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FIRST ORDER CHEMICAL REACTION EFFECTS ON A PARABOLIC FLOW PAST AN INFINITE VERTICAL PLATE WITH VARIABLE TEMPERATURE AND MASS DIFFUSION IN THE PRESENCE OF THERMAL RADIATION

R. Muthucumaraswamy[1] and P. Sivakumar[2]
[1]Department of Applied Mathematics, Sri Venkateswara College of Engineering, Irungattukottai, Sriperumbudur, India
[2]Department of Mathematics, P. B.College of Engineering, Irungattukottai, Sriperumbudur, India
E-Mail: sivakumarpushparaj@gmail.com

ABSTRACT

An analysis is performed to study the effect on a parabolic flow past an infinite vertical plate with variable temperature and mass diffusion in the presence of thermal radiation. Closed form analytic solutions are obtained for temperature, concentration, velocity by Laplace Transform technique and presented graphically for different values of physical parameters. The effects of various parameters on flow variables are illustrated graphically and the physical aspects of the problem are discussed.

Keywords: chemical reaction, vertical plate, mass diffusion, thermal radiation, Laplace transforms technique.

INTRODUCTION

Free convection flow involving coupled heat and mass transfer occurs frequently in several areas of chemical engineering and manufacturing process areas. A few representative fields of interest in which combined heat and mass transfer plays an important role are in designing of chemical processing equipment, formation and dispersion of fog, distribution of temperature and moisture over agricultural fields and fruit trees, crop damage due to freezing and environmental disorders. Thermal radiation has become a significant branch of engineering sciences and is an essential aspect of various scenarios in mechanical, aerospace, chemical and solar power engineering.

The growing need for chemical reactions in chemical and hydrometallurgical industries requires the study of heat and mass transfer with chemical reaction. There are many transport processes that are governed by the combined action of buoyancy forces due to both thermal and mass diffusion in the presence of the chemical reaction effect. These processes are observed in nuclear reactor safety and combustion systems, solar collectors, as well as metallurgical and chemical engineering. Actually, many processes in new engineering areas occur at high temperature, and knowledge of radiation heat transfer becomes imperative for the design of the pertinent equipment. Nuclear power plants, gas turbines, and the various propulsion devices for aircraft, missiles, satellites, and space vehicles are examples of such engineering areas. Their other applications include solidification of binary alloys and crystal growth dispersion of dissolved materials or particulate water in flows, drying and dehydration operations in chemical and food processing plants, and combustion of atomized liquid fuels. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction.

Diffusion rates can be changed tremendously with chemical reactions. The chemical reaction effects depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In majority cases, a chemical reaction depends on the concentration of the species itself. A reaction is said to be first order, if the rate of reaction is directly proportional to the concentration itself. A few representative areas of interest in which heat and mass transfer combined along with chemical reaction play an important role in chemical industries like food processing and polymer production.

Chambre and Young [1] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Das et al. [2] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started vertical plate with uniform heat flux and mass transfer. Gupta et al. [3] studied free convection flow past a linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method. Kafousias and Raptis [4] extended this problem to include mass transfer effects subjected to variable suction or injection. Mass transfer effects on flow past an accelerated vertical plate a uniformly accelerated vertical plate was studied by soundalgekar [5]. Mass transfer effects on flow past an accelerated vertical plate with uniform heat flux was analyzed by the Singh and Singh

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[6]. Basant kumar Jha and Ravindra Prasad [7] analyzed mass transfer effects on the flow past an accelerated infinite vertical plate with heat sources.

Soundalgekar and Gupta [8] have studied free convection effects on the flow past an accelerated vertical plate. Raptis and Singh [9] have analyzed MHD free convection flow past an accelerated vertical plate. Muthucumaraswamy and Visalakshi [10] have considered thermal radiation effects on the unsteady free convective flow of a viscous incompressible flow past an exponentially accelerated infinite vertical plate with variable temperature and uniform mass diffusion. A radiation effect on an exponentially accelerated vertical plate with a uniform mass diffusion was studied by Sathappan and Muthucumaraswamy [11]. Singh and Kumar [12] have investigated analytically the free-convection flow of an incompressible and viscous fluid past an exponentially accelerated infinite vertical plate. Rajput and Kumar [13] analyzed with the Laplace-transform technique the rotation and radiation effects on a MHD free convection flow past an impulsively started vertical plate with variable temperature. Hussain and Takhar [14] have considered radiation effects on mixed convection along a vertical plate with uniform surface temperature. Effects of radiation in and optically thin gray gas flowing past a vertical infinite plate in the presence of magnetic field was studied by Rapits et al [15]. Raju *et al*. [16], studied radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface.

The objective of the present investigation is to study effects on a parabolic flow past an infinite vertical plate with variable temperature and also with variable mass diffusion in the presence of a homogeneous chemical reaction of first order. The dimensionless governing equations involved in the present analysis are solved using the Laplace Transform technique.

MATHEMATICAL ANALYSIS

Here the unsteady radiative flow of a viscous incompressible flow past an infinite vertical plate with variable temperature and also with variable mass diffusion in the presence of a homogeneous chemical reaction of first order has been considered. The unsteady flow of a viscous incompressible fluid which is initially at rest and surrounds an infinite vertical plate with temperature T_∞ and concentration C'_∞. The *x*-axis is taken along the plate in the vertically upward direction and the *y*-axis is taken normal to the plate. At time $t' \le 0$, the plate and fluid are at the same temperature T_∞. At time *t'> 0*, the plate is started with a velocity $u = u_0 . t'^2$ in its own plane against the gravitational field. The temperature from the plate as well as the concentration level near the plate is raised linearly with time t. It is assumed that the effect of viscous dissipation is negligible in the energy equation and there is a first order chemical reaction between the diffusing species and the fluid. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. Then under the usual Boussinesq's approximation the unsteady flow is governed by the following equations

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

$$\rho C_p \frac{\partial T}{\partial t'} = k \frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} \quad (2)$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y^2} - k_l (C' - C'_\infty) \quad (3)$$

With the following initial and boundary conditions:

$$\begin{aligned} & u = 0, T = T_\infty, \quad C' = C'_\infty \text{ for all } y, t' \le 0 \\ & t' > 0 : u = u_0 . t'^2, \; T = T_\infty + (T_W - T_\infty) A t', \\ & \qquad C' = C'_\infty + (C'_W - C'_\infty) A t' \text{ at } \; y = 0 \\ & u \to 0 \;\; T \to T_\infty, \; C' \to C'_\infty \text{ as } y \to \infty \end{aligned} \quad (4)$$

Where, $A = \left(\frac{u_0^2}{\nu} \right)^{\frac{1}{3}}$

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

$$\frac{\partial q_r}{\partial y} = -4a^* \sigma (T_\infty^4 - T^4) \quad (5)$$

It is assumed 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

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (6)$$

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

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

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On introducing the following non-dimensional quantities:

$$U = u\left(\frac{u_0}{\nu^2}\right)^{1/3},\ \ t = \left(\frac{u_0^{\ 2}}{\nu}\right)^{1/3} t',\ \ Y = y\left(\frac{u_0}{\nu^2}\right)^{1/3},$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ Gr = \frac{g\beta(T_w - T_\infty)}{(\nu . u_0)^{1/3}},$$

$$Gc = \frac{g\beta(C'_w - C'_\infty)}{(\nu . u_0)^{1/3}},\quad \Pr = \frac{\mu C_p}{k} \tag{8}$$

$$R = \frac{16a^*\sigma . T_\infty^{\ 3}}{k}\left(\frac{\nu^2}{u_0}\right)^{\frac{2}{3}},,\ \ Sc = \frac{\nu}{D}$$

The equations (1), (3) and (7), reduces to the following dimensionless form

$$\frac{\partial U}{\partial t} = Gr\,\theta + GcC + \frac{\partial^2 U}{\partial Y^2} \tag{9}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial Y^2} - \frac{R}{\Pr}\theta \tag{10}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Y^2} - KC \tag{11}$$

The initial and boundary conditions in non-dimensional quantities are

$$\begin{aligned} &U = 0, \theta = 0, C = 0 \ \text{for all}\ Y, t \le 0 \\ &t > 0: \quad U = t^2, \theta = t, C = t \ \text{at}\ Y = 0 \\ &U \to 0, \theta \to 0, C \to 0 \ \text{as}\ \ Y \to \infty \end{aligned} \tag{12}$$

The dimensionless governing equations (9) to (11) and the corresponding initial and boundary conditions (12) are tackled using Laplace transform technique.

$$U = 2\left(\frac{t^2}{6}\left[\left(3 + 12\eta^2 + 4\eta^4\right)erfc(\eta) - \frac{\eta}{\sqrt{\pi}}\left(10 + 4\eta^2\right)\exp(-\eta^2)\right]\right)$$

$$+d\left(\begin{array}{l} erfc(\eta) - \frac{\exp(bt)}{2}\left[\exp\left(2\eta\sqrt{bt}\right)erfc\left(\eta + \sqrt{bt}\right) + \exp\left(-2\eta\sqrt{bt}\right)erfc\left(\eta - \sqrt{bt}\right)\right] \\ -\frac{1}{2}\left[\exp\left(2\eta\sqrt{\Pr at}\right)erfc\left(\eta\sqrt{\Pr} + \sqrt{at}\right) + \exp\left(-2\eta\sqrt{\Pr at}\right)erfc\left(\eta\sqrt{\Pr} - \sqrt{at}\right)\right] \\ +\frac{\exp(bt)}{2}\left[\exp\left(2\eta\sqrt{\Pr(a+b)t}\right)erfc\left(\eta\sqrt{\Pr} + \sqrt{(a+b)t}\right) + \exp\left(-2\eta\sqrt{\Pr(a+b)t}\right)erfc\left(\eta\sqrt{\Pr} - \sqrt{(a+b)t}\right)\right] \end{array}\right)$$

$$+d\left[b\left(\begin{array}{l} t\left[\left(1 + 2\eta^2\right)erfc(\eta) - \frac{2\eta}{\sqrt{\pi}}\exp(-\eta^2)\right] \\ -\frac{t}{2}\left[\exp\left(2\eta\sqrt{\Pr at}\right)erfc\left(\eta\sqrt{\Pr} + \sqrt{at}\right) + \exp\left(-2\eta\sqrt{\Pr at}\right)erfc\left(\eta\sqrt{\Pr} - \sqrt{at}\right)\right] \\ +\frac{\eta\sqrt{\Pr}\sqrt{t}}{2\sqrt{a}}\left[\exp\left(-2\eta\sqrt{\Pr at}\right)erfc\left(\eta\sqrt{\Pr} - \sqrt{at}\right) - \exp\left(2\eta\sqrt{\Pr at}\right)erfc\left(\eta\Pr + \sqrt{at}\right)\right] \end{array}\right)\right]$$

$$+e\left(\begin{array}{l} erfc(\eta) - \frac{\exp(ct)}{2}\left[\exp\left(2\eta\sqrt{ct}\right)erfc\left(\eta + \sqrt{ct}\right) + \exp\left(-2\eta\sqrt{ct}\right)erfc\left(\eta - \sqrt{ct}\right)\right] \\ -\frac{1}{2}\left[\exp\left(2\eta\sqrt{ScKt}\right)erfc\left(\eta\sqrt{Sc} + \sqrt{Kt}\right) + \exp\left(-2\eta\sqrt{ScKt}\right)erfc\left(\eta\sqrt{Sc} - \sqrt{Kt}\right)\right] \\ +\frac{\exp(ct)}{2}\left[\exp\left(2\eta\sqrt{Sc(K+c)t}\right)erfc\left(\eta\sqrt{Sc} + \sqrt{(K+c)t}\right) + \exp\left(-2\eta\sqrt{Sc(K+c)t}\right)erfc\left(\eta\sqrt{Sc} - \sqrt{(K+c)t}\right)\right] \end{array}\right)$$

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$$+e\left[c\left(\begin{array}{l} t\left[\left(1+2\eta^2\right)erfc(\eta)-\frac{2\eta}{\sqrt{\pi}}\exp(-\eta^2)\right] \\ -\frac{t}{2}\left[\exp\left(2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}+\sqrt{Kt}\right)+\exp\left(-2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}-\sqrt{Kt}\right)\right] \\ +\frac{\eta\sqrt{Sc}\sqrt{t}}{2\sqrt{K}}\left[\exp\left(-2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}-\sqrt{Kt}\right)-\exp\left(2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}+\sqrt{Kt}\right)\right] \end{array}\right)\right]$$

$$\theta=\frac{t}{2}\left[\exp\left(2\eta\sqrt{\Pr a\,t}\right)erfc\left(\eta\sqrt{\Pr}+\sqrt{at}\right)+\exp\left(-2\eta\sqrt{\Pr a\,t}\right)erfc\left(\eta\sqrt{\Pr}-\sqrt{at}\right)\right]$$

$$-\frac{\eta\sqrt{\Pr}\sqrt{t}}{2\sqrt{a}}\left[\exp\left(-2\eta\sqrt{\Pr a\,t}\right)erfc\left(\eta\sqrt{\Pr}-\sqrt{at}\right)-\exp\left(2\eta\sqrt{\Pr a\,t}\right)erfc\left(\eta\sqrt{\Pr}+\sqrt{at}\right)\right]$$

$$C=\frac{t}{2}\left[\exp\left(2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}+\sqrt{Kt}\right)+\exp\left(-2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}-\sqrt{Kt}\right)\right]$$

$$-\frac{\eta\sqrt{Sc}\sqrt{t}}{2\sqrt{K}}\left[\exp\left(-2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}-\sqrt{Kt}\right)-\exp\left(2\eta\sqrt{Sc\,K\,t}\right)erfc\left(\eta\sqrt{Sc}+\sqrt{Kt}\right)\right]$$

Where $a=\frac{R}{\Pr}, b=\frac{R}{1-\Pr}, c=\frac{KSc}{1-Sc}, d=\frac{Gr}{b^2(1-\Pr)}, e=\frac{Sc}{c^2(1-Sc)}$ and $\eta=\frac{y}{2\sqrt{t}}$

RESULTS AND DISCUSSIONS

The numerical values of the velocity, temperature and concentration are computed for different physical parameters like thermal radiation parameter, chemical reaction parameter, Schmidt number, thermal Grashof number and mass Grashof number. The value of the Schmidt number Sc is taken to be 0.6 which corresponds to water-vapor. Also, the value of Prandtl number Pr is chosen such that they represent air (Pr = 0.71). The purpose of the calculations given here is to assess the effects of the parameters R, K, Gr, Gc and Sc upon the nature of the flow and transport. The solutions are in terms of exponential and complementary error function.

Figure-1 demonstrates the effects of the radiation parameter on velocity when (R= 2, 5, 10), K=2, Gr = Gc =5 and t = 0.4. It is observed that velocity increases with the decreasing thermal radiation parameter. The trend shows that velocity is suppressed due to higher thermal radiation.

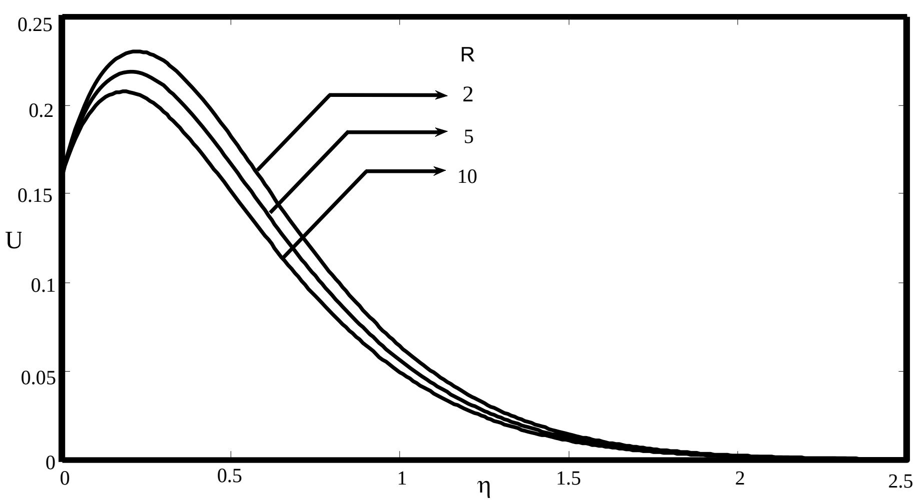

Figure-1. Velocity profiles for different R.

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Figure-2 demonstrates the effect of velocity profiles for different values of the chemical reaction parameter (K = 2, 5, 10), Gr = Gc = 5, R =2, and t = 0.4. It is observed that velocity increases with decreasing values of the chemical reaction parameter. The trend shows that there is a fall in velocity due to increasing values of the chemical reaction parameter.

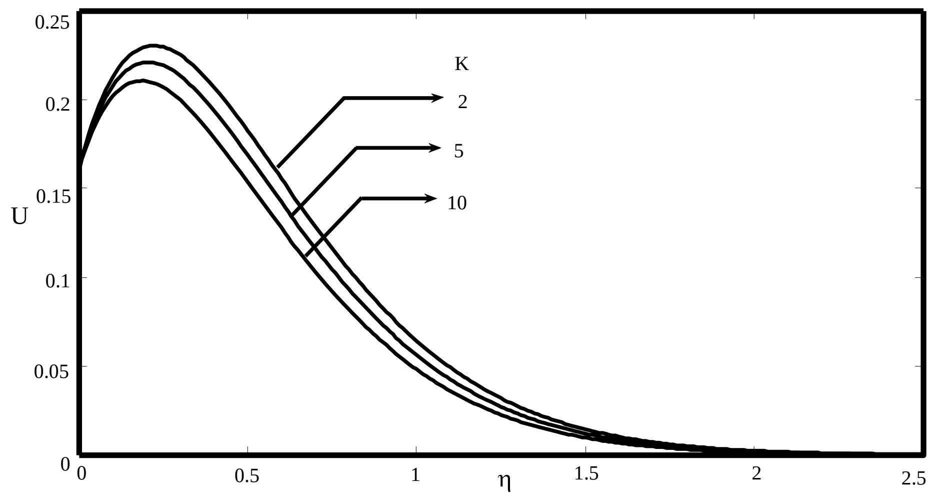

Figure-2. Velocity profiles for different K.

Figure-3 demonstrates the effects of the velocity profiles for different values of (t = 0.4, 0.6, 0.8,) R=2 and Gr = Gc =10. It is observed that the velocity increases with increasing values of the time. The profiles have the common feature that the concentration decreases in a motone fashion from the surface to a zero value far away in the free stream.

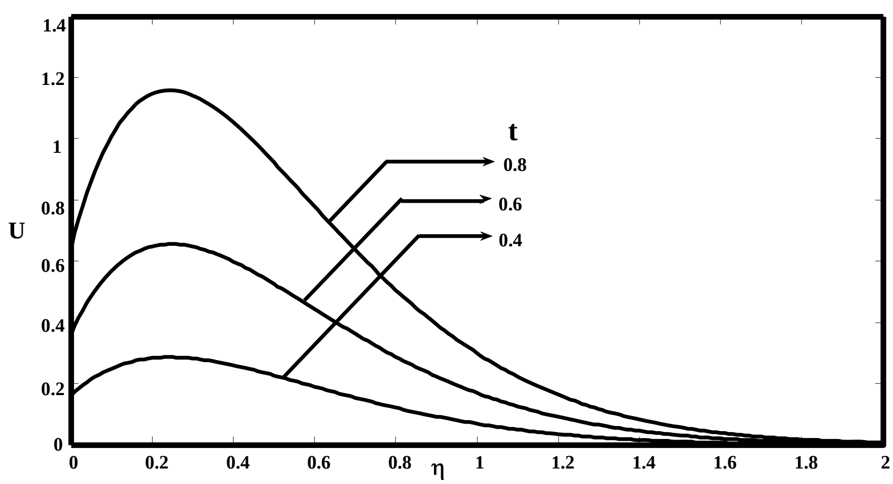

Figure-3. Velocity profiles for different t.

Figure-4 demonstrates the effect of velocity fields for different thermal Grashof number (Gr = 2, 5, 5), mass Grashof number (Gc = 5, 5, 10), K = 2, Sc = 0.6 and t = 0.4. It is clear that the velocity increases with increasing values of the thermal Grashof number or mass Grashof number. It is quite interesting to that the velocity increases very rapidly in the presence of mass Grashof number than thermal Grashof number.

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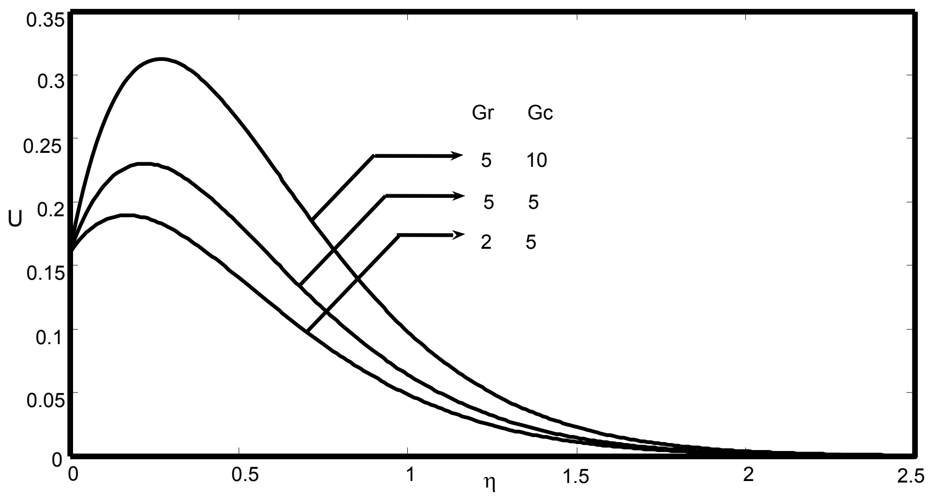

Figure-4. Velocity profiles for different Gr and Gc.

Figure-5 represents the effect of velocity profiles for different Schmidt number (Sc = 0.16, 0.3, 0.6,), Gr = 5, Gc= 5, K = 2, Pr = 0.71 and t = 0.4. The trend shows that the velocity increases with decreasing Schmidt number. It is observed that the relative variation of the velocity with the magnitude of the Schmidt number.

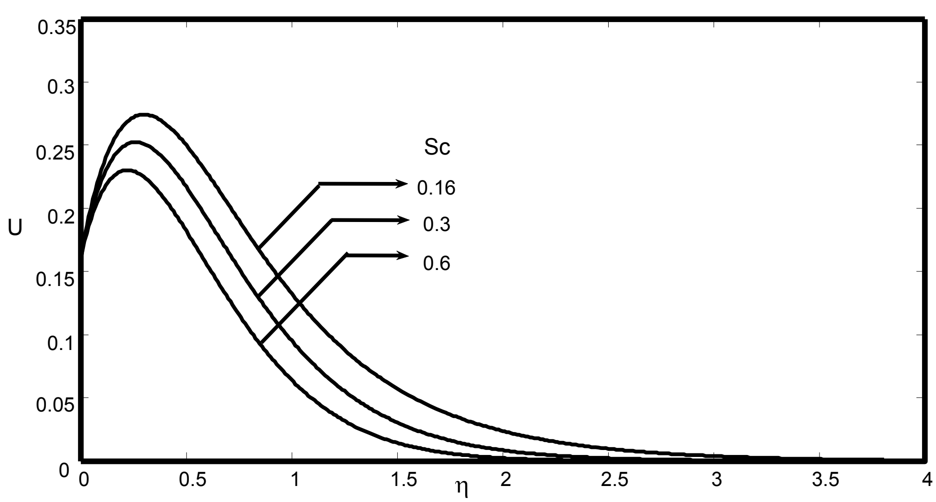

Figure-5. Velocity profiles for different Sc.

The concentration profiles for different Schmidt number (Sc = 0.16, 0.3, 0.6, K = 0.2 at time t = 0.2 are shown in Figure-6. The effect of the concentration is important in a concentration field. The profiles have a common feature that the concentration decreases in a monotone fashion from the surface to a zero value far away in the free stream. It is observed that the wall concentration increases with decreasing the values of the Schmidt number.

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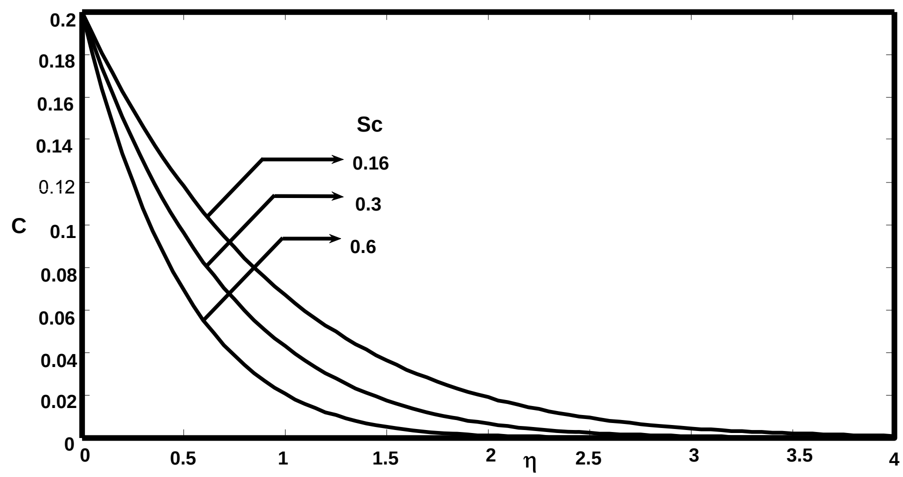

Figure-6. Concentration profile for several Sc.

The temperature profiles are calculated for different values of the thermal radiation parameter (R= 2, 5, 10) at time t = 0.4 and these are shown in Figure-7. It is observed that the temperature increases with the decreasing radiation parameter. The trend shows that there is a fall in plate temperature due to higher thermal radiation.

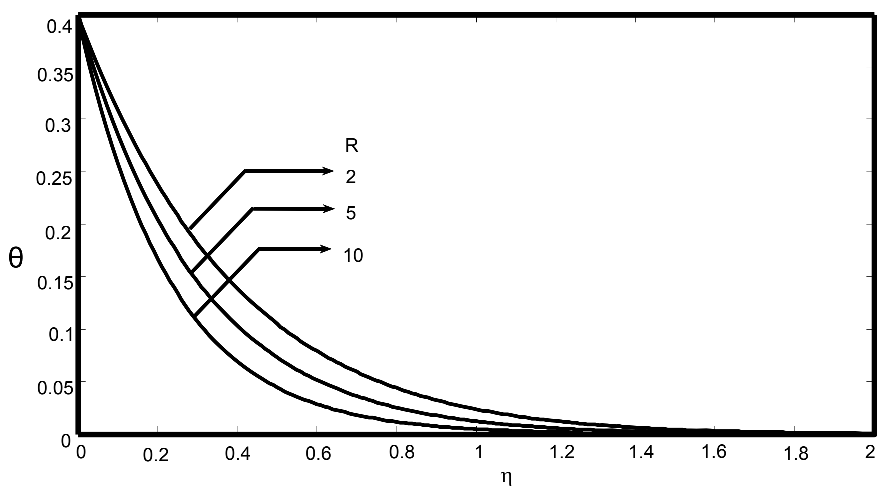

Figure-7. Temperature profiles for different R.

CONCLUSIONS

An exact solution of effects on a parabolic flow past an infinite vertical plate with variable temperature and also with variable mass diffusion in the presence of a homogeneous chemical reaction of first order. The dimensionless governing equations are solved by the usual Laplace-transform technique. The effect of different parameters like thermal Grashof number, mass Grashof number, chemical reaction parameter, radiation parameter and t are studied graphically. The conclusions of the study are as follows:

a) The concentration of the plate increases with decreasing values of the chemical reaction parameter or Schmidt number. But the trend is just reversed with respect to time t.

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b) The plate temperature decreases with increasing values of the thermal radiation parameter.

c) The velocity decreases with increasing values of the Prandtl number or thermal radiation parameter or Schmidt number in the case of the cooling of the plate but the trend is just reversed in the case of the heating of the plate.

Nomenclature

A constants
C' species concentration in the fluid $kg\,m^{-3}$
C dimensionless concentration
C_p specific heat at constant pressure $J.kg^{-1}.k$
D mass diffusion coefficient $m^2.s^{-1}$
Gc mass Grashof number
Gr thermal Grashof number
g acceleration due to gravity $m.s^{-2}$
k thermal conductivity $W.m^{-1}.K^{-1}$
Pr Prandtl number
Sc Schmidt number
T temperature of the fluid near the plate K
t' time s
u velocity of the fluid in the x'-direction $m.s^{-1}$
u_0 velocity of the plate $m.s^{-1}$
u dimensionless velocity

Greek symbols

β volumetric coefficient of thermal expansion K^{-1}
β^* volumetric coefficient of expansion with concentration K^{-1}
μ coefficient of viscosity $Ra.s$
ν kinematic viscosity $m^2.s^{-1}$
ρ density of the fluid $kg.m^{-3}$
τ dimensionless skin-friction $kg.m^{-1}.s^2$
θ dimensionless temperature
η similarity parameter
$erfc$ complementary error function

Subscripts

w conditions at the wall
∞ free stream conditions

REFERENCES

[1] Chambre P.L; Young J.D. 1958. On the diffusion of a chemically reactive species in a laminar boundary layer flow, The Physics of Fluids. 1: 48-54.

[2] Das U.N.; Deka, R.K; Soundalgekar V.M. 1999. Effects of mass transfer on flow past an impulsively started infinite vertical plate with chemical reaction. The Bulletin of GUMA. 5: 13-20.

[3] Gupta A.S.; Pop I., Soundalgekar V.M. 1979. Free convection effects on the flow past an accelerated vertical plate in an incompressible dissipative fluid. Rev. Roum. Sci.Techn.-Mec. Apl. 24: 561-568.

[4] Kafouias N.G., Raptis A.A. 1981. Mass transfer and free convection effects on the flow past an accelerated vertical infinite plate with variable suction or injection. Rev. Roum. Sci. Techn.-Mec. Apl. 26(1981): 11-22.

[5] Soundalgekar V.M. 1982. Effects of mass transfer on the flow past an accelerated vertical plate Letters in Heat and Mass Transfer. 9(1982): 65-72.

[6] Singh A.K., Singh J. 1983. Mass transfer effects on the flow past an accelerated vertical plate with constant heat flux. Astrophysics and Space Science. 97: 57-61.

[7] Basanth Kumar Jha, Ravindra Prasad, Surendra Rai. 1991. Mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux. Astrophysics and Space Science. 181: 125-134.

[8] Soundalgekar V.M. and S.K. Gupta. 1980. Free Convection effects on the flow past an accelerated vertical plate. Act Cienica India, Vim. 3: 138-143.

[9] Raptis A. and Singh A.K. 1983. MHD Free convection flow past an accelerated vertical plate. Int. Comm. Heat Mass Transfer. 10: 313-321.

[10] Muthuchumaraswamy R and Visalakshi V. 2011. Radiative flow past an exponentially accelerated

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ARPN Journal of Engineering and Applied Sciences

vertical plate with variable temperature and Mass diffusion. Annals of Faculty Engineering Hunedoara-Int. Journal of Engineering, IX: 137-140.

[11] Sathappan K.E and Muthucumaraswamy R. 2011. Radiation effects on exponentially accelerated vertical plate with uniform mass diffusion. Int. J. of Automotive and Mechanical Engineering (IJAME). 3: 341-349.

[12] Singh A.K and Naveen Kumar. 1983. Fee-Convection flow past an exponentially accelerated vertical plate. Astrophysics and space Science. 98: 245-248.

[13] Rajput U.S and Surendra Kumar. 2011. Rotation and Radiation effects on MHD flow past an impulsively started vertical plate with variable temperature. Int. J. of Math. Analysis. 5, 2011: 1155-1163.

[14] Hossain M.A. and Takhat H.S. 1996. Radiation effects on mixed convection along a vertical plate with uniform surface temperature. Int. J. heat Mass transfer. 31: 243- 248.

[15] Rapits A., Perdikis C. and Leontitsis A. 2003a. Effects of radiation in an optically thin gray gas flowing past a vertical infinite plate in the presence of magnetic field. Int. J. Heat mass transfer. 39: 771-773.

[16] Raju M.C, Varma S.V.K, Reddy N.A. 2012. Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Journal of Future Engineering and Technology. 7: 7-12.