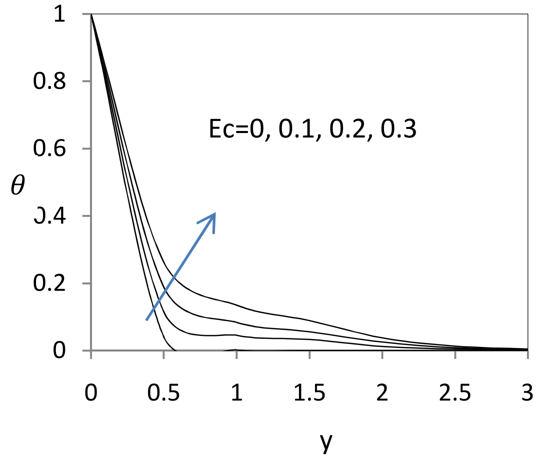


Fig 5(d): Temperature profiles for different values of **Ec** with **Pr=2.0,** a=0.1, t=0.5.

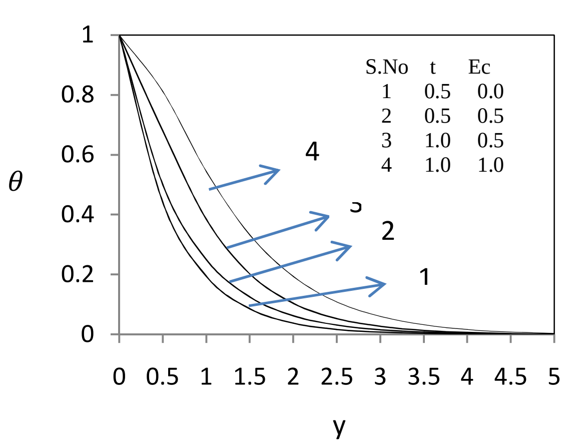


Fig 5(e): Temperature profiles for different values of **Ec & t** with a=0.1, Pr=0.71.

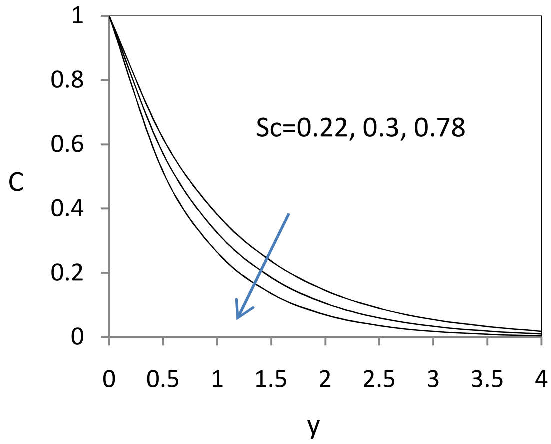


Fig.6 (a): Concentration profiles for different values of Sc with a=0.1,t=0.5.

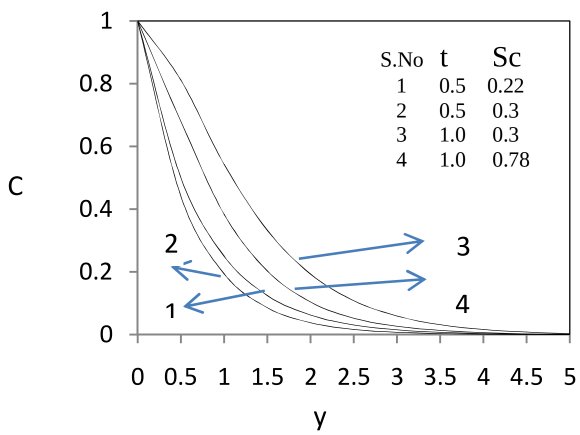


Fig 6(b): Concentration profiles for different values of **Sc & t** with a=0.1, t=0.5

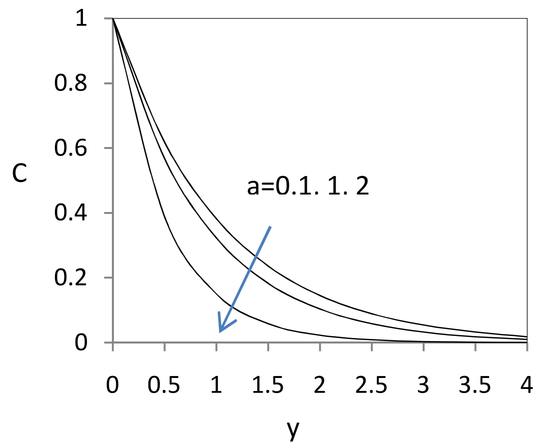


Fig.6 (c): Concentration profiles for different values of **a** with Sc=0.22, t=0.5.

## CONCLUSION

The above study brings out the following inferences of physical interest on the velocity, temperature and concentration distribution of the flow fields.

- The greater suction leads to reduction in the velocity, temperature and concentration of the flow fields.
- The porosity parameter ($\alpha$) retards the velocity of the flow field at all points. The concentration profiles decreases with the increase of Schmidth number (Sc).
- The effect of Prandtl number (*Pr*) is to reduce the temperature flow field at all points.
- The Grashof number for heat transfer (*Gr*) and mass transfer (G*c*) accelerate the velocity of the flow field at all points. But the increase in velocity of the flow field is more significant in presence of mass transfer.
- The effect of Eckert number (Ec) is to increase the velocity flow field. The effect of Eckert number (Ec) is negligible when there is a greater suction. The effect of Eckert number (Ec) is increase the temperature profiles greatly.
- The velocity profiles increases with the increase of time t, the temperature profiles and concentration profiles are also increases with the increase in the time t.

## REFERENCES

[1] P.S. Gupta and A.S. Gupta, *Can J Chem Eng*, 55, 744–746, **1977.**
[2] A.Raptis.,G.T Zivnidis,N.Kafousis, *Letters in Heat and Mass Transfer*, 8,5,417-424,**1981**.
[3] M. A. Satter, *Int.J. Pure Appl.Math*. 23, 759-766, **1994.**
[4] Singh, N.P., Singh, A.K., and Kumar, R. *Indian Journal of Theoretical Physics*, 44,255-264, **1996.**
[5] S.S. Das, S.K. Sahoo and G.C. Dash, *Bull. Malays. Math. Sci. Soc*.,2, 29,(1), 33–42, **2006.**
[6] S.S.Das, A.Satapathy, J.K Das, J.P.Panda, *Int.J.Heat and Mass Transfer*.52, 25-26, 5962-5969, 2009.
[7] Gebhart B. and Mollendorf J. *J. Fluid Mech*. 38, 97-107,**1969**.
[8] Soundalgekar. V.M. *Int. J. Heat Mass Transfer*. 15, 1253-1261, 1972.
[9] K. Vajravelu, *Acta Mech*. 34, 153-159, **1979**
[10] I.Pop and V.M.Soundalgekar, *Z.Angew.Math.Mech*, 60,167-168, **1980.**
[11] A. K. Singh, *Astrophys. Space Sci*. 94, 395-400, **1983.**
[12] A. Raptis, A. K. Singh and K. D. Rai, *Mech.Res. Comm*.,14, 9-16, **1987.**
[13] A. K. Singh and V. M. Soundalgekar, *Int. J. of Energy Res*. 14, 413-420, **1990.**
[14] B.K.Jah, *J.Pure Appl.Math.* 29,441-445,**1998.**
[15] P.Chandran,N.C.Sacheti and A.K.Singh, *J.Phys.Soc.Japan* 67,124-129,**1998.**
[16] V. M. Soundalgekar, B. S. Jaisawal, A. G. Uplekar and H. S. Takhar, *J. Appl. Mech. Engng*. 4, 203-218, **1999**.
[17] Y.J.Kim, *Int.J.Engg.Sci*.38, 833-445, **2000.**
[18] A. Postelnica, T. Grosan and I. Pop, *Int.J.Commun Heat Mass Transfer*, 27, 729–738, **2000.**
[19] C.Israel-Cookey, A.Ogulu and V.B.Omubo-pepple, *Int.J.Heat Mass transfer* 46, 2305-2311, **2003.**
[20] R.A. Mohameda, Ibrahim A. Abbasb, S.M. Abo-Dahaba, *Communications in Nonlinear Science and Numerical Simulation.* 14, 4, 1385-1395, **2009.**