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# Radiation Effect on Unsteady Mixed Convective MHD Flow of Heat and Mass Transfer Over An Accelerated Infinite Vertical Porous Plate With Suction And Chemical Reaction

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***Abstract***

*This paper analyzes the unsteady mixed convective MHD flow of a viscous incompressible electrically conducting fluid past an accelerated infinite vertical porous flat plate with suction in presence of radiation. The governing equations are solved both analytically and numerically using finite difference scheme. The flow phenomenon has been characterized with the help of flow parameters such as magnetic parameter (M), suction parameter (a), Grashof number for heat and mass transfer (Gr, Gc), Schmidt number (Sc), radiation parameter (R) and Prandtl number (Pr). The effects of these parameters on the fluid velocity, temperature, concentration distribution, skin friction and heat flux have been analyzed and the results are presented graphically and discussed quantitatively. This type of problem is significantly relevant to geophysical, astrophysical and cosmical studies.*

***Keywords:*** *MHD flow, mixed convection, mass transfer, accelerated plate,chemical reaction, thermal radiation.*

***MSC 2010 No.*** *: 76E25, 76E06, 80A20, 74K20 74FO5, 74F25 ,78A40*

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## I. Introduction

The problem of mixed convective MHD flow with mass transfer has been given much importance because of its possible applications to nuclear research and in the study of stars and planets. These problems are of general interest in the field of geophysical and astrophysical studies. In view of these applications a series of investigations were made to study the flow past a vertical wall.

Convective flows under different physical situations have become a subject of interest of several researchers. Alam and Sattar (1999) analyzed the transient MHD heat and mass transfer flow in a rotating system in presence of thermal diffusion. Brinkman (1947) estimated the viscous force imparted by a flowing fluid in a dense swarm of particles. Chandran et al. (1998) studied the unsteady hydromagnetic free convection flow with heat flux and accelerated boundary motion. Choudhury and Das (2000) investigated the magnetohydrodynamic boundary layer flow of a non-Newtonian fluid past a flat plate. Das and his associates (2006) solved numerically the mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Dash and Das (1999) analyzed the effect of Hall current on MHD flow along an accelerated porous flat plate with mass transfer and internal heat generation. Hasimoto (1957) discussed the boundary layer growth on a flat plate with suction or injection. Makinde et al. (2003) have explained the unsteady free convection flow with suction on an accelerating porous plate.

Mansutti et al. (1993) have analyzed the steady flows of non-Newtonian fluids past a porous plate with suction or injection. Pathal and his co-workers (2005) discussed the unsteady mass, momentum and heat transfer in MHD free convection flow past a vertical plate suddenly set in motion. Raptis et al. (1987) have studied the unsteady free convective flow through a porous medium adjacent to a semiinfinite vertical plate using finite difference scheme. Sattar (1994) reported the free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with time dependant temperature and concentration. Sharma and Pareek

(2002) have discussed the steady free convection MHD flow past a vertical porous moving surface. Singh and Soundalgekar (1990) investigated the transient free convection effect in cold water past an infinite vertical porous plate. Soundalgekar (1974) analyzed the free convection effects on steady MHD flow past a vertical porous plate. Das and Mitra (2009) studied the unsteady mixed convective MHD flow and mass transfer past an accelerated infinite vertical porous plate with suction. Gangadhar and Bhaskar Reddy (2013) has analyzed by chemically reacting MHD boundary layer flow of heat and mass transfer over a moving vertical plate in a porous medium with suction. Bhattacharyya (2011) studied the effects of heat source/sink on MHD flow and heat transfer over a shrinking sheet with mass suction

The role of thermal radiation is of major importance in the design of many advanced energy convection systems operating at high temperature. Thermal radiation within the systems is usually the result of emission by hot walls and the working fluid. Convective boundary layers are often controlled by injection or withdrawing fluid through porous bounding surface. This can lead to enhanced heating or cooling of the system and can help to delay the transition from laminar to turbulent flow. The effects of blowing and suction on free convection boundary layers with radiation have been studied by Hossain et al. (1999), who studied the effect of radiation on free convection from a vertical porous plate. Abd El-Naby et al. (2004) presented a finite difference solution of radiation effects on MHD unsteady free convection flow over a vertical porous plate. Raptis (1998) analyzed the thermal radiation and free convection flow through a porous medium by using perturbation technique. Bakier and Gorla (1996) investigated the effect of thermal radiation on mixed convection from horizontal surfaces in saturated porous media

The study reported herein considers the unsteady mixed convective MHD flow of a viscous incompressible electrically conducting fluid past an accelerated infinite vertical porous flat plate with suction in presence of radiation. The governing equations are solved both analytically and numerically using finite difference scheme. The flow phenomenon has been characterized with the help of flow parameters and the\ effects of these parameters on the velocity field, temperature field, and skin friction, Nusselt number and Sherwood number have been analyzed and the results are presented graphically and discussed quantitatively with the help of graphs and tables. This type of problem has some relevance in geophysical, astrophysical and cosmical studies.

## II. Mathematical Formulation

Consider the unsteady mixed convective mass transfer flow of a viscous incompressible electrically conducting fluid past an accelerating vertical infinite porous flat plate in presence of a transverse magnetic field $B_0$. 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 x- and y-axes respectively. We assume that the plate is accelerating with a velocity u = Ut in its own plane at time t ≥ 0. The level of concentration of foreign mass is assumed to be low, so that the Soret and Dufour effects are negligible. Under these assumptions along with the Boussinesq and boundary layer approximations, the system of equations, which models the flow is given by

Continuity equation

$$\frac{\partial v}{\partial y} = 0 \qquad (2.1)$$

Linear momentum equation

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B^2}{\rho}u + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) \qquad (2.2)$$

Energy equation

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \qquad (2.3)$$

Species equation

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} \qquad (2.4)$$

The boundary conditions for the velocity, temperature and concentration fields are

$$u = Ut, T = T_w, C = C_w \quad \text{at} \quad y = 0$$

$$u \to 0, T \to T_\infty, C \to C_\infty \quad \text{as} \quad y \to \infty \quad \text{for} \quad t \to \infty \qquad (2.5)$$

where, $v$ is the kinematic viscosity, $k$ is the thermal diffusivity, $\beta$ is the volumetric coefficient of expansion for heat transfer, $\beta^*$ is the volumetric coefficient of expansion for mass transfer, $\rho$ is the density, $\sigma$ is the electrical conductivity of the fluid, $g$ is the acceleration due to gravity, $q_r$ is the radiative heat flux, $T$ 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 of the fluid far away from the plate and $D$ is the molecular diffusivity.

By using the Rosseland approximation (Brewster (1992)), the radiative heat flux $q_r$ is given by

$$q_r = -\frac{4\sigma^*}{3K'}\frac{\partial T^4}{\partial y} \tag{2.6}$$

where $\sigma^*$ is the Stefan-Boltzmann constant and $K'$ - the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If temperature differences within the flow are sufficiently small, then Equation (2.6) can be linearized by expanding $T^4$ into the Taylor series about $T_\infty$, which after neglecting higher order terms takes the form

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{2.7}$$

In view of equations (2.6) and (2.7), equation (2.3) reduces to

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = k\left(1 + \frac{16\sigma^* T_\infty^3}{3kK'}\right)\frac{\partial^2 T}{\partial y^2} \tag{2.8}$$

In order to transform equations (2.2) (2.8) and (2.4) into a set of ordinary differential equations, the following similarity transformations and dimensionless variables are introduced.

$$\eta = \frac{y}{2\sqrt{\upsilon t}}, u = Utf(\eta), Gr = 4g\beta\frac{T_w - T_\infty}{U}, Gc = 4g\beta^*\frac{C_w - C_\infty}{U}$$
$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, M = \frac{\sigma B_0^2}{\rho}\frac{\upsilon}{v^2}, \Pr = \frac{\upsilon}{\alpha}, Sc = \frac{\upsilon}{D}, R = \frac{4\sigma^* T_\infty^3}{K'k} \tag{2.9}$$

where $f(\eta)$ is the dimensionless stream function, $\theta$ - the dimensionless temperature, $\phi$ - the dimensionless concentration, $\eta$ - the similarity variable, $M$ - the magnetic parameter, $Pr$ - the Prandtl number, $Sc$ - the Schmidt number and $R$- the radiation parameter.

Following Hasimoto (1957), Das et al. (2006) and Singh and Soundalgekar (1990), we choose

$$v = -a\left(\frac{\upsilon}{t}\right)^{1/2} \tag{2.10}$$

where $a > 0$ is the suction parameter.

In view of equations (2.9) and (2.10), the equations (2.2), (2.4) and (2.8) transform into

$$f'' + 2(\eta + a)f' - 4(1 + a^2 M)f + Gr\theta + Gc\phi = 0 \tag{2.11}$$

$$\left(1 + \frac{4}{3R}\right)\theta'' + 2(\eta + a)\Pr\theta' = 0 \tag{2.12}$$

$$\phi'' + 2(\eta + a)Sc\phi' = 0 \tag{2.13}$$

The transformed boundary conditions can be written as

$$f = 1, \theta = 1, \phi = 1 \quad \text{at} \quad \eta = 0$$
$$f = \theta = \phi = 0. \quad \text{as} \quad \eta \to \infty \tag{2.14}$$

The skin friction at the wall is given by

$$\tau = \rho\upsilon\left(\frac{\partial u}{\partial y}\right)_{y=0} = -\rho U\frac{\sqrt{\upsilon t}}{2}f'(0) \tag{2.15}$$

In non-dimensional form, we get

$$\tau' = -\frac{2\tau}{\rho U\sqrt{\upsilon t}} = -f'(0) \tag{2.16}$$

The non-dimensional local heat flux in terms of Nusselt number (Nu) at the plate is given by

$$Nu = \frac{2q_w\sqrt{\upsilon t}}{k(T_w - T_\infty)} = -\theta'(0) \qquad (2.17)$$

The non-dimensional local heat flux in terms of Nusselt number (Nu) at the plate is given by

$$Nu = \frac{2q_w\sqrt{\upsilon t}}{k(T_w - T_\infty)} = -\theta'(0)$$

## III. Method Of Solution

Solving equations (2.11), (2.12) and (2.13) exactly by error function subject to boundary conditions (2.14), we get

$$\theta = \frac{erfc\left((\eta + a)\sqrt{\Pr\Gamma}\right)}{erfc\left(a\sqrt{\Pr\Gamma}\right)} \qquad (3.1)$$

$$\phi = \frac{erfc\left((\eta + a)\sqrt{Sc}\right)}{erfc\left(a\sqrt{Sc}\right)} \qquad (3.2)$$

where $\Gamma = \frac{3R}{3R + 4}$

Equation (2.11) is solved employing finite difference scheme. In order to solve equation (2.11) by this method, we set up the following difference approximations:

$$f' = \frac{f_{i+1} - f_{i-1}}{2h},\ f'' = \frac{f_{i+1} - 2f_i + f_{i-1}}{h^2} \qquad (3.3)$$

Introducing these difference approximations (3.3) in equation (2.11), we obtain

$$A_0 f_{i+1} + A_1 f_i + A_2 f_{i-1} = B_1 + B_2 \qquad (3.4)$$

Where

$$A_0 = \frac{1 + h(\eta_i + a)}{h^2},\ A_1 = -\frac{2 + 4h^2(1 + a^2M)}{h^2}$$
$$A_2 = \frac{1 - h(\eta_i + a)}{h^2},\ B_1 = -Gr\theta,\ B_2 = -Gc\phi \qquad (3.5)$$

$$\eta_i = ih,\ h = \frac{L}{N+1},\ 0 \le \eta_i \le L \qquad (3.6)$$

We take L = 2.0 and N = 200, since it lies well outside the boundary layer.

## IV. Results And Discussion

The problem of unsteady mixed convective mass transfer MHD flow past an accelerated infinite vertical porous flat plate with suction and radiation has been formulated, analyzed and solved both analytically and numerically using error function and finite difference scheme. The effects of the flow parameters such as magnetic parameter (*M*), suction parameter (a), Grashof number for heat and mass transfer (Gr, Gc), Schmidt number (Sc), radiation parameter (R) and Prandtl number (Pr) on the velocity, temperature and concentration profiles of the flow field are presented with the help of velocity profiles (Figs.1-5), temperature profiles (Figs.6-8) and concentration profiles (Figs.9, 10). The non-dimensional skin friction at the wall and Nusselt number and Sherwood number are also discussed (Figs. 11-13). The velocity of the flow field varies to an appreciable extent with the variation of the flow parameters.

Fig.1 shows the effect of suction parameter (a) on the velocity profiles of the flow field. 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 faster as the suction parameter becomes larger. One interesting inference of this finding is greater suction leads to a faster reduction in the velocity of the flow field. Keeping the other parameters of the flow field constant, the magnetic parameter is varied and its effect is studied. The magnetic parameter is found to retard the velocity at all points of the flow field. Higher the parameter, the sharper is the reduction in velocity of the flow field. The effect of Grashof number for heat transfer (Gr) on the velocity of the flow field is shown in Fig.3. Here, the velocity of the flow field is plotted against $\eta$ for four different values of the Grashof number keeping other parameters of the flow field constant. A study of the curves of the said figure shows that the

Grashof number for heat transfer (Gr) accelerates the velocity of the flow field at all points. Fig.4 depicts the effect of Grashof number for mass transfer (Gc) on the velocity of the flow field. It is observed that the Grashof number for mass transfer has an accelerating effect on the velocity of the flow field at all points. Fig.5 shows the effect of radiation parameter (R) on the velocity profiles of the flow field. The reduction in velocity at any point of the flow field is faster as the radiation parameter becomes larger.

The temperature of the flow field varies vastly with the variation of suction parameter (a), radiation parameter (R) and the Prandtl number (Pr).These variations in the temperature of the flow field are shown in Fig.6, 7 and 8. Fig.6 presents the temperature profiles against η for four different values of the suction parameter (a) keeping R and Pr as constant. The suction parameter is found to decrease the temperature of the flow field at all points. Fig.7 presents the temperature profiles against η for four different values of the radiation parameter (R) keeping *a* and Pr as constant. The radiation parameter is found to decrease the temperature of the flow field at all points. It is further observed that cooling of the plate is faster as the radiation parameter becomes larger. Thus, larger suction leads to faster cooling of the plate. Fig.8 shows the plot of temperature of the flow field against η for different values of Prandtl number (Pr). It is observed that the temperature of the flow field decreases in magnitude as Pr increases. Thus, higher Prandtl number (Pr) leads to faster cooling of the plate.

The concentration distribution of the flow field is found to change more or less with the variation of suction parameter (a) and the Schmidt number (Sc). These variations are shown graphically in Fig.7 and 8 respectively. Fig.9 depicts the variation in the concentration distribution of the flow field against the non-dimensional distance $\eta$ for four different values of the suction parameter. The suction parameter is found to decrease the concentration boundary layer of the flow field at all points. Greater suction leads to a sharper reduction in the concentration boundary layer of the flow field. The variation in the concentration boundary layer of the flow field due to different values of Schmidt number is shown in Fig.10. The effect of Schmidt number is to decrease the concentration distribution of the flow field. It is further found that the decrease in the concentration boundary layer of the flow field is more significant in presence of heavier diffusing species.

Figs. 11 show the variation of the skin-friction with the suction parameter and magnetic field parameter. It is observed that the skin-friction increases with an increase in the suction parameter or magnetic parameter. Figs. 12 show the variation of the heat transfer rate with the suction parameter or Prandtl number. It is observed that the heat transfer rate increases with an increase in the suction parameter or Prandtl number. Figs. 13 show the variation of the mass transfer rate with the suction parameter and Schmidt number. It is observed that the Sherwood number increases with an increase in the suction parameter or Schmidt number. In Table 1, the present results are compared with those of Das and Mitra (2009) and found that there is a perfect agreement.

Graphs:

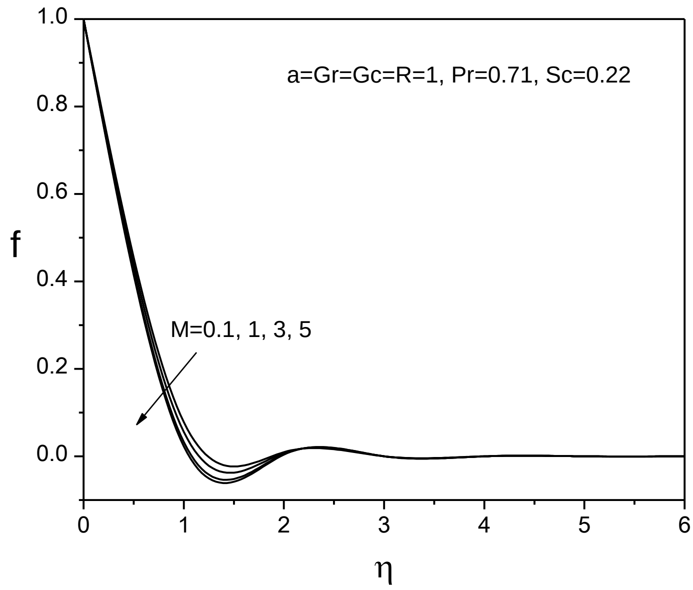


**Fig.1 Velocity profiles for different values of *M***

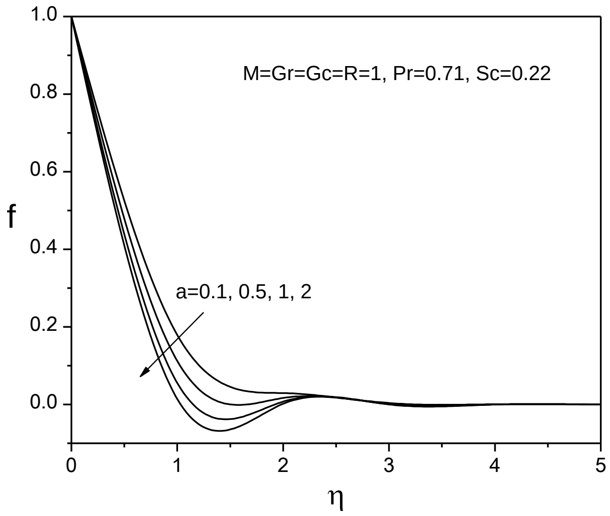


**Fig.2 Velocity profiles for different values of *a***

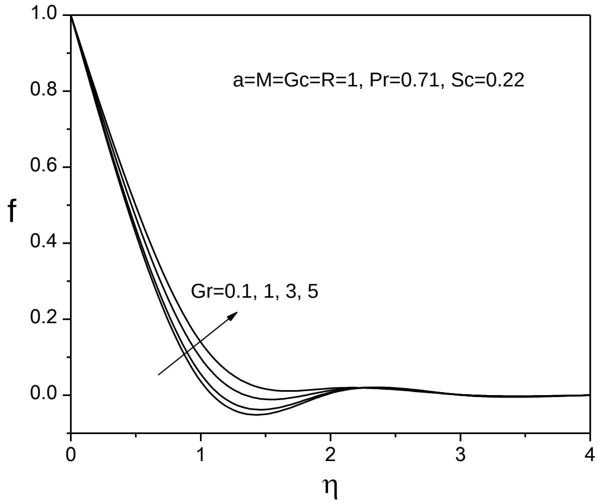


**Fig.3 Temperature profiles for different values of *Gr***

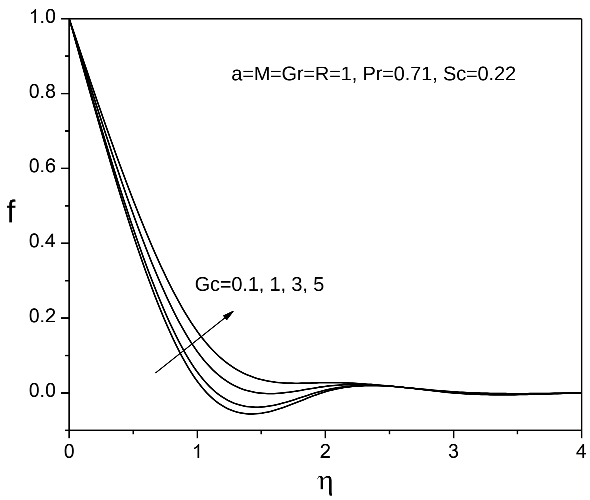


**Fig.4 Temperature profiles for different values of *Gc***

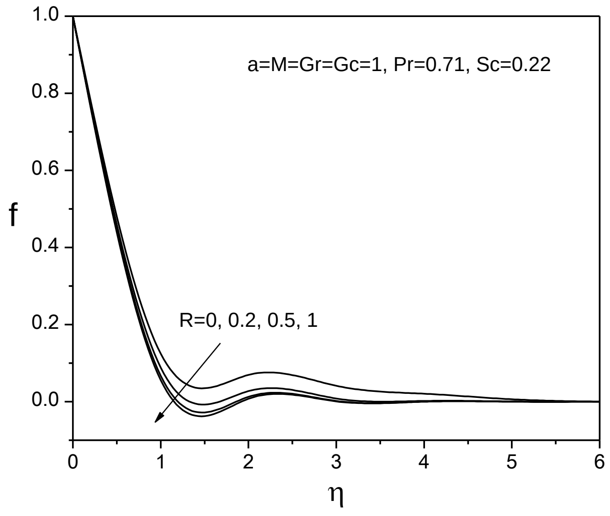


**Fig.5 Velocity profiles for different values of *R***

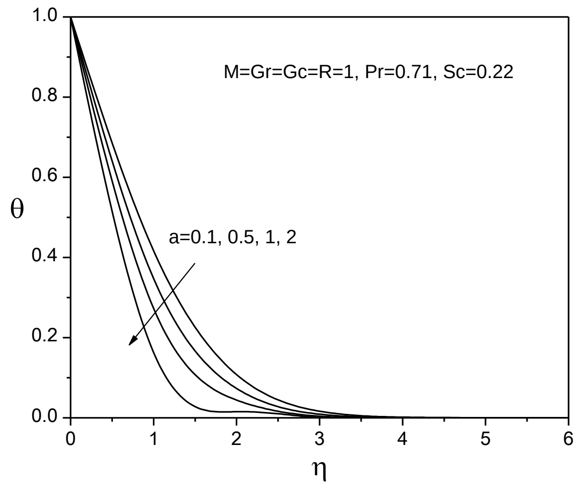


**Fig.6 Temperature profiles for different values of *a***

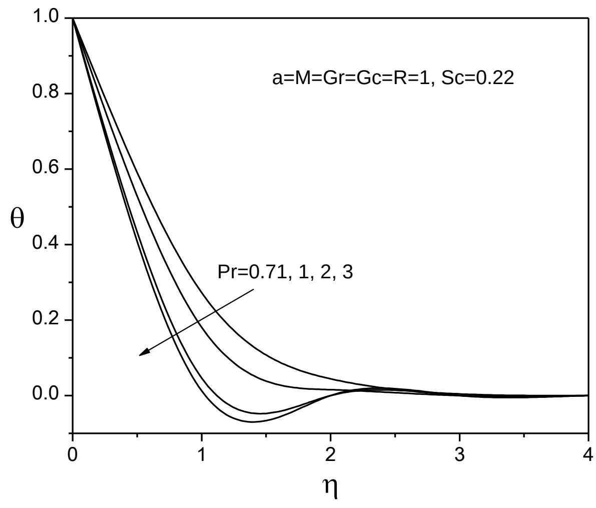


**Fig.7 Temperature profiles for different values of *Pr***

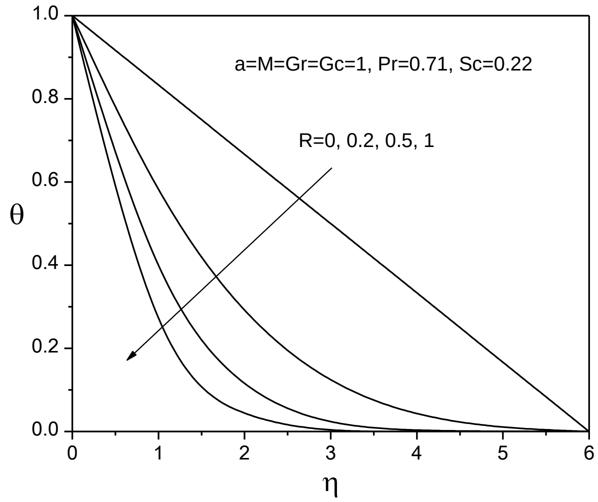


**Fig.8 Temperature profiles for different values of *R***

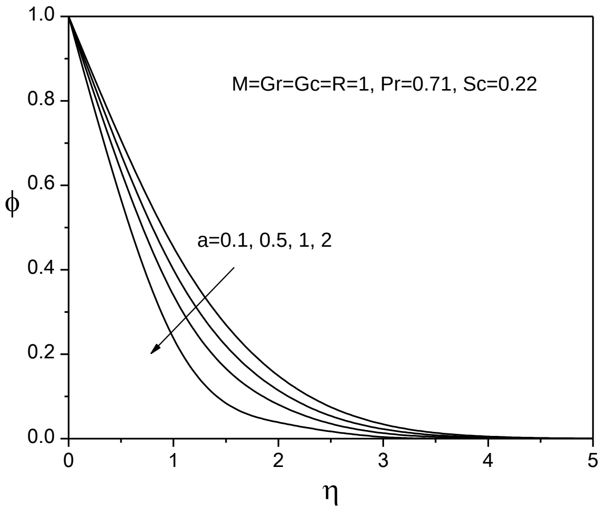


**Fig.9 Concentration profiles for different values of *a***

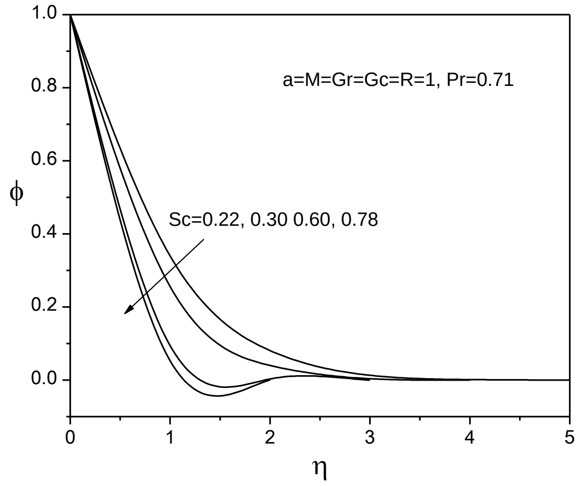


**Fig.10 Concentration profiles for different values of *Sc***

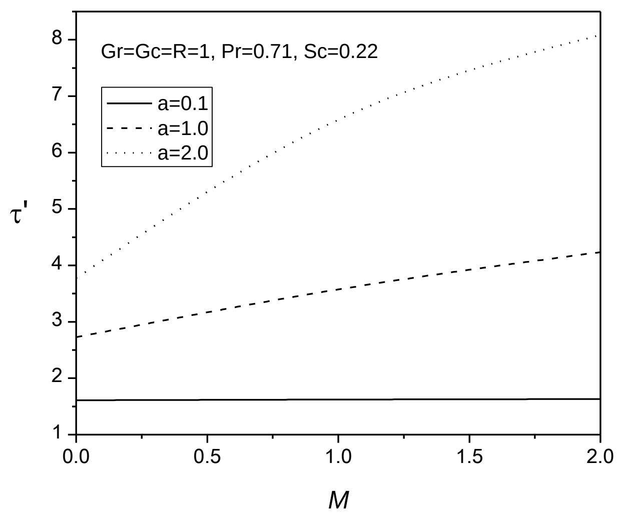


**Fig.11 Variation of the skin friction for different *a* with *M***

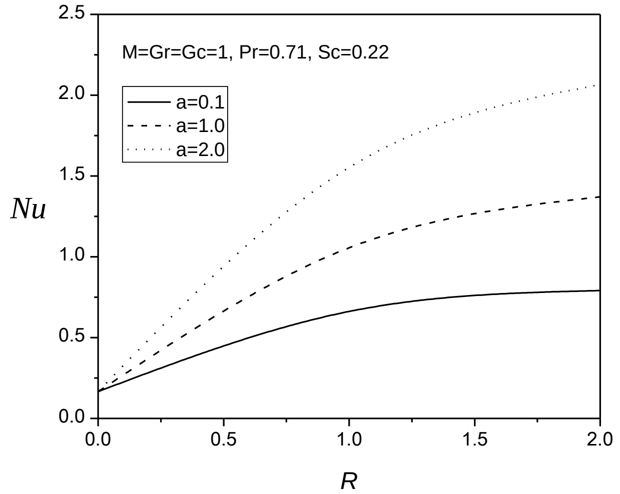


**Fig.12 Variation of the Nusselt number for different *a* with *R***

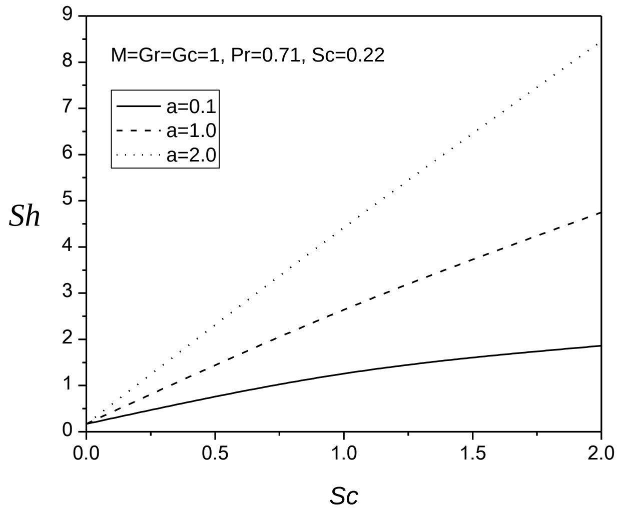


**Fig.13 Variation of the Sherwood number for different *a* with *Sc***

**Table 1** Numerical values of $Nu$ at the sheet for different values of *a* when *Pr=0.71, Gr=Gc=1, R=Sc=0.* Comparison of the present results with that of Das and Mitra (2009).

| A | Das and Mitra (2009) | Present results |
|---|---|---|
| 0.1 | 1.04299514 | 1.04300 |
| 1 | 2.00275564 | 2.00276 |
| 2 | 3.23732738 | 3.23733 |

## V. Conclusions

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

1. Greater suction (a) leads to a faster reduction in the velocity of the flow field.
2. The magnetic parameter (M) retards the velocity of the flow field at all points.
3. The Grashof numbers for heat transfer (Gr) and mass transfer (Gc) have accelerating effect on the velocity of the flow field at all points.
4. The radiation parameter (R) leads to a faster reduction in the velocity of the flow field.
5. At any point in the flow field, the cooling of the plate is faster as the suction parameter (a), radiation paramer (R) and Prandtl number (Pr) become larger. Thus greater suction/ radiation/ Prandtl number leads to faster cooling of the plate.
6. Heavier diffusing species has a significant decrease in the concentration boundary layer of the flow field. The Schmidt number (Sc) and the suction parameter (a) have a retarding effect on the concentration distribution of the flow field.
7. The effect of suction parameter is to enhance both the skin friction ( $\tau'$ ), Nusselt number (Nu) and Sherwood number (Sh) at the wall.

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