International Journal of Mathematical Archive-3(8), 2012, 3028-3035
Available online through www.ijma.info ISSN 2229 – 5046

RADIATION AND MASS TRANSFER EFFECTS ON MOVING VERTICAL PLATE WITH VARIABLE TEMPERATURE AND VISCOUS DISSIPATION

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(Received on: 30-07-12; Revised & Accepted on: 22-08-12)

ABSTRACT

The objective of this paper is to study the thermal radiation and heat generation effects on unsteady flow of a viscous incompressible fluid past an impulsively started infinite vertical plate with variable temperature and uniform mass diffusion. The fluid considered here is gray, absorbing-emitting radiation but a non scattering medium. The governing equations of the flow field were solved numerically using Crank-Nicolson implicit finite difference method. The results are obtained for velocity, temperature, and concentration. The effects of various material parameters are discussed on flow variables and are presented by graphs. It is observed that the velocity increases with decreasing values of the radiation parameter.

Key words: *Thermal radiation, viscous dissipation, heat generation, mass transfer.*

1. INTRODUCTION

Heat transfer by simultaneous radiation and convection has applications in numerous technological problems, including combustion, furnace design, advanced energy conversion devices and many others, when heat transfer by radiation is of the same order of magnitude as by convection. A separate calculation of radiation and convection and their superposition without considering the interaction between them can lead to significant errors in the results, because of the presence of the radiation in the medium, which alters the temperature distribution within the fluid. Therefore, in such situation heat transfer by convection and radiation should be solved for simultaneously.

Extensive research has been published on free convection flow past a vertical plate. Boundary layer flow on moving horizontal surfaces was studied by Sakiadis [1]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate was studied by Soundalgekar *et al.*[2]. MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar *et al.* [3]. The dimensionless governing equations were solved using Laplace transform technique. Kumari and Nath [4] studied the development of the asymmetric flow of a viscous electrically conducting fluid in the forward stagnation point region of a two-dimensional body and over a stretching surface with an applied magnetic field, when the external stream or the stretching surface was set into impulsive motion from the rest. The governing equations were tackled using implicit finite difference scheme. Basant Kumar Jha and Ravindra Prasad [5] examined the heat source characteristics on the free convection and mass transfer flow past an impulsively started infinite non-conducting vertical plate of a viscous incompressible electrically conducting fluid under the action of a uniform magnetic field through porous medium.

Hossain and Takhar [6] analyzed the effect of radiation on mixed convection along a vertical plate with uniform surface temperature. Bakier and Gorla [7] investigated the effect of radiation on mixed convection flow over horizontal surfaces embedded in a porous medium. Kim and Fedorov [8] analyzed transient mixed radiative convective flow of a micropolar fluid past a moving semi-infinite vertical porous plate. Bestman and Adjepong [9] presented unsteady hydromagnetic free convection flow with radiative heat transfer in a rotating fluid. Abd EI-Naby et al. [10] studied the

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effects of radiation on unsteady free convective flow past a semi-infinite vertical plate with variable surface temperature using Crank-Nicolson finite difference method. They observed that, both the velocity and temperature are found to decrease with an increase in the temperature exponent. Chamkha et al. [11] analyzed the effects of radiation on free convection flow past a semi-infinite vertical plate with mass transfer, by taking into account the buoyancy ratio parameter N. Ganesan and Loganadhan [12] studied the radiation and mass transfer effect on flow of incompressible viscous fluid past a moving vertical cylinder using Rosseland approximation by the Crank-Nicolson finite difference method. Takhar et al. [13] considered the effect of radiation on MHD free convection flow of a radiating gas past a semi-infinite vertical plate. Recently Dulal Pal *et al* [14] studied Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Prasad *et al.* [15] studied radiation and mass transfer effects on two-dimensional flow past an impulsively started infinite vertical plate. Effects of thermal radiation on various flow fields were studied by [16-21] using analytical methods.

The aim of the present work is to study the effects of thermal radiation and heat generation on moving infinite vertical plate in the presence of variable temperature and viscous dissipation. The equations of continuity, energy and diffusion, which govern the flow field, are solved numerically using Crank-Nicolson implicit finite difference method. The effect of different pertinent physical parameters on the velocity, temperature and concentration are discussed and presented graphically.

NOMENCLATURE

t'	: time
p'	: pressure
g	: acceleration due to gravity
T'_∞	: temperature of the fluid far away from the plate
C'_∞	: species concentration in the fluid far away from the plate
k	: thermal conductivity
q'	: radiative heat flux
u'_p	: plate velocity
T'_w and C'_w	: temperature and concentration of the plate
U'_∞	: free stream velocity
U_0 and n'	: constants
A	: real positive constant
V_0	: non-zero positive constant
M	: magnetic parameter
Gr	: thermal Grashof number
Gm	: solutal Grashof Number
Pr	: Prandtl Number
Sc	: Schmidt number
R	: radiation parameter
Ec	: Eckert number

Greek symbols

β and β*	: thermal and concentration expansion coefficients respectively,
ν	: kinematic viscosity
σ	: electrical conductivity of the fluid
ϕ	: heat absorption parameter
ρ	: fluid density
σ	: fluid thermal diffusivity
σ^*	: Stefan- Boltzmann constant

Subscripts

w	: condition at plate
∞	: condition at infinity

2. MATHEMATICAL ANALYSIS

Here the unsteady flow of a viscous incompressible fluid past an impulsively started infinite vertical plate with variable temperature and uniform mass diffusion, in the presence of thermal radiation, heat generation/ absorption is considered. The x – axis is taken along the plate in the vertically upward direction and the y – axis is taken normal to plate. It is also assumed that the radiation heat flux in the x – direction is negligible as compared to that in the y –direction. Initially, the plate and fluid are at the same temperature and concentration in a stationary condition. At time $t' > 0$, the plate is given impulsive motion in the vertical direction against gravitational field with constant velocity u_0, the plate temperature is raised linearly with time and the concentration level near the plate is raised C'_w. The fluid considered here is gray, absorbing – emitting radiation but a non-scattering medium. Then by usual Boussinesqs approximation, the flow of a radiative fluid governed by the following equations:

$$\frac{\partial u}{\partial t'} = g\beta\left(T - T_\infty\right) + g\beta^*\left(C' - C'_\infty\right) + \nu\frac{\partial^2 u}{\partial y^2} \tag{1}$$

$$\rho c_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} + \mu\left(\frac{\partial u}{\partial y}\right)^2 - Q_0\left(T - T_\infty\right) \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} \tag{3}$$

Initial and boundary conditions are as follows:

$$\begin{aligned} t \le 0:\ & u = 0, \quad T = T_\infty, C = C'_\infty \qquad && for\ \ all\ \ \ y \\ t > 0:\ & u = u_0, \quad T = T_\infty + \left(T_w + T_\infty\right)At', C = C'_w && as\ \ \ y = 0 \\ & u = 0, \quad T \to T_\infty, C = C'_\infty && as\ \ \ y \to \infty \end{aligned} \tag{4}$$

where $A = \dfrac{u'_0}{\nu}$

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial\, q_r}{\partial\, y} = 4a^*\sigma\left(T'_\infty - T^4\right) \tag{5}$$

We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4 \cong 4T_\infty{}^3\, T - 3T^4 \tag{6}$$

By using equations (5) and (6), equation (2) reduces to

$$\rho C_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial t'} + 16a^* T_\infty^3\left(T_\infty - T\right) \tag{7}$$

On introducing the following non-dimensional quantities

$$\begin{aligned} & U = \frac{u}{u_0}, Y = \frac{yu_0}{\nu}, t = \frac{t'u_0{}^2}{\nu}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty} \\ & Sc = \frac{\nu}{D}, R = \frac{16a^*\sigma\nu^2 T_\infty^3}{\mathrm{k}\, u_0{}^2}, G_r = \frac{\nu\beta g\left(T_w - T_\infty\right)}{u_0{}^3}, \phi = \frac{\nu Q_0}{\rho C_p u_0{}^2} \\ & Ec = \frac{u_0^2}{c_p(T_w - T_\infty)}, P_r = \frac{\nu\rho C_p}{k}, G_c = \frac{\nu\beta^* g\left(C'_w - C'_\infty\right)}{u_0{}^3} \end{aligned} \tag{8}$$

In equations (1), (3) and (7), leads to

$$\frac{\partial U}{\partial t} = G_r\theta + G_c\, C + \frac{\partial^2 U}{\partial Y^2} \tag{9}$$

$$\Pr\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial Y^2} + Ec\left(\frac{\partial U}{\partial Y^2}\right) - \theta\left(R+\phi\right) \tag{10}$$

$$S_C\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial Y^2} \tag{11}$$

Initial and boundary conditions in non-dimensional form are:

$$\begin{aligned} &U=0, \quad \theta=0, C=0 \quad for\ \ all \quad y,t\le 0\\ T>0:\ &U=1, \quad \theta=t,\ C=1 \quad as \quad y=0\\ &U=0, \quad \theta\to 0, C\to 0\ as \quad y\to\infty \end{aligned} \tag{12}$$

3. METHOD OF SOLUTIONS

The unsteady, non-linear, coupled partial differential equations (9), (10) and (11) along with their boundary and initial conditions (12) have been solved numerically using an implicit finite difference scheme of Crank-Nicolson type which is discussed by many authors Muthucumaraswamy and Ganesan [17] , Ganesan and Rani [18], Ganesan and Loganathan [12],Prasad *et al.*[15] and Bapuji *et al.*[19].

The equivalent finite difference scheme of equations for (9), (10) and (11) are as follows:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t} = \frac{u_{i+1,j}-2u_{i,j}+u_{i-1,j}}{\left(\Delta Y\right)^2} + Gr\,\theta_{i,j} + Gc\,\phi_{i,j} \tag{13}$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t} = \frac{1}{\Pr}\left[\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{\left(\Delta Y\right)^2}\right] - R\,\theta_{i,j} - \phi\,\theta_{i,j} + \Pr E\left[\frac{u_{i+1,j}-u_{i,}}{\Delta Y}\right]^2 \tag{14}$$

$$\frac{\phi_{i,j+1}-\phi_{i,j}}{\Delta t} = \frac{1}{Sc}\left[\frac{\phi_{i+1,j}-2\phi_{i,j}+\phi_{i-1,j}}{\left(\Delta Y\right)^2}\right] \tag{15}$$

here, index *i* refers to *y* and *j* refers to time, the mesh system is divided by taking $\Delta y = 0.1$.

From the initial conditions in (12) we have the following equivalent

$$\left.\begin{aligned} &u(0,0)=0,\ \theta(0,0)=0,\ \phi(0,0)=0\\ &u(i,0)=0,\ \theta(i,0)=0, \qquad \phi(i,0)=0\ \ forall\ \ i,\ \ except\ \ \ i=0 \end{aligned}\right\} \tag{16}$$

The boundary conditions from (12) are expressed in finite-difference form as follows

$$\left.\begin{aligned} &u(0,j)=1,\ \theta(0,j)=t,\ \phi(0,j)=1,\ \ forall\ j\\ &u(1,j)=0,\ \theta(1,j)=0\ \ \ \phi(1,j)=0\ \ \ \ forall\ j \end{aligned}\right\} \tag{17}$$

Here infinity is taken as *y* = 4.1. First the velocity at the end of the time step namely $\left(u_{i,j+1}\right)$, *i* = 1 to 200 is computed from the equation (13) and temperature $\left(\theta_{i,j+1}\right)$, *i* = 1 to 200 from equation (14) and concentration $\left(\phi_{i,j+1}\right)$, *i* = 1 to 200 from equation (15). The procedure is repeated until *t* = 1 (i.e., j = 400). During computation Δt was chosen as 0.0025. These computations are carried out for Pr = 1, 7, 11.4; Sc = 0.3, 0.6, 2.01; R = 0.2, 2, 5, 10, 20; Q = 1, 2, 3, 5; Gr = 2, 5; Gc = 2, 5; E = 0.01, 0.02, 0.03, 0.04; t = 0.2, 0.4, 0.6, 1.0.

4. DISCUSSIONS OF RESULTS

The formulation of the problem that accounts for the effects of radiation and viscous dissipation on the flow of a viscous incompressible fluid past an impulsively started infinite vertical plate with variable temperature and uniform mass diffusion in the presence of heat generation was accomplished in the preceding sections. The governing equations of the flow field were solved numerically using Crank-Nicolson implicit finite difference method. In order to get physical insight into the problem, the velocity, temperature, and concentration fields have been discussed by assigning numerical values of magnetic parameter *M*, thermal Grashof number *Gr*, the solutal Grashof number *Gm*, Prandtl number *Pr*, Schmidt number *Sc*, the radiation parameter *R* and the Eckert number *Ec*. The velocity profiles for different values of the radiation parameter are shown in figure 1. We note from this figure that there is decrease in the horizontal velocity profiles with increase in the radiation parameter R. The increase of the radiation parameter R leads to decrease the boundary layer thickness and to enhance the heat transfer rate in the presence of thermal and solutal buoyancy force.

In figure 2 the effect of the velocity for different values of thermal Grashof number (Gr) and mass Grashof number (Gc) are shown graphically in the presence of thermal radiation. It is observed that the velocity increases with increasing thermal Grashof number or mass Grashof number. This is due to the fact that buoyancy force enhances fluid velocity and increase the boundary layer thickness with increase in the value of Gr or Gc. It is interesting to note that the velocity increases tremendously with increasing mass Grashof number as compared to the thermal Grashof number. Figures 3 represent the velocity profiles for different values of $\Pr$ with $Gr = 2, Gc = 5, Sc = 2.01, R = 2.0, t = 0.4$. It is seen that velocity decreases as *Pr* increases. This is an agreement with the physical fact that the thermal boundary layer thickness decreases with increasing $\Pr$.The effect of increasing the value of the heat absorption parameter ϕ is to decrease the boundary layer as shown in Fig. 4, which is as expected due to the fact that when heat is absorbed the buoyancy force decreases which retards the flow rate and there by giving rise to decrease in the velocity profiles. Figure 5 illustrates the variation of dimensionless velocity function (u) versus y with various Schmidt number. *Sc* measures the relative effectiveness of momentum and mass transport by diffusion. Further, it is observed that the momentum boundary layer decreases with increase in the value of Sc.

The influence of the time *t* on velocity profiles is illustrated in Figure 6**.** It is seen that the velocity increases with the increase of *t* values. The effect of Eckert number E on temperature profiles is shown in figure 7.Here *E* expresses the relationship between the kinetic energy in the flow and the enthalpy. It embodies the conversion of kinetic energy into internal energy by work done against the viscous fluid stresses. Although this parameter is often used in high-speed compressible flow, for example in rocket aerodynamics at very high altitude, it has significance in high temperature incompressible flows, which are encountered in chemical engineering systems, radioactive waste repositories, nuclear engineering systems etc. Positive Eckert number implies cooling of the wall and therefore a transfer of heat to the fluid. We conclude that with the increase of Eckret number leads to increases the temperature. From Figure 8 it is observed that as increase in the Prandtl number results an increase of the thermal boundary layer thickness and in general lower average temperature with in the boundary layer. The reason is that smaller values of $\Pr$ are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of $\Pr$. Hence in the case of smaller Prandtl numbers as thermal boundary layer is thicker and the heat transfer is reduced. Figure 9 depicts the effect of heat absorption parameter ϕ on the temperature filed. From this graph we observe that temperature profile decreases with increase in the heat absorption parameter ϕ because when heat is absorbed, the buoyancy force decreases the temperature profile.

The temperature profiles are calculated from equation (14) for different values of thermal radiation parameter $(R = 0.2, 2.0, 5.0, 10.0), t = 0.2$ and $\Pr = 0.71$ are shown in Figure 10. The effect of thermal radiation parameter is important temperature profiles. Further, it is observed from this figure that increase in the radiation parameter decreases the temperature distribution in the thermal boundary layer due to decrease in the thickness of the thermal boundary layer with thermal radiation parameter R. This is because large values of radiation parameter corresponds to an increase in dominance of conduction over radiation, thereby decreasing the buoyancy force and the thickness of the thermal boundary layer. Figure 11 illustrates the influences of t on the temperature. It is obvious from the figure that the maximum velocity attains in the vicinity of the plate then decreases to zero as $y \to \infty$. It is noted that the temperature increases with increasing time t. This is due to the fact that heat energy is stored in the liquid as time increases. Figure 12 concerns with the effect of Sc on the concentration. As the Schmidt number increases, the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. Reductions in the concentration distributions are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

5. CONCLUSIONS

The above analysis brings out the following results of physical interest on the velocity, temperature and concentration distribution of the flow field.

- The radiation parameter R decreases both the velocity and temperature of the flow fieldat all points.
- The effect of heat generation parameter ϕ is to decreases the velocity of the flow field at all points.
- The concentration is observed to significantly decrease with an increase in Schmidt number.
- The temperature is observed to decrease with an increase in prandtl number Pr.
- The effect of Eckert number *Ec* is to enhance the velocity of the flow field at all points.

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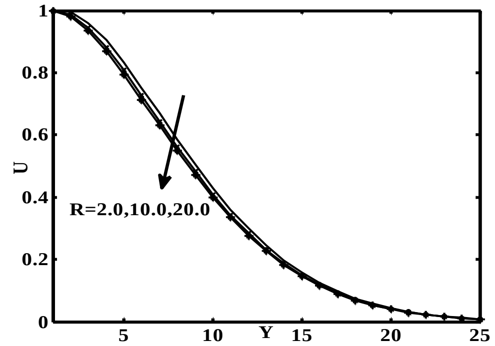

Figure 1. Velocity profiles for different values of R

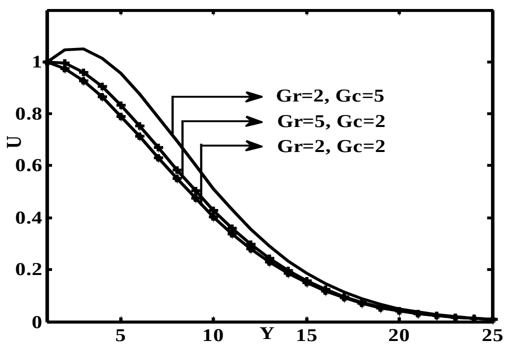

Figure 2. Velocity profiles for different values of GR and Gc

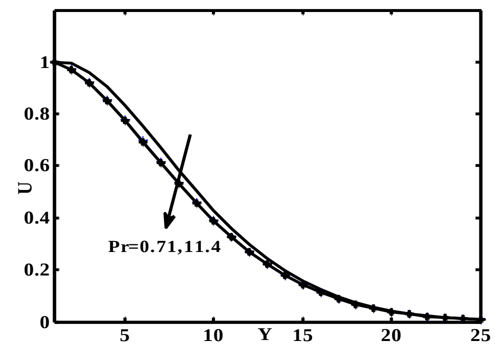

Figure 3. Velocity profiles for different values of Pr

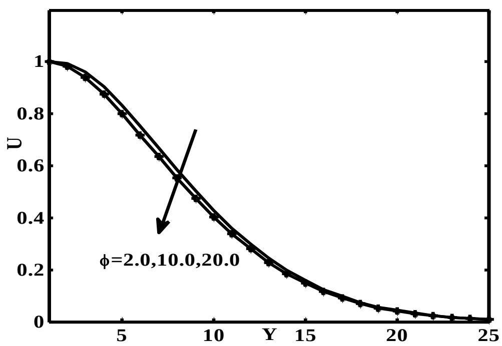

Figure 4. Velocity profiles for different values of ϕ

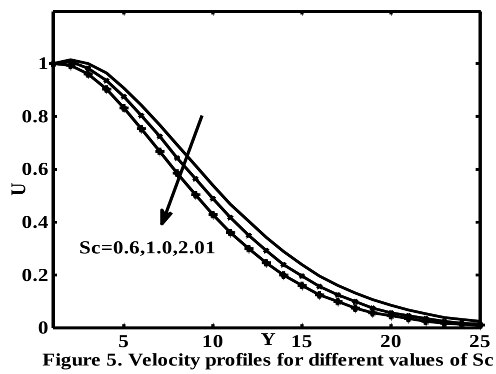

Figure 5. Velocity profiles for different values of Sc

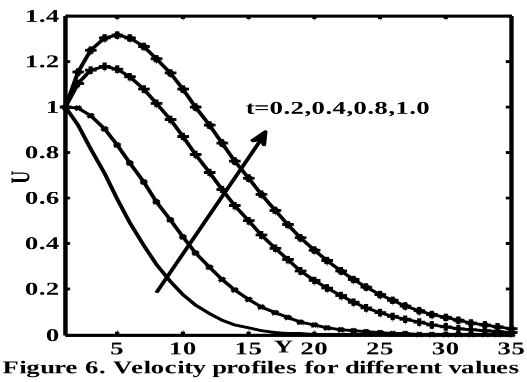

Figure 6. Velocity profiles for different values of t

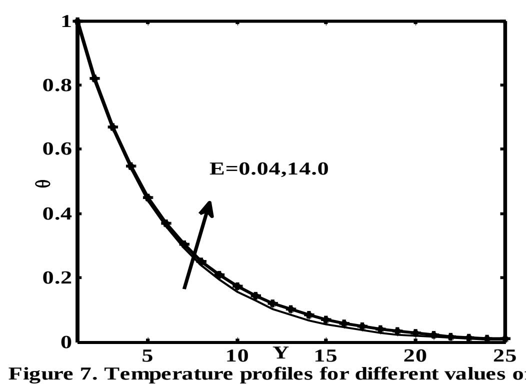

Figure 7. Temperature profiles for different values of E

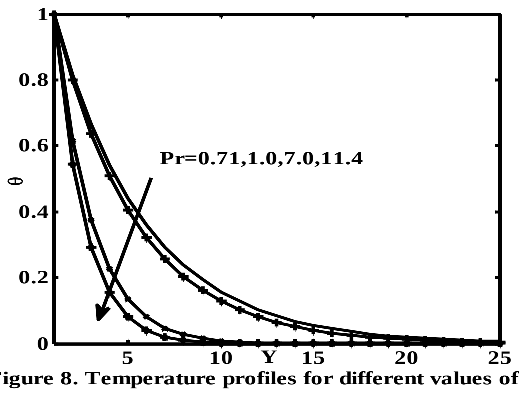

Figure 8. Temperature profiles for different values of Pr

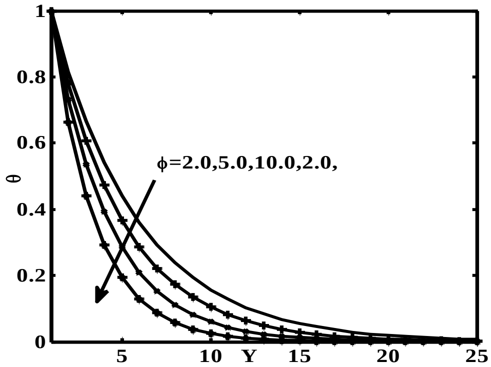

Figure 9. Temperature profiles for different values of ϕ

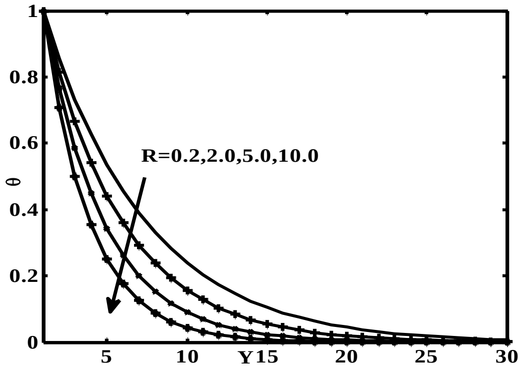

Figure 10. Temperature profiles for different values of R

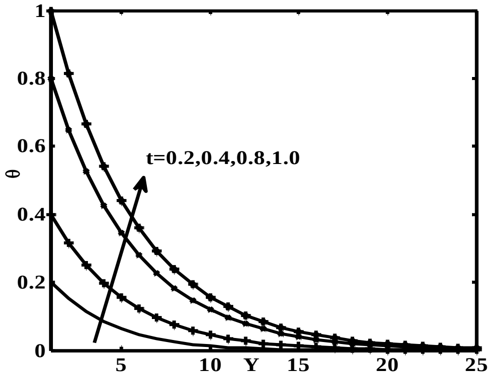

Figure 11. Temperature profiles for different values of t

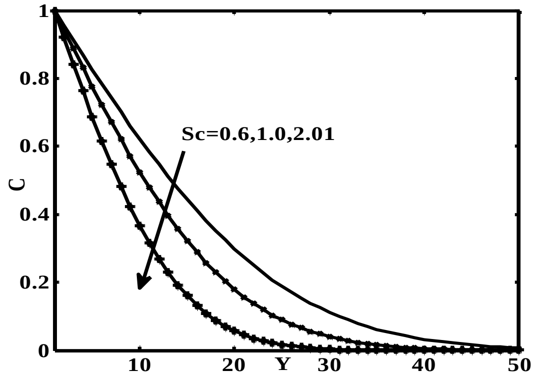

Figure 12. Concentration profiles for different values of Sc

Source of support: Nil, Conflict of interest: None Declared

