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Radiation and Chemical Reaction Effects on Free Convection and Mass Transfer Flow of Dissipative Fluid past an Exponentially Infinite Vertical Plate through a Porous Medium

R.K. Mondal, Md.A. Hossain, B.M. Jewel Rana and S.F. Ahmmed
Khulna University, Khulna-9208, Bangladesh.

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ABSTRACT

In this paper the numerical study of unsteady flow of a viscous incompressible fluid past an exponentially accelerated infinite vertical plate with radiation, viscous dissipation, chemical reaction and variable heat and mass diffusion have been analyzed in the porous medium. To obtain the non-similar momentum, energy, and concentration equations usual non-dimensional variables have been used. The dimensionless governing equations are solved numerically by explicit finite difference method. Here velocity, temperature and concentration fields are described graphically for the different physical parameters. Skin friction and Nusselt number profiles have been also described graphically here.

Introduction

MHD has drawing the attention of large number scholars due to its diverse applications such as astrophysics and geophysics; it is applied to study the stellar and solar structures, interstellar matter, radio propagation through the ionosphere etc. At a time heat and mass transfer from different geometrics embedded in porous medium has many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulations, enhanced oil recovery, cooling of nuclear reactors and underground energy transport. Free convection flow is a significant fact in various practical applications that include cooling of electronic components, in designs related to the thermal insulation, material processing and geothermal systems etc. The study of effects of magnetic field on free convection is important in liquid metals, electrolytes and ionized gasses. The thermal physics of hydro magnetic problems with mass transfer is of interest in power engineering and metallurgy. Thermal radiation in the fluid dynamics has become significant branch of engineering sciences and is a necessary aspect of different scenarios in mechanical, aerospace, chemical environmental and solar power engineering. Viscous dissipation effects are necessary in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number.

Many studies have been carried out to investigate the magneto hydrodynamic transient convective flow. The transient natural convection flow from a plate in the presence of magnetic current has been discussed by Gupta [1]. Chowdhury and Islam [2] analyzed magneto hydrodynamic free convection flow past vertical surface by Laplace transform technique. Transient hydro magnetic free convection flow over a surface described by Aldoss and Al-Nimr [3]. All of the above studies are concerned with the absence of porous medium. Last three decades there have been a great interest in convective heat transfer through porous medium. Recently only some studies have been performed on transient convective flows in porous medium. Bradean et. al [4] and Pop et. al [5], Magyari et. al [6] have described analytical solutions for unsteady free convection In porous medium. Geindreau et. al [7] have been considered the magnetic current in porous medium. MHD free convection flow of dissipative fluid past an exponentially accelerated vertical plate have discussed by Bhagya Lakshmi, K. et.al [17].

Gupta et al. [14] (Gupta et al. 1979) studied free convection on flow past a linearly accelerated vertical plate in the arrival of viscous dissipative heat using perturbation method. Free convection flow past an accelerated infinite plate discussed by Pop, I. and. Soundalgekar [15] (Pop, I. and. Soundalgekar 1980). Kafousias and Raptis [9] (Kafousias and Raptis 1981) expanded the problem of Gupta et al. to involve mass transfer effects subjected to variable suction and injection. Sing and Naveen Kumar [8] (Sing and Naveen Kumar 1984) was studied free convection effects on flow past an exponentially accelerated vertical plate. Hossain and Shayo [12] (Hossain and Shayo 1986) discussed skin friction for accelerated vertical plate analytically. Basant kumar Jha [16] (Basant kumar Jha 1991) studied MHD free convection and mass transform flow through a porous medium. Latterly Combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium have analyzed by R.C. Chaudhary and Arpita Jain [10] (R.C. Chaudhary et al. 2007). Recently Muthukumaraswamy et al. [11] (Muthukumaraswamy et al. 2008) discussed mass transfer effects on exponentially accelerated isothermal vertical plate. Although different authors studied mass transfer with or without radiation and viscous dissipation effects on the flow past an exponentially vertical plate by considering different surface conditions but the study on the effects of magnetic field on free convection heat and mass transfer with thermal radiation, viscous dissipation, chemical reaction and variable surface conditions in flow through an exponentially vertical plate has not been found in literature. It is

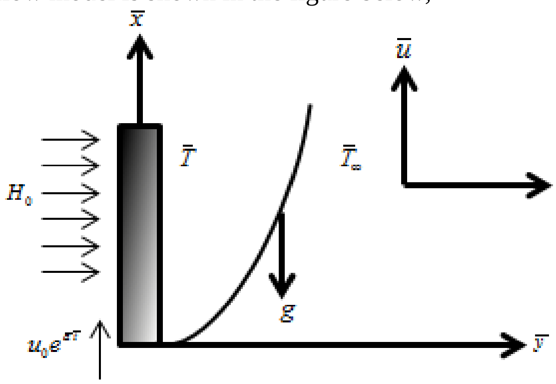
Tele:
E-mail addresses: razonkumarku@gmail.com

Therefore proposed to study the effects of radiation and chemical reaction on free convection and mass transfer flow of dissipative fluid past an exponentially infinite vertical plate through a porous medium.

In this work, we have studied about the effects of radiation and chemical reaction on free convection and mass transfer flow of dissipative fluid past an exponentially infinite vertical plate through a porous medium. The governing equations for the unsteady case are also studied. Then these governing equations are transformed into dimensionless momentum, energy and concentration equations are solved numerically by using explicit finite difference technique with the help of a computer programming language Compaq visual FORTRAN 6.6. The obtained results of this problem have been discussed for the different values of well-known parameters. The tecplot 9.0 is used to draw graph of the flow.

Mathematical Formulations

The transient MHD free convection flow of an electrically conducting, thermally radiating, chemically reacting and viscous dissipative incompressible fluid past an exponentially infinite vertical plate through a porous medium has been considered. The flow model is shown in the figure below,



The $\bar{x}$ axis is taken along the plate in the vertically upward direction and the $\bar{y}$ axis is taken normal to the plate. Since the plate is considered infinite in $\bar{x}$ direction, all flow quantities self-similar away from the leading edge. Therefore, all the physical variables become functions of $\bar{t}$ and $\bar{y}$ only. When the time $\bar{t} \le 0$, the plate and fluid are at the same temperature $\bar{T}_\infty$ and concentration $\bar{C}_\infty$ lower than the constant wall temperature $\bar{T}_w$ and $\bar{C}_\infty$ respectively. But when $\bar{t} > 0$, The plate is accelerated exponentially with a velocity $\bar{u} = u_0 \exp(\bar{a}\bar{t})$ in its own plane and the plate temperature and concentration are raised linearly with time $\bar{t}$. A uniform magnetic field of intensity H_0 is applied in the $\bar{y}$ direction. The velocity and and the magnetic field are given by $\bar{q} = (u, v)$ and $\bar{H} = (0, H_0)$. The heat due to the viscous dissipation is taken into the account. Under the above assumptions as well as the Boussinesq's approximations, the unsteady flow is governed by the following equations

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \tag{1}$$

$$\frac{\partial \bar{u}}{\partial \bar{t}} = g\beta(\bar{T} - \bar{T}_\infty) + g\beta'(\bar{C} - \bar{C}_\infty) + \nu \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma B_0{}^2}{\rho}\bar{u} - \frac{\nu \bar{u}}{\bar{K}} \tag{2}$$

$$\rho C_p \frac{\partial \bar{T}}{\partial \bar{t}} = \kappa \frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \frac{\partial q_r}{\partial \bar{y}} + \mu\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 \tag{3}$$

$$\frac{\partial \bar{C}}{\partial \bar{t}} = D\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} - K_l\left(\bar{C} - \bar{C}_\infty\right) \tag{4}$$

Boundary conditions related with the problem are,

$$\begin{aligned} &\bar{t} \le 0,\ \ \bar{u} = 0,\ \ \bar{T} = \bar{T}_\infty,\ \ \bar{C} = \bar{C}_\infty \ \text{ for all } \ \bar{y} \\ &\bar{t} > 0,\ \bar{u} = u_0 e^{\bar{a}\bar{t}},\ \bar{T} = \bar{T}_\infty + (\bar{T}_w - \bar{T}_\infty)A\bar{t}, \\ &\bar{C} = \bar{C}_w + (\bar{C}_w - \bar{C}_\infty)A\bar{t} \ \text{ for all } \ \bar{y} = 0 \\ &\bar{u} \to 0,\ \ \bar{T} \to \bar{T}_\infty,\ \ \bar{C} = \bar{C}_\infty,\ \ \text{ as } \ \bar{y} \to \infty \end{aligned} \tag{5}$$

Here, $A = \frac{u_0{}^2}{\nu}$

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

$$\frac{\partial q_r}{\partial \bar{y}} = -4a^*\sigma\left(\bar{T}_\infty^4 - \bar{T}^4\right) \tag{6}$$

It is noticed that the temperature differences with in the flow are sufficiently small that $\bar{T}^4$ may be expressed as a linear function of the temperature. Now expanding $\bar{T}^4$ in a Taylor series about $\bar{T}_\infty$ and neglecting the higher order terms,

$$\bar{T}^4 = 4\bar{T}_\infty^3\bar{T} - 3\bar{T}_\infty^4 \tag{7}$$

Using (5) and (6), equation (3) reduces to

$$\rho C_p \frac{\partial \bar{T}}{\partial \bar{t}} = \kappa \frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + \mu\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 + 16a^*\sigma\bar{T}_\infty^3\left(\bar{T}_\infty - \bar{T}\right) \tag{8}$$

Since the solutions of the governing equations under the boundary conditions will be based on the finite difference method so it is necessary to make the equation dimensionless. For this reason now we introduce the following dimensionless quantities,

$$\begin{aligned} &u = \frac{\bar{u}}{u_0},\quad y = \frac{\bar{y}u_0}{\nu},\quad t = \frac{\bar{t}u_0^2}{\nu},\quad \theta = \frac{\bar{T} - \bar{T}_\infty}{\bar{T}_w - \bar{T}_\infty}, \\ &G_r = \frac{g\beta\nu(\bar{T}_w - \bar{T}_\infty)}{u_0^3},\quad a = \frac{\bar{a}\,\nu}{u_0^2},\quad P_r = \frac{\mu C_p}{\kappa}, \\ &G_m = \frac{g\beta'\nu(\bar{C}_w - \bar{C}_\infty)}{u_0^3},\quad R = \frac{16a^*\partial\nu^2 T_\infty^3}{ku_0^2}, \\ &S_c = \frac{\nu}{D},\quad M = \frac{\sigma B_0^2\nu}{\rho u_0^2},\quad E = \frac{u_0^2}{C_p\left(\bar{T}_w - \bar{T}_\infty\right)}, \\ &k = \frac{u_0^2\bar{K}}{\nu^2},\quad K_r = \frac{\nu K_l}{u_0^2} \end{aligned} \tag{9}$$

Using the equation (9) the equation (1)-(4) with the boundary conditions (5) leads to,

$$\frac{\partial u}{\partial t} = G_r\theta + G_m C + \frac{\partial^2 u}{\partial y^2} - Mu - \frac{u}{k} \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{P_r}\theta + E\left(\frac{\partial u}{\partial y}\right)^2 \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K_r C \tag{12}$$

With the initial and boundary conditions,

$$t \le 0: \quad u = 0, \quad \theta = 0, \quad C = 0, \quad \text{for all} \quad y$$
$$t > 0: \quad u = e^{at}, \quad \theta = t, \quad C = t \quad \text{for all} \quad y = 0 \tag{13}$$

Skin-friction and Nusselt number

Now we calculate the skin friction from the velocity field which is given in non-dimensional form as $\tau = \frac{1}{2\sqrt{2}} Gr^{-\frac{3}{4}} (\frac{\partial u}{\partial y})_{y=0}$ and Nusselt number from the temperature field which is given in non-dimensional form as $Nu = \frac{1}{\sqrt{2}} Gr^{-\frac{3}{4}} (\frac{\partial T}{\partial y})_{y=0}$.

Numerical Solution

For the simplicity explicit finite difference method has been used to solve from equations (6) to (8) subject to the conditions given by (9). To obtain the difference equations the region of the flow is divided into a grid or mesh of lines parallel to *X* and *Y* axis is taken along the plate and *Y*-axis is normal to the plate.

Here the plate of height $X_{\max}(=20)$ i.e. *X* varies from 0 to 20 and regard $Y_{\max}(=50)$ as corresponding to $Y \to \infty$ i.e. *Y* varies from 0 to 50. There are *m*=100 and *n*=200 grid spacing in the *X* and *Y* directions respectively.

It is assumed that ΔX and ΔY are constant mesh sizes along *X* and *Y* directions respectively and taken as follows,

$$\Delta X = 0.20\left(0 \le x \le 20\right)$$
$$\Delta Y = 0.25\left(0 \le x \le 50\right)$$

With the smaller time-step, Δt=0.005.

Using the explicit finite difference approximation, the following appropriate set of finite difference equations are obtained as;

$$\frac{U'_{i,j} - U_{i,j}}{\Delta t} = G_r \theta_{i,j} + G_m C_{i,j} + \frac{U_{i,j+1} - 2U_{i,j} + U_{i,j-1}}{(\Delta y)^2}$$
$$- MU_{i,j} - \frac{U_{i,j}}{k} \tag{14}$$

$$\frac{\theta'_{i,j} - \theta_{i,j}}{\Delta t} = \frac{1}{P_r}\left(\frac{\theta_{i,j+1} - 2\theta_{i,j} + \theta_{i,j-1}}{(\Delta y)^2}\right) - \frac{R}{P_r}\theta_{i,j} + E\left(\frac{U_{i,j+1} - U_{i,j}}{\Delta y}\right) \tag{15}$$

$$\frac{C'_{i,j} - C_{i,j}}{\Delta t} = \frac{1}{S_c}\left(\frac{C_{i,j+1} - 2C_{i,j} + C_{i,j-1}}{(\Delta y)^2}\right) - K_r C_{i,j} \tag{16}$$

Initial and boundary condition takes the following forms,

$$t \le 0: \; U^0_{i,0} = 0, \; \theta^0_{i,0} = 0, \; C^0_{i,0} = 0, \quad \text{for all} \quad i$$
$$t > 0: U^0_{0,j} = \exp(a.j.\Delta t), \; \theta^0_{o,j} = j.\Delta t, \; C^0_{o,j} = j.\Delta t$$
$$U^n_{L,j} = 0, \; \theta^n_{L,j} = 0, \; C^n_{L,j} = 0, \tag{17}$$

Where L corresponds to ∞.

Results and Discussion

For describing the physical understanding of the problem, the numerical computations are carried out for different physical parameter like as magnetic field parameter (*M*), Eckert number (*E*), thermal Grashof number (G_r), radiating parameter (*R*), mass Grashof number (G_m), accelerated parameter (*a*), permeability parameter (*k*), chemical reaction parameter (K_r) and Schmidt number (S_c). It is very hard to study the effects of all physical parameter in the present problem with title the effects of radiation and chemical reaction on free convection and mass transfer flow of dissipative fluid past an exponentially infinite vertical plate through a porous medium. In this problem the study is specially nave on the effects of all governing parameter on the transient velocity, temperature, concentration, Skin friction and Nusselt number. Default values of the thermo physical parameter are specified as follows,

Magnetic field parameter *M*=1.0, Eckert number *E*=0.1, thermal Grashof number G_r=10, radiating parameter *R*=2, mass Grashof number G_m=5, permeability parameter *k*=0.5, chemical reaction parameter K_r=1.0, Schmidt number S_c=2.01, Prandtl number P_r=0.71 (air), accelerated parameter *a*=0.2 and time *t*=0.2. All graphs are corresponds to these values unless otherwise indicated.

Figure (1) describes the velocity profiles for different values of *M* (magnetic field parameter). It is found that the velocity decreases with increasing value of magnetic parameter for air (P_r=0.71). The presence of transverse magnetic field produces a resistive force on the fluid flow. This force leads to slow down the motion of electrically conducting fluid.

The effects of *E* (Eckert number) on the velocity field display in the figure (2). Ratio between the kinetic energy of the flow to the boundary layer enthalpy difference is called the Eckert number. The effects of viscous dissipation on the flow field is causes to the increase of energy which imparting a greater fluid temperature and as a greater buoyancy force. The increase in the buoyancy force due to an increase in the dissipation parameter promoting the velocity of the flow.

Figure (3) and (6) express the velocity variations with G_r (thermal Grashof number) and G_m (mass Grashof number). It is due to the that fact that the increase in the values of thermal Grashof number and mass Grashof number has the propensity to increase the thermal and mass buoyancy effect. This gives rise to an increase in the induced flow.

It is found that from the figure (4) is velocity decreases for the increasing value of *R* (radiation parameter). The reverse effect is noticed for the *a* (accelerating parameter) which is shown in the figure (5) that velocity increases for the increasing value of accelerating parameter in the air. It is marked from the figure (7) and (8) that velocity rises for the rising value of *k* (permeability parameter) and velocity reduces for the rising value of K_r (chemical reaction parameter).

In figure (9) the velocity profiles shown for the different values of S_c (Schimdt number) on air (P_r=0.71). An increasing Schimdt number implies that the viscous forces dominate over the diffusional effects. Schimdt number in free convection controls, in fact, represents the relative effectiveness of momentum and mass transport by diffusion in the velocity and concentration boundary layers. Therefore an increase in Schimdt number will counter-act momentum diffusion since viscosity effects will increase and molecular effects will reduced. The flow will therefore be decelerated with a increase in Schimdt number.

The figure (10)-(14) illustrates the temperature profiles for different parameter like as *R*, K_r, *k*, *E*, G_r in air (P_r=0.71). It is clear from the figure that temperature increases for the increasing value of permeability parameter (*k*), Eckert number (*E*) and Thermal Grashof number (G_r). Temperature decreases for the increasing value of chemical reaction parameter (K_r) and radiating parameter (*R*).

The effects of various parameter on the concentration profiles are described by the figure (15) and (16). It shows that for the increasing values of Schmidt number (S_c) and chemical reaction parameter (K_r) causes the decrease of concentration.

The skin friction and Nusselt number profiles are also demonstrated with the help of graph. Skin friction are explained in the figure from (17)-(21) for the different values of *a*, *R*, G_r, *M* and *E*. For increasing the value of accelerated parameter (*a*), radiating parameter (*R*) and magnetic field parameter (*M*) skin friction decreases. As well as increase of Eckert number for the (*E*) and permeability parameter (*k*) the skin friction increases. It is marked from the figure (22)-(25) that the Nusselt number profiles decreases for the increase of Eckert number (*E*) and accelerated parameter (*a*). But when the values of radiating parameter (*R*) and magnetic field parameter (*M*) increases the Nusselt number increases. In this paper we extended the work of Rajesh, V[13] numerically.

Figures:

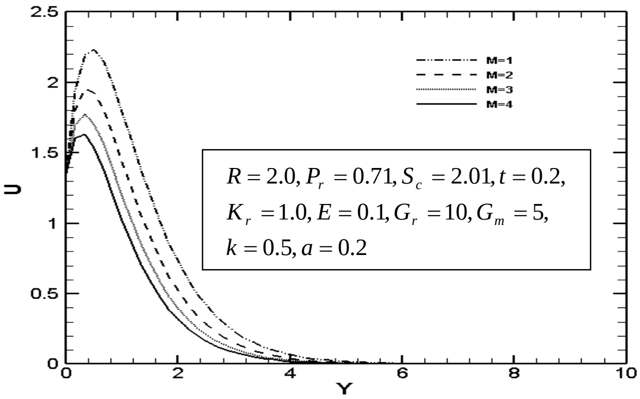


Fig 1. Velocity profiles for different values of magnetic parameter *M* against *Y*

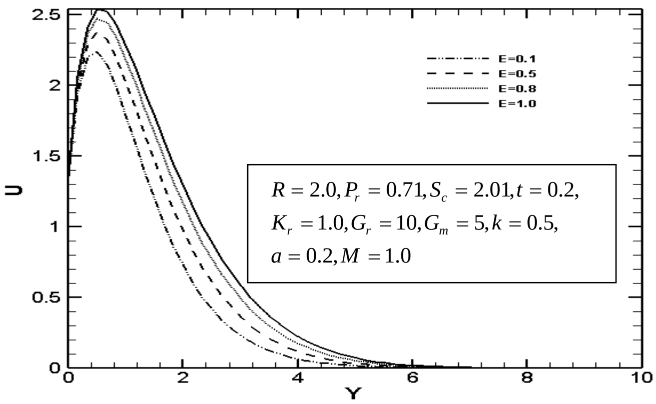


Fig 2. Velocity profiles for different values of Eckert number *E* against *Y*

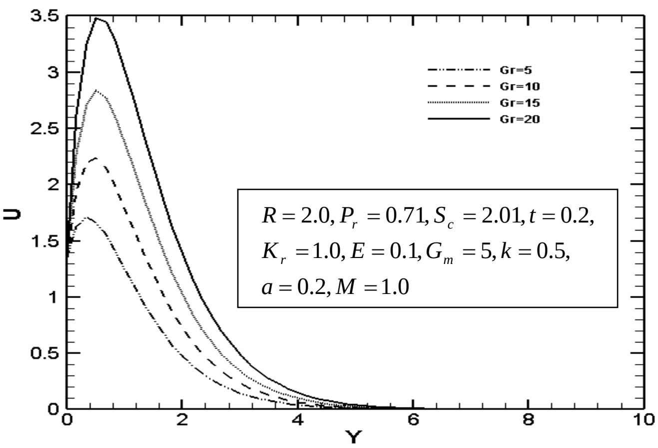


Fig 3. Velocity profiles for different values of thermal Grashof number G_r against *Y*

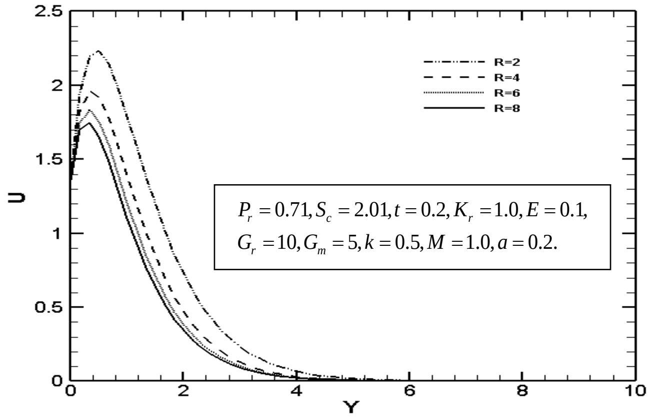


Fig 4. Velocity profiles for different values of radiating parameter *R* against *Y*

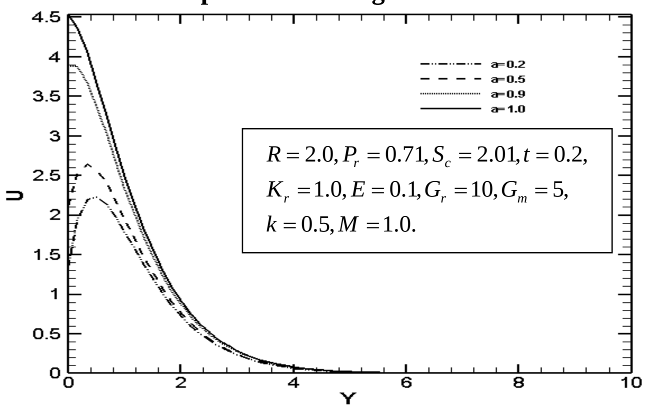


Fig 5. Velocity profiles for different values of accelerating parameter *a* against *Y*

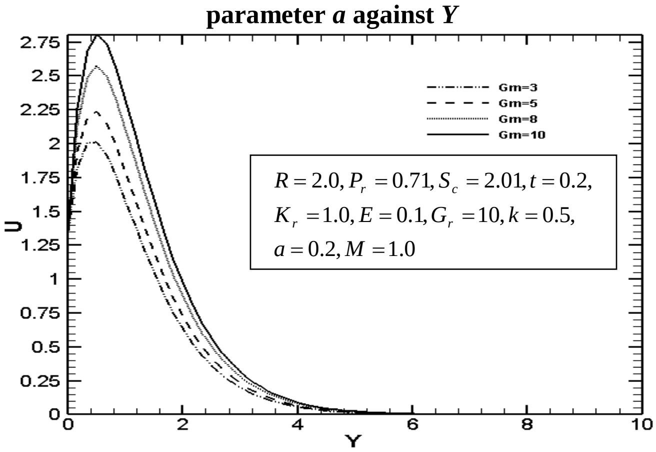


Fig 6. Velocity profiles for different values of mass Grashof number G_m against *Y*

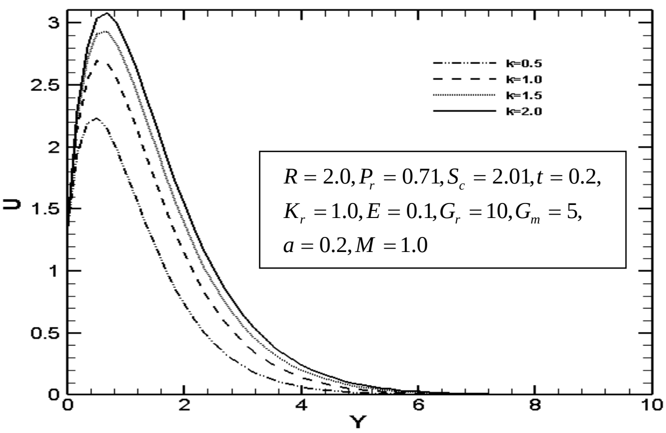


Fig 7. Velocity profiles for different values of permeability parameter *k* against *Y*

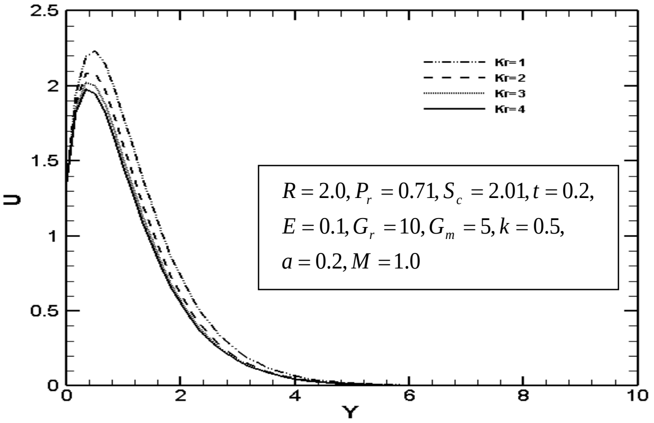


Fig 8. Velocity profiles for different values of chemical reaction K_r against Y

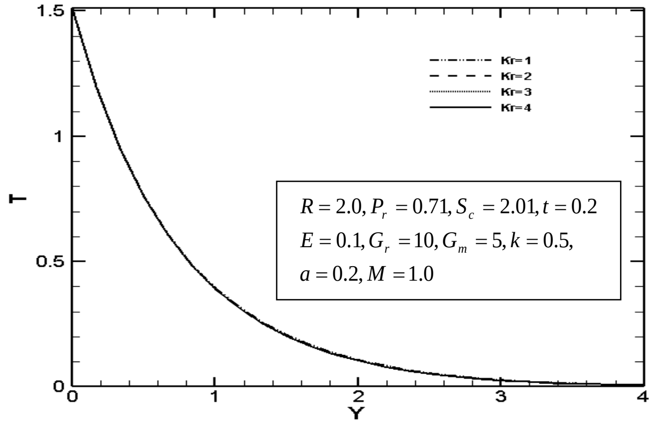


Fig 12. Temperature profiles for different values of chemical reaction K_r against Y

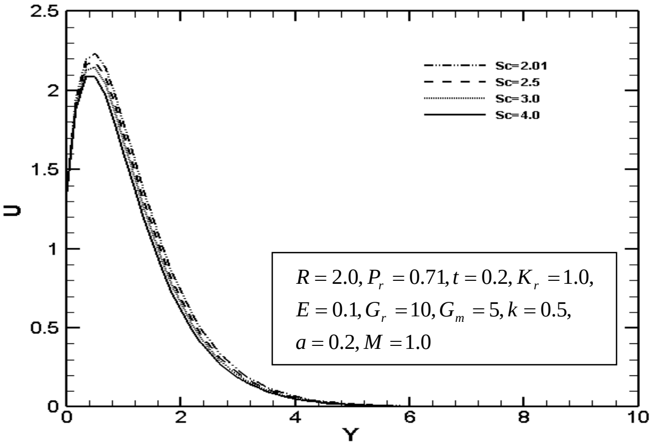


Fig 9. Velocity profiles for different values of Schmidt number S_c against Y

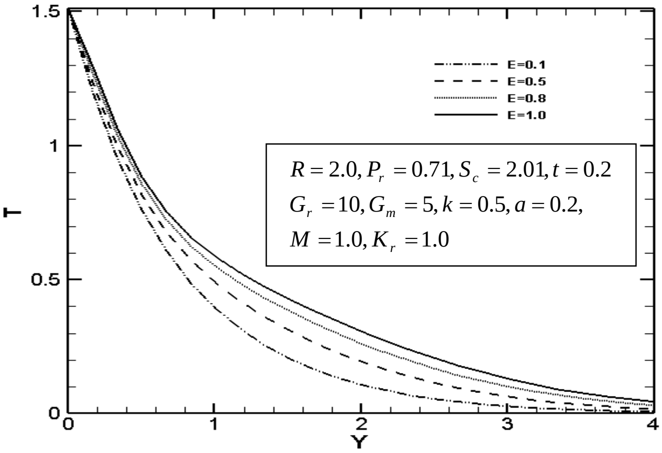


Fig 13. Temperature profiles for different values of Eckert number E against Y

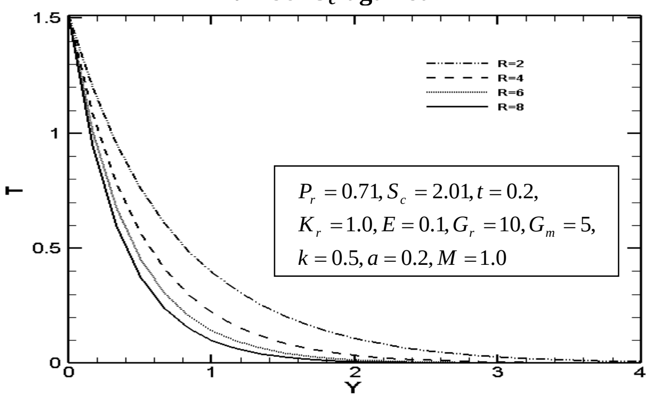


Fig 10. Temperature profiles for different values of radiating parameter R against Y

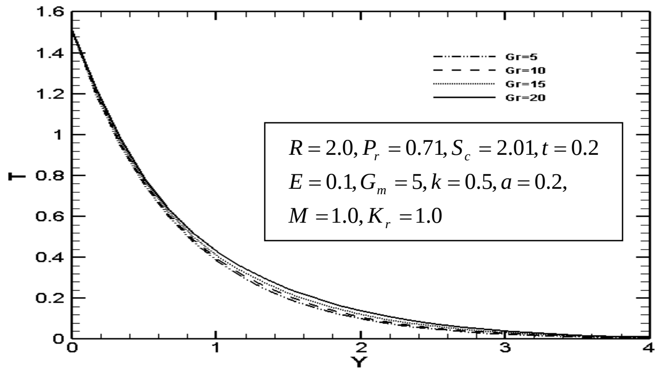


Fig 14. Temperature profiles for different values of thermal Grashof number G_r against Y

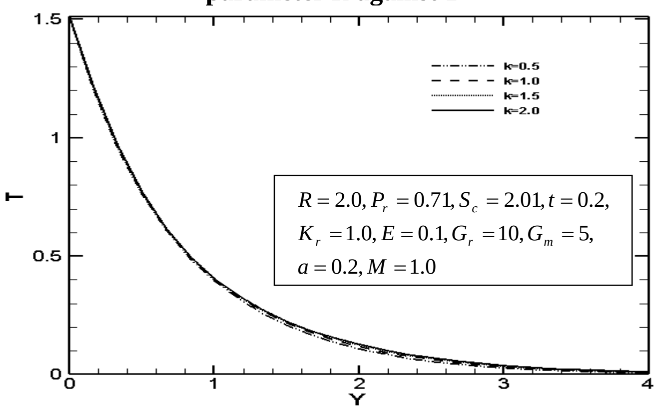


Fig 11. Temperature profiles for different values of permeability parameter k against Y

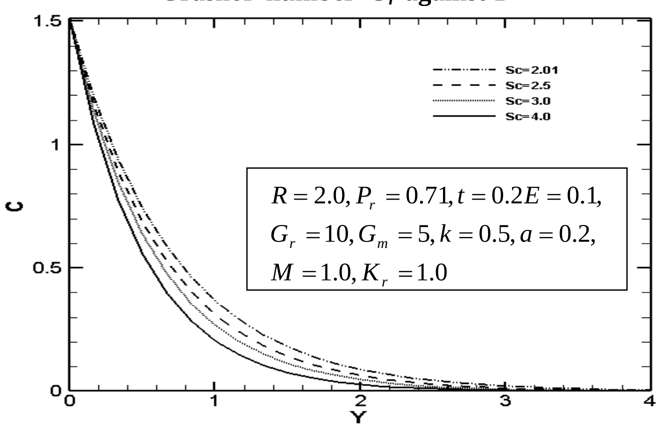


Fig 15. Concentration profiles for different values of Schmidt number S_c against Y

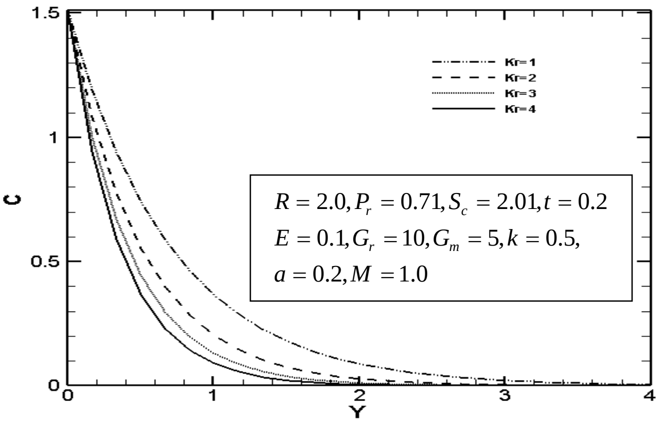


Fig 16. Concentration profiles for different values of chemical reaction K_r against *Y*

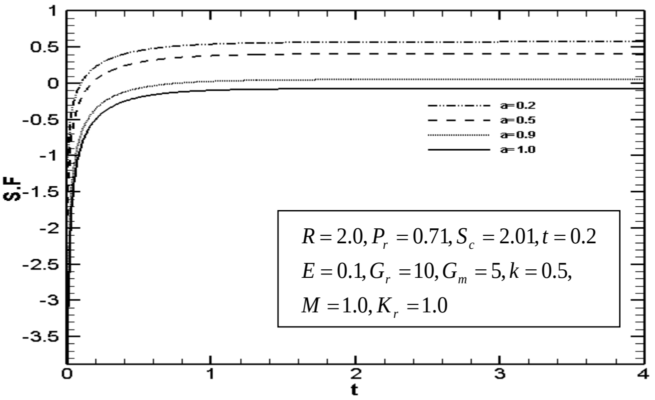


Fig 17. Skin friction profiles for different values of accelerating parameter *a* against *t*

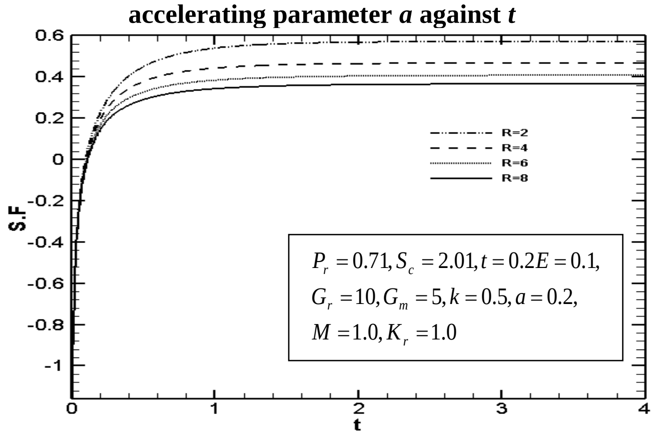


Fig 18. Skin friction profiles for different values of radiating parameter *R* against *t*

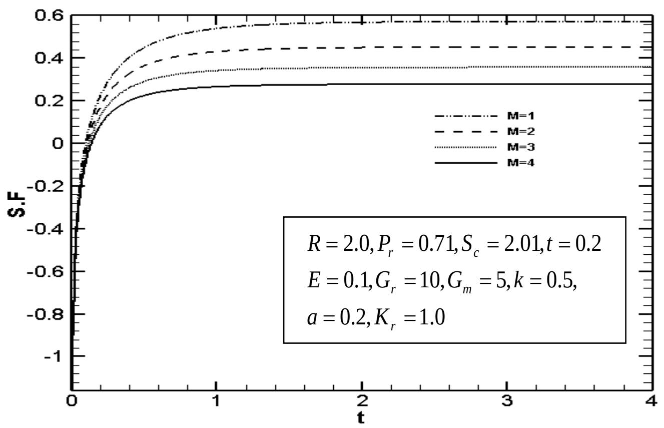


Fig 19. Skin friction profiles for different values of magnetic parameter *M* against *t*

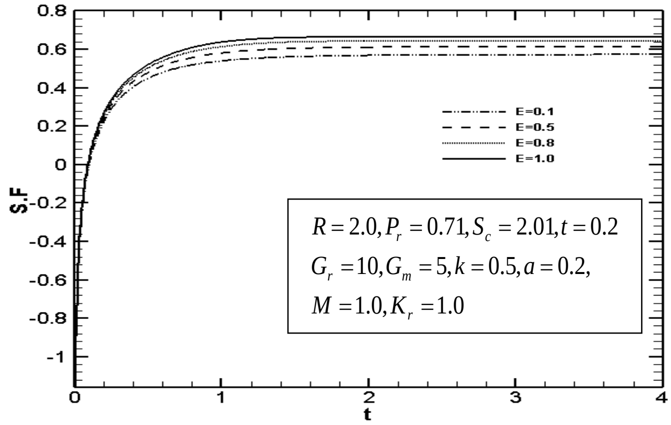


Fig 20. Skin friction profiles for different values of Eckert number *E* against *t*

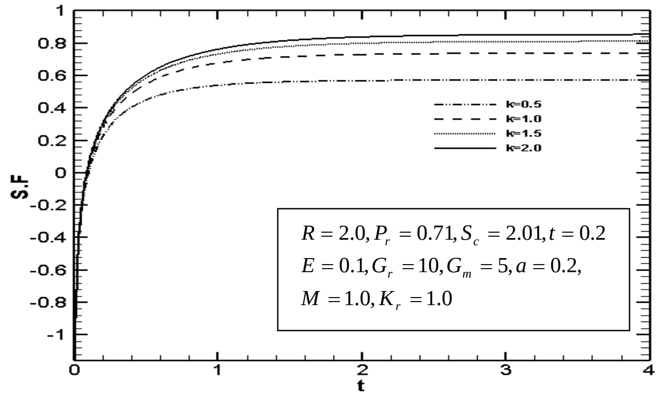


Fig 21. Skin friction profiles for different values of permeability parameter *k* against *t*

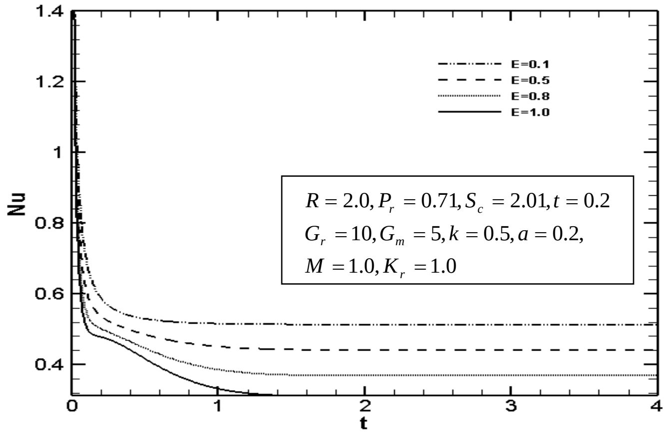


Fig 22. Nusselt number profiles for different values of Eckert number *E* against *t*

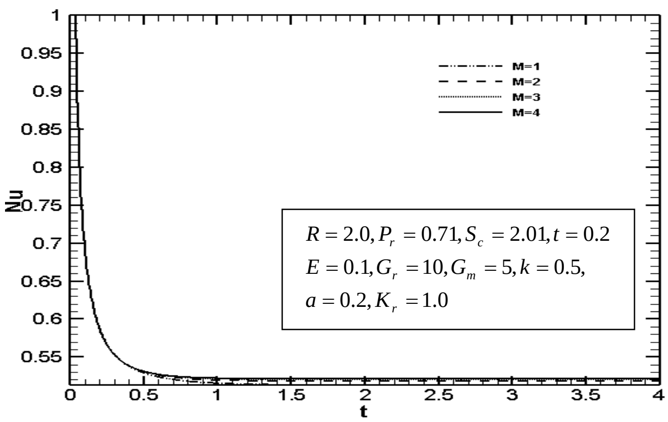


Fig 23. Nusselt number profiles for different values of magnetic parameter *M* against *t*

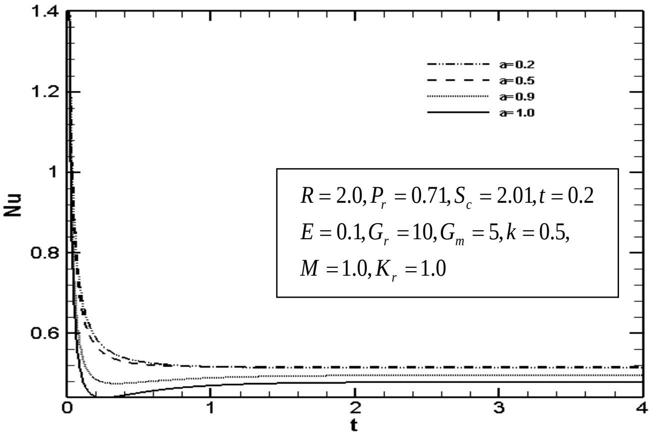


Fig 24. Nusselt number profiles for different values of accelerating parameter *a* against *t*

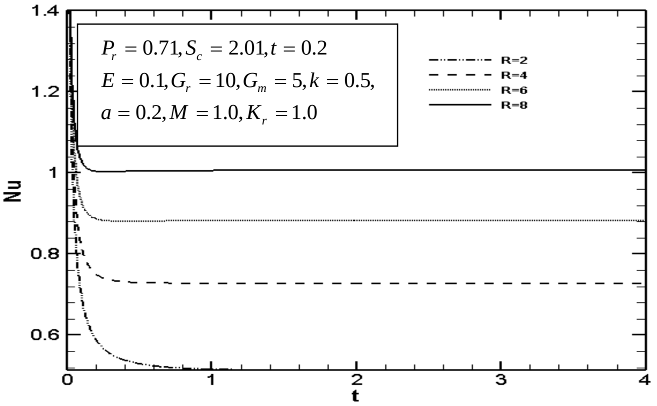


Fig 25. Nusselt number profiles for different values of radiating parameter *R* against *t*

Conclusion

In our present research work we have done the boundary layer equations into non-dimensional by using dimensionless quantities. These non-dimensional equations are the nonlinear partial differential equations and we solved them by explicit finite difference method. The following conclusions are shown in the overall observations.

The velocity increases with increasing value of E, G_r, G_m, a and k and velocity decreases for the increasing value of M, R, K_r and S_c. Temperature increases for the increasing value of k, E and G_r and temperature decreases for the increasing value of K_r and R. Concentration decreases for the increasing values of S_c and K_r. The skin friction decreases with increasing of M and a whereas skin friction increases with the increasing value of K. For increasing the value of a, R and M skin friction decreases. As well as for the increase of E and k the skin friction increases. Nusselt number profiles decreases for the increase of E and a. But when the values of R and M increases the Nusselt number increases.

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Nomenclature

S.F Skin friction

$\bar{C}_\infty$ Concentration in the fluid far away from the plate

$\bar{C}_w$ Concentration of the plate

A Constant

$\bar{y}$ Coordinate axis normal to the plate

C Dimensionless Concentration

y Dimensionless Concentration axis normal to the plate

u Dimensionless velocity

B_0 External magnetic field

H_0 Magnetic field intensity

G_m Mass Grashof number

E Eckert number

p_r Prandtl number

N_u Nusselt number

S_c Schmidt number
q_r The radiation heat flux
$\bar{C}$ Species concentration in the fluid
C_p Specific heat at constant pressure
$\bar{T}_\infty$ Temperature of the fluid far away from the plate
$\bar{T}$ Temperature of the fluid near the plate
$\bar{T}_w$ Temperature of the plate
k Thermal conductivity of the fluid
G_r Thermal Grashof number
$\bar{t}$ Time
$\bar{u}$ Velocity of the fluid in the $\bar{x}$ -direction
u_0 Velocity of the plate
a Accelerating parameter
D Mass diffusivity coefficient
g Acceleration due to gravity
K Permeability parameter
M Magnetic field parameter
t Dimensionless time

Greek symbols

μ Coefficient of viscosity
σ Electrical conductivity
ρ Density of the fluid
τ Dimensionless skin friction
θ Dimensionless temperature
ν Kinematic viscosity
α Thermal diffusivity
β' Volumetric coefficient of expansion Concentration
β Volumetric coefficient of thermal expansion

Subscripts

w Conditions on the wall
∞ Free stream conditions