Radiation Effect of Jeffery Fluid on Heat and Mass Transfer in a Vertical Channel with Chemical Absorption, Dufour and Variable Thermal Conductivity.

E. Omokhuale[1] and I.J. Uwanta[2]

[1]Department of Mathematical Sciences, Federal University Gusau, PMB 1001, Gusau, Nigeria.
[2]Department of Mathematics, Usmanu Danfodiyo University, PMB 2346, Sokoto, Nigeria.

E-mail: emmanuelomokhuale@yahoo.com*
imeuwanta@yahoo.com

ABSTRACT

This paper studies radiation effect of Jeffery Fluid on heat and mass transfer in a vertical channel with chemical absorption, Dufour and variable thermal conductivity. The governing non–linear partial differential equations in dimensionless form are approximated by implicit finite difference schemes of Crank-Nicolson type and solved numerically for the velocity, temperature and concentration. The Rosseland approximation has been used to describe the radiative heat flux in the energy equation. Effect of the parameters governing the flow like Jeffery parameter, thermal Grashof number, mass Grashof number, Schmidt number, Prandtl number, magnetic parameter, Dufour number, chemical absorption, permeability parameter, Radiation parameter, Radiation, and suction parameters were shown graphically and discussed. Velocity and temperature profiles drawn for controlling parameters reveal the tendency of the solution.

(Keywords: Dufour effect, heat and mass transfer, radiation, Jeffery fluid, porous medium, variable thermal conductivity)

INTRODUCTION

The effect of thermal radiation has significant industrial applications such as glass production and furnaces design and in space technology such as; cosmic flight, aerodynamics rocket, propulsion system, and plasma physics which operates at high temperatures.

A numerical investigation on the effect of chemical reaction, radiation and magnetic field on the unsteady free convective flow, heat and mass transfer characteristics in a viscous, incompressible and electrically conducting fluid past an exponentially accelerated vertical plate is carried out by Kishore *et al.* (2013).

Kurunakar *et al.* (2013) studied the effects of heat and mass transfer on MHD mixed convection flow of a vertical surface with radiation, heat source/absorption, and chemical reaction. They obtained their results using perturbation method. Jha and Ajibade (2010) researched on free convection heat and mass transfer flow in a vertical channel with Dufour effect. Sivaiah *et al.* (2012) studied unsteady MHD mixed convection flow past a vertical porous plate in the presence of radiation numerically by finite difference method.

Sharma *et al.* (2012) examined using explicit finite difference method Soret and Dufour effects on unsteady MHD mixed convection flow past a radiative vertical porous plate embedded in a porous medium with chemical reaction. The effects of various parameters on the velocity, temperature and concentration field were discussed. Sharma *et al.* (2006) have reported on the radiation effect with simultaneous thermal mass diffusion in MHD mixed convection flow from a vertical surface.

Nadeem *et al.* (2011) investigated effects of thermal radiation on the boundary layer flow of a Jeffery fluid over an exponentially stretching surface.

Olajuwon and Oahimire (2013) reported unsteady free convection heat and mass transfer in an MHD micro-polar fluid in the presence of thermo diffusion and thermal radiation.

Ahmmed *et al.* (2013) discussed radiation and mass transfer effects on MHD free convection flow past a vertical plate with variable temperature and concentration.

Krishna Reddy *et al.* (2012) analyzed heat and mass transfer effects on unsteady MHD free convection flow past a vertical permeable moving plate with radiation. Uwanta and Sani (2013) discussed heat and mass transfer flow past an infinite vertical plate with thermal conductivity numerically using implicit finite difference method. Chamkha *et al.* (2001) investigated laminar free convection flow of air past a semi-infinite vertical plate in the presence of chemical species concentration and thermal radiation effects by implicit finite difference technique.

Kasavaiah *et al.* (2012) examined the steady two dimensional free convection heat and mass transfer flow of an electrically conducting and chemically reacting fluid through a porous medium bounded by a vertical porous medium bounded by a vertical infinite surface with constant suction heat flux in the presence of uniform magnetic field.

Makinde (2005) studied free convection flow with thermal radiation and mass transfer past a moving vertical plate. Radiation and mass transfer effect on moving vertical plate with variable temperature and viscous dissipation was studied numerically by Kesavaiah *et al.* (2012). Prasad *et al.* (2007) analyzed the interaction of free convection with thermal radiation of viscous incompressible unsteady flow past an impulsively stated vertical plate with heat and mass transfer using implicit finite difference method.

Olajuwon and Oahimere (2013) investigated analytically the effects of thermo-diffusion and thermal radiation on unsteady heat and mass transfer of free convective MHD micro-polar fluid flow bounded by a semi-infinite porous plate in a rotating frame under the action of transverse magnetic field and suction. Krishna Reddy *et al.* (2012) analyzed the effect of radiation on unsteady MHD free convection heat and mass transfer flow on a viscous incompressible, electrically conducting fluid past a vertical permeable moving plate numerically.

In view of the importance of chemical absorption, Dufour and variable thermal conductivity, in this paper, radiation effect of Jeffery fluid on heat and mass transfer past a vertical porous plate with chemical absorption, Dufour and variable thermal conductivity is investigated. The dimensionless equations have been solved numerically by implicit finite difference schemes of Crank – Nicolson type. The results show that the velocity field increases as Gr, Gc, Ec, Du, Sr, S, η , t and λ_1 increased but decreases for Pr, Sc, M, R, N, γ and K.

The temperature profile increases due to the presence of heat generation, Dufour number, and time but reduces for increased values of Prandtl number, radiation and suction. Similarly, concentration rises with chemical absorption parameter and time, and decreases with increasing values of chemical reaction parameter and Schmidt number (Sc), and suction.

PROBLEM FORMULATION

An unsteady two–dimensional heat and mass transfer flow of an incompressible electrically conducting viscous fluid past a finite vertical porous plate moving with Jeffery fluid. The x-axis is taken on the infinite plate, and parallel to the free stream velocity which is vertical and the y-axis is taken normal to the plate.

A magnetic field B_0 of uniform strength is applied transversely to the direction of the flow. Where fluid suction or injection and magnetic field are raised to T'_w and C'_w respectively and are higher than the ambient temperature and that of fluid.

In addition, the chemical absorption, Dufour, radiation chemical reaction and variable thermal conductivity effect is taken into account. It is assumed that induced magnetic field is negligible, viscous dissipation and the heat generated is not neglected.

The governing equations of the flow under the usual Boussinesq and boundary-layer approximation can be written as:

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

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \frac{\nu}{1+\lambda_1}\frac{\partial^2 u'}{\partial y'^2} + g\beta\left(T' - T_0'\right) + g\beta^*\left(C' - C_0'\right) - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K^*}u' \tag{2}$$

$$\begin{aligned}\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} &= \frac{k_0}{\rho Cp}\frac{\partial}{\partial y'}\left\{\left[1 + m\left(T' - T_0'\right)\right]\frac{\partial T'}{\partial y'}\right\} + \frac{Q}{\rho Cp}\left(T' - T_0'\right) \\ &\quad + \frac{D_m}{\rho Cp}\left(C' - C_0'\right) - \frac{1}{\rho Cp}\frac{\partial q_r}{\partial y'} + \frac{\mu}{Cp}\left(\frac{\partial u'}{\partial y'}\right)^2\end{aligned} \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} + Q_1\left(T' - T_0'\right) - R^*\left(C' - C_0'\right) \tag{4}$$

with the following initial and boundary conditions:

$$\left.\begin{aligned} t' \le 0, u' = 0, T' \to T_0', C' \to C_0' \; for\, all\; y' \\ t' > 0, u' = 0, T' \to T_w', C' \to C_w' \;\; at\; y' = 0 \\ u' = 0, T' = T_0', C' = C_0'\, at\; y' = 1 \end{aligned}\right\} \tag{5}$$

The radiative heat flux term by using Rosseland approximation is given by:

$$q_r = -\frac{4\sigma^*}{3a_R}\frac{\partial T^4}{\partial y'} \tag{6}$$

where *u* and *v* are velocity components in x' and y' directions respectively, *T* is the temperature, *t* is the time, g is the acceleration due to gravity, β is the thermal expansion coefficient, β^* is the concentration expansion coefficient, υ is the kinematic viscosity, D is the chemical molecular diffusivity, C_p is heat capacity at constant pressure, B_0 is a constant magnetic field intensity, σ is the electrical conductivity of the fluid, k_0 is the variable thermal conductivity, ρ is the density, λ_1 is the Jeffery fluid, q_r is the radiative heat flux, T_S is the mean fluid temperature T_w is the wall temperature, T_0 is the free stream temperature, C_w is the species concentration at the plate surface, C_0 is the free stream concentration, Q is the heat generation coefficient, Q_1 is the chemical absorption parameter, and is the chemical reaction parameter . $v_0 > 0$ is the suction parameter and $v_0 < 0$ is the injection parameter. On introducing the following non-dimensional quantities:

$$\left.\begin{aligned}
&u=\frac{u'}{u_0},y=\frac{y'}{h},t=\frac{t'u_0{}^2}{t_0},\nu=\frac{\mu}{\rho},\theta=\frac{(T'-T'_0)}{(T'_w-T'_0)},C=\frac{(C'-C'_\infty)}{(C'_w-C'_0)}\\
&\Pr=\frac{\mu Cp}{k_0},M=\frac{\sigma B_0^2\nu}{\rho u_0{}^2},K=\frac{\nu}{K^*u_0{}^2},Gr=\frac{g\beta\nu(T'_w-T'_0)}{u_0{}^2}\\
&Gc=\frac{g\beta^*\nu(C'_w-C'_0)}{u_0{}^2},Sc=\frac{\nu}{D},\phi=\frac{Q_1(T'_w-T'_0)}{\nu(C'_w-C'_0)},S=\frac{Q\nu}{\rho Cpu_0{}^2}\\
&Ec=\frac{k_0u_o{}^2}{\rho Cp(T'_w-T'_0)},Du=\frac{D_m\nu(C'_w-C'_0)}{T_S(T'_w-T'_0)u_0{}^2},\gamma=\frac{v_0}{u_0},\eta=m(T'_w-T'_0)\\
&N=\frac{R^*\nu}{u_0{}^2},R=\frac{4\sigma^*T_\infty^3}{ka_R}
\end{aligned}\right\}\tag{7}$$

where u_0 and t_0 are reference velocity and time respectively. Using (1) and (6), Equations (2) - (5) are transformed to the following:

$$\frac{\partial u}{\partial t}-\gamma\frac{\partial u}{\partial y}=\frac{1}{1+\lambda_1}\frac{\partial^2u}{\partial y^2}+Gr\theta+GcC-Mu-Ku\tag{8}$$

$$\frac{\partial\theta}{\partial t}-\gamma\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\left(1+\frac{4}{3}R+\eta\theta\right)\frac{\partial^2\theta}{\partial y^2}+\frac{\eta}{\Pr}\frac{\partial\theta}{\partial y}+S\theta+DuC+Ec\left(\frac{\partial u}{\partial y}\right)^2\tag{9}$$

$$\frac{\partial C}{\partial t}-\gamma\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2C}{\partial y^2}+\phi\theta-NC\tag{10}$$

The corresponding boundary conditions are:

$$\left.\begin{aligned}
&u=0,\theta=0,C=0\ for\,all\ y:t\le 0\\
&u=0,\theta=1,C=1\ at\ y=0\\
&u=0,\theta=0,C=0\,at\ y=1
\end{aligned}\right\}\tag{11}$$

where Gr is the thermal Grashof number, Gc is the mass Grashof number, Sc is the Schmidt number, $\Pr$ is the Prandtl number, M is the magnetic parameter, Du is the Dufour number, ϕ is the chemical absorption, K is the permeability parameter, γ is the suction parameter, S is the heat generation, R is the radiation parameter, N is the chemical reaction parameter, Ec is the Eckert number. η is a constant. These equations (7) to (10) are now solved by implicit finite difference schemes of Crank – Nicolson type. The finite difference approximations of these equations are as follows:

$$\begin{aligned}
\left(\frac{u_{i,j+1}-u_{i,j}}{\Delta t}-\gamma\frac{u_{i+1,j}-u_{i,j}}{\Delta y}\right)=\frac{1}{2(1+\lambda_1)}\left[\frac{u_{i-1,j+1}-2u_{i,j+1}+u_{i+1,j+1}}{(\Delta y)^2}+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}\right]\\
-\frac{M}{2}(u_{i,j+1}+u_{i,j})-\frac{K}{2}(u_{i,j+1}+u_{i,j})+\frac{Gr}{2}(\theta_{i,j+1}+\theta_{i,j})+\frac{Gc}{2}(C_{i,j+1}+C_{i,j})
\end{aligned}\tag{12}$$

$$\left(\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}-\gamma\frac{\theta_{i+1,j}-\theta_{i,j}}{\Delta y}\right)=\frac{1}{\Pr}\cdot\left[1+\frac{4}{3}R+\frac{\eta}{2}\left(\theta_{i,j+1}+\theta_{i,j}\right)\right]\left[\frac{\theta_{i+1,j}-\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j+1}+\theta_{i-1,j+1}-2\theta_{i,j+1}}{2\left(\Delta y\right)^2}\right]$$
$$+\frac{\eta}{\Pr}\left(\frac{\theta_{i+1,j}-\theta_{i,j}}{\Delta y}\right)+\frac{S}{2}\left(\theta_{i,j+1}+\theta_{i,j}\right)+\frac{Du}{2}\left(C_{i,j+1}+C_{i,j}\right)+Ec\left(\frac{u_{i+1,j}-u_{i,j}}{\Delta y}\right)^2 \tag{13}$$

$$Sc\left(\frac{C_{i,j+1}-C_{i,j}}{\Delta t}-\gamma\frac{C_{i+1,j}-C_{i,j}}{\Delta y}\right)=\frac{1}{2}\left[\frac{C_{i-1,j+1}-2C_{i,j+1}+C_{i+1,j+1}}{\left(\Delta y\right)^2}+\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{\left(\Delta y\right)^2}\right]$$
$$+\frac{\phi}{2}\left(\theta_{i,j+1}+\theta_{i,j}\right)-\frac{N}{2}\left(C_{i,j+1}+C_{i,j}\right) \tag{14}$$

The initial and boundary conditions become:

$$\begin{aligned}
&u_{i,0}=0,\theta_{i,0}=0,C_{i,0}=0 \text{ for all i except } i=0\\
&u_{i,0}=0,\theta_{i,0}=1,C_{i,0}=1\\
&u_{Z,0}=0,\theta_{Z,0}=0,C_{Z,0}=0
\end{aligned} \tag{15}$$

where Z corresponds to 1. The suffix i corresponds to y and j is equals to t. consequently, $\Delta t=t_{j+1}-t_j$ and $\Delta y=y_{i+1}-y_i$.

NUMERICAL PROCEDURE

In order to access the effects of parameters on the flow variables namely; Jeffery parameter, thermal Grashof number, mass Grashof number, Schmidt number, Prandtl number, magnetic parameter, chemical absorption, Dufour number, permeability parameter, suction parameter, heat generation parameter, radiation parameter, chemical reaction parameter and Eckert number on the velocity, temperature and concentration, and have grips of the physical problem, the unsteady coupled non-linear partial differential Equations (8) – (10) with boundary conditions (11) have been solved using implicit finite difference schemes of Crank – Nicolson type.

This method converges fast and is unconditionally stable. The finite difference approximations of these equations were solved by using the values for Gr = Gc = M = η = Sr = 1, $\lambda_1=0.5$, *Pr* = 0.71, *Sc* = 0.3, Ec = 0.2, Du = 0.03, S = 0.1, N = 0.5, R = 0.1, K= 0.5, $\gamma=0.5$ except where they are varied. A step size of ΔY = 0.01 is used for the interval $Y_{\min}$ = 0 to $Y_{\max}$ = 1 for a desired accuracy and a convergence criterion of 10^{-6} is satisfied for various parameters.

RESULTS AND DISCUSSION

Knowing the values of C, θ, u at time t, the values at a time $t+\Delta t$ can obtained as follows. Substituting $i=1,2,...,Z-1$ in (14). Thus, C is known at all values of y at time $t+\Delta t$ and applying the same procedure and using boundary conditions, similarly calculate θ and u from (13) and (12). This procedure is continued to obtain the solution till desired time t. If:

$$\lambda_1=M=\eta=K=Gc=S=Sc=Du=\phi=R=N=0$$

and Gr = 1, the results of Soundalgekar *et al.* (2004) are obtained.

Velocity Profiles

Figures 1 to 14 represent the velocity profiles with varying parameters, respectively.

Figure 1 presents the effect of Prandtl number on the velocity. The Pr defines the ratio of momentum diffusivity to thermal diffusivity. It is observed that, the velocity decreases with increasing Prandtl number. The reason is that smaller values of Pr are equivalent to increasing thermal conductivities, and therefore heat is able to diffuse away from the heated surface more rapidly than for higher values of Pr. Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced.

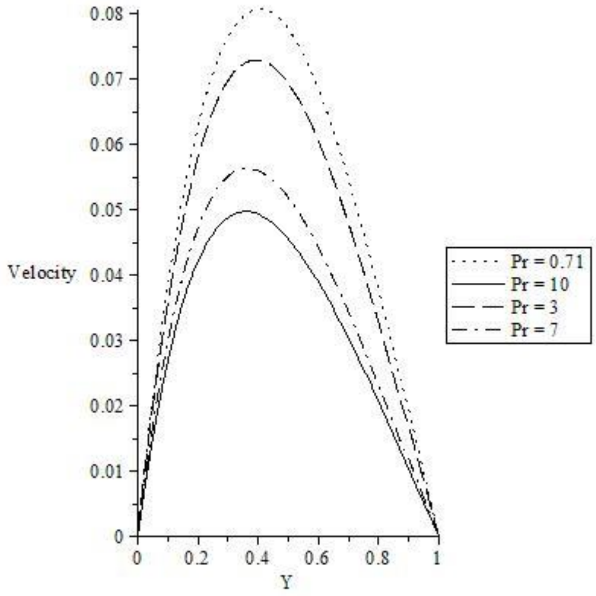

Figure 1: Velocity Profiles for Different Values of Pr.

Influence of Hartmann number M on the velocity is shown in Figure 2. It is found that, the velocity decreases with the increase in magnetic parameter.

Figure 3 shows variation of Schmidt number on the velocity profile. The Sc therefore quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic (velocity) and concentration(species) boundary layers. It is observed that the velocity decreases with increase in Schmidt number.

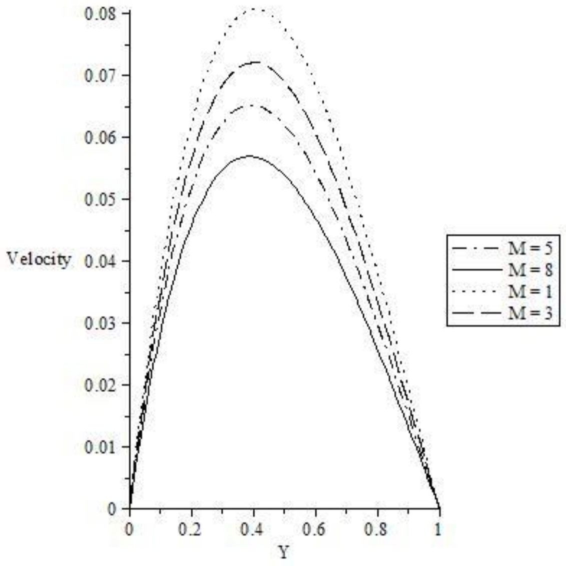

Figure 2: Velocity Profiles for Different Values of M.

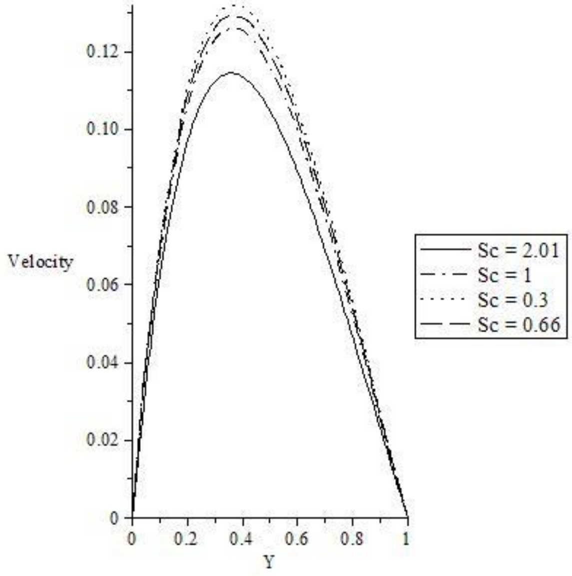

Figure 3: Velocity Profiles for Different Values of Sc.

Dufour number on the velocity profile is shown in Figure 4. It is observed that, the velocity decreases with increasing chemical Dufour number parameter.

Figure 5 illustrates different values of constant η on the velocity. It is found that, the velocity increases with the increase of the constant.

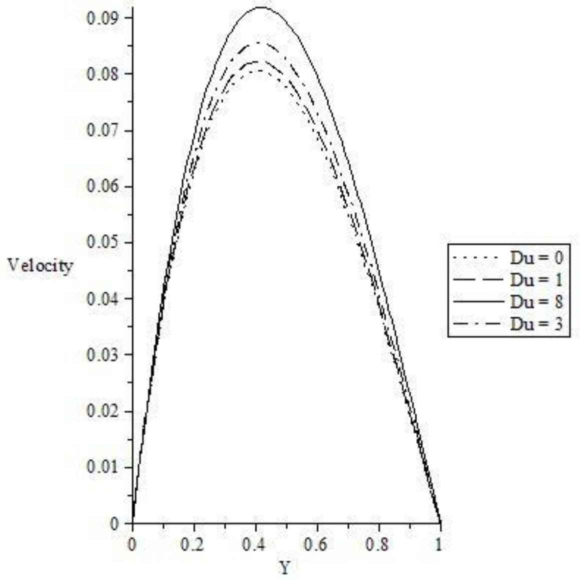

Figure 4: Velocity Profiles for Different Values of Du .

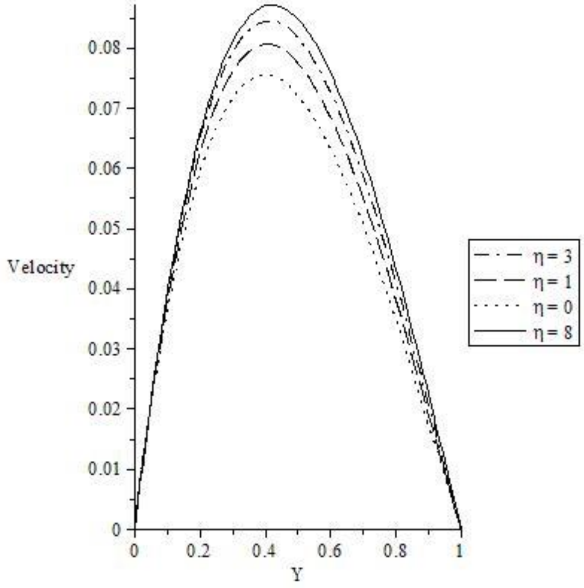

Figure 5: Velocity Profiles for Different Values of η .

Effect of Jeffery parameter on the velocity is illustrated in Figure 6. It is clear that, the velocity increases with increase in Jeffery parameter.

Figure 7 depicts that with the increase in heat generation, the velocity of the fluid increases.

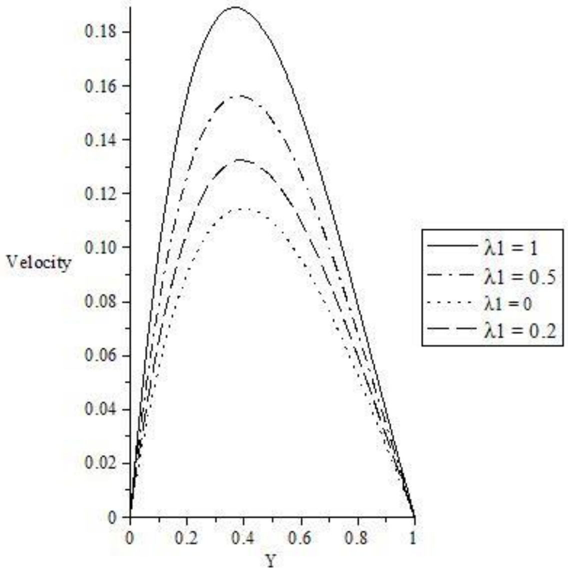

Figure 6: Velocity Profiles for Different Values of λ_1 .

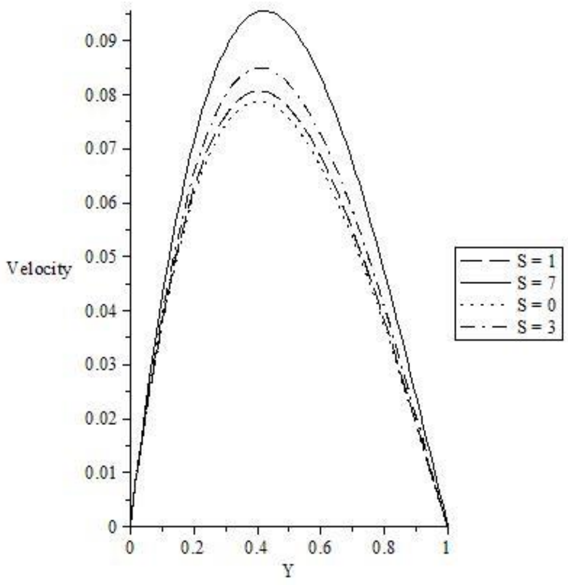

Figure 7: Velocity Profiles for Different Values of S.

Influence of suction parameter on the velocity is demonstrated in Figure 8. It is seen that, the velocity is higher with due to an increase in suction parameter.

Figure 9 represents different values of thermal Grashof number on the velocity, it is noted that, the velocity rises with increasing thermal Grashof number.

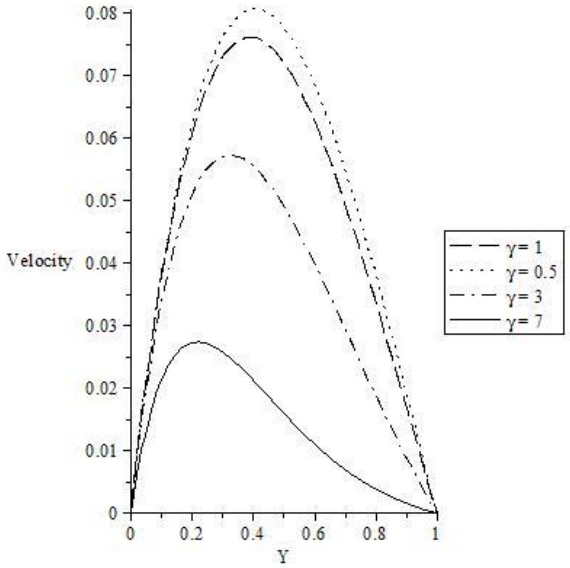

Figure 8: Velocity Profiles for Different Values of γ.

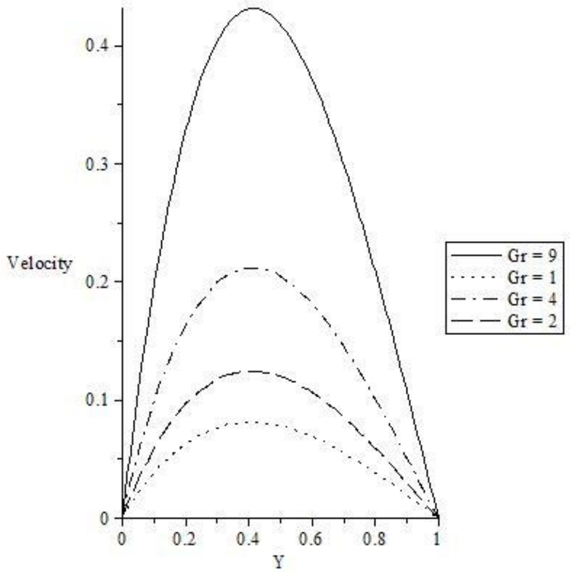

Figure 9: Velocity Profiles for Different Values of Gr.

In Figure 10, the effect of mass Grashof number on the velocity is presented. It is observed that, the velocity increases with increase in mass Grashof number.

The influence of chemical absorption parameter on the velocity is given in Figure 11. It is noticed that, the velocity rises with an increase in ϕ.

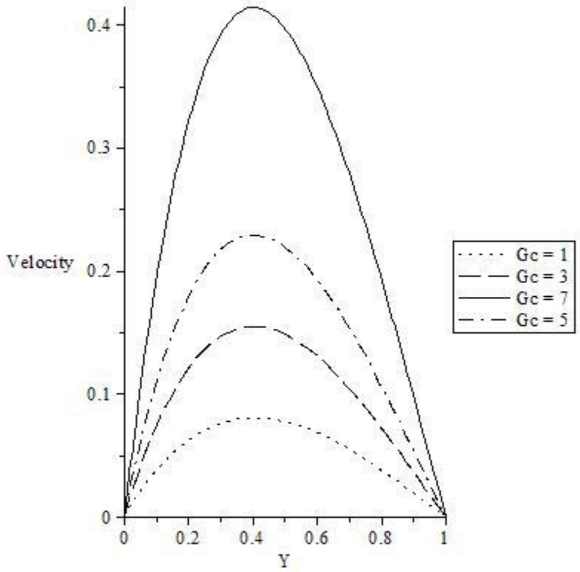

Figure 10: Velocity Profiles for Different Values of Gc.

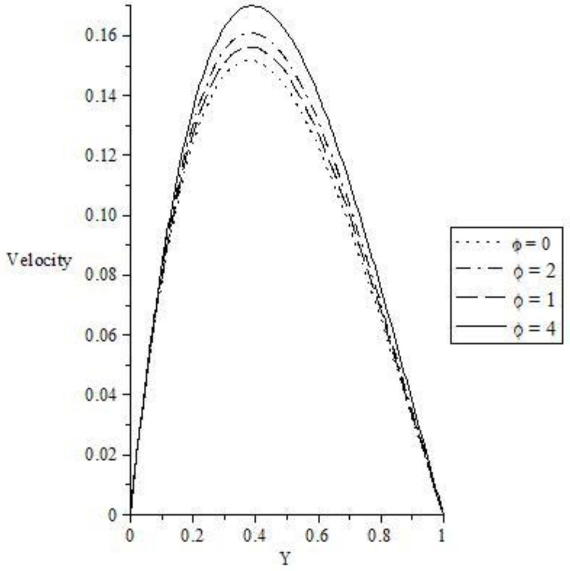

Figure 11: Velocity Profiles for Different Values of ϕ.

Figure 12 depicts that for an increase in chemical reaction parameter, the velocity falls.

Figure 13 illustrates the variation of permeability parameter on the velocity. It is shown that, the velocity falls with increase of permeability parameter.

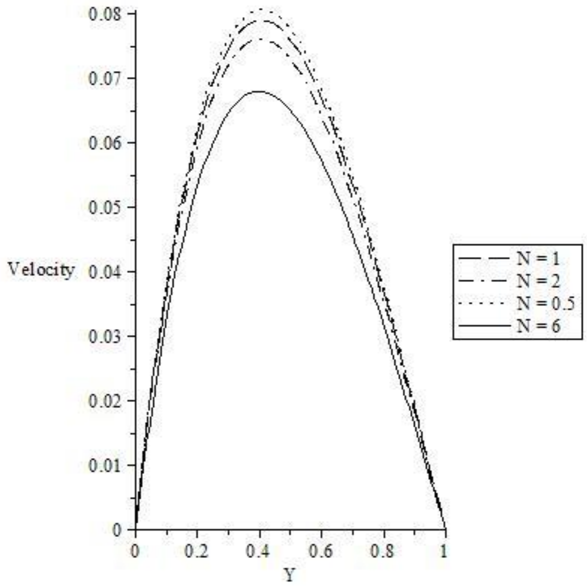

Figure12: Velocity Profiles for Different Values of N.

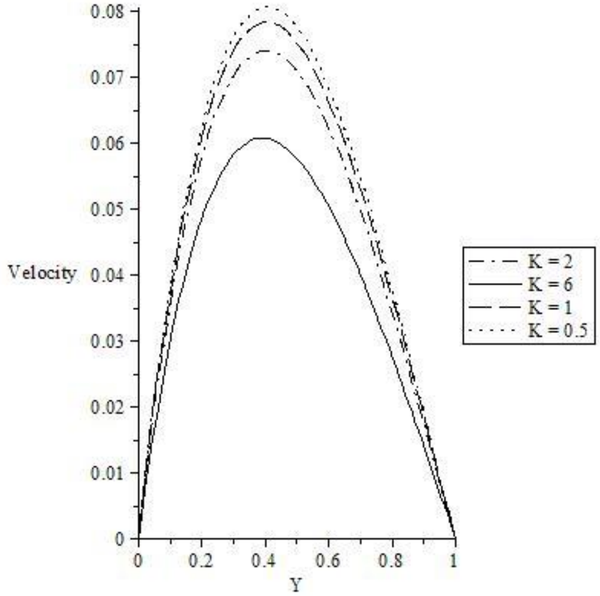

Figure 13: Velocity Profiles for Different Values of K.

In Figure 14, it is observed that, the velocity increases with for different values of radiation parameter.

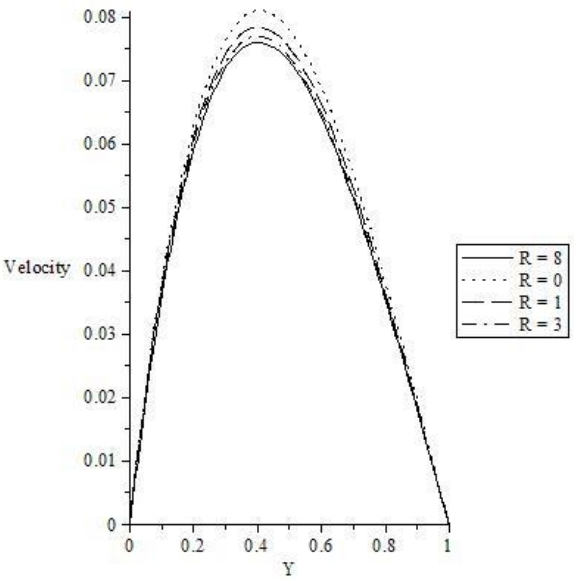

Figure 14: Velocity Profiles for Different Values of R.

Temperature Profiles

Figures 15 to 21 show the temperature profiles. In Figure 15, the influence of Prandtl number on the temperature is depicted. It is seen that an increase in the Prandtl number leads to a fall in the thermal boundary layer thickness and in general lower average temperature within the boundary layer.

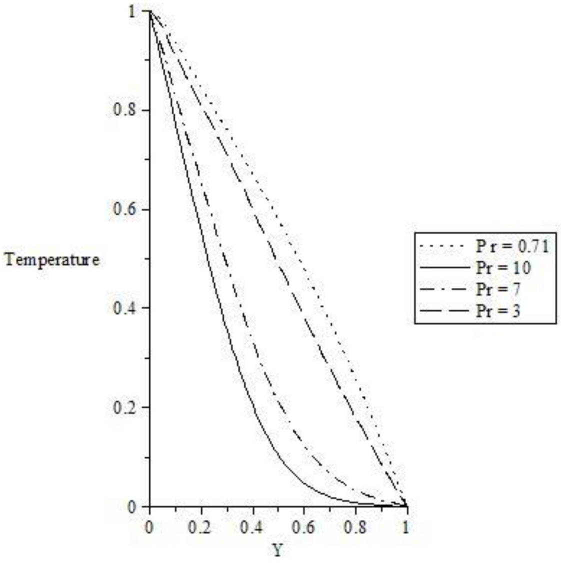

Figure 15: Temperature Profiles for Different Values of Pr.

Figure 16 shows effect of heat sink on the temperature. It is depicted that, the temperature increases with increase in heat generation.

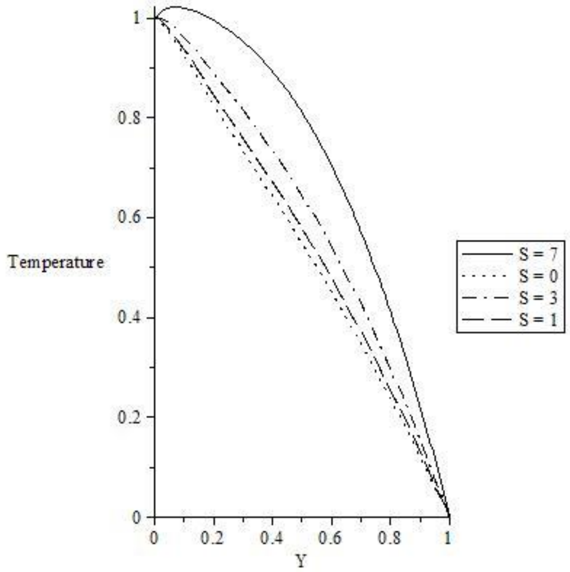

Figure 16: Temperature Profiles for Different Values of S.

Variation of suction parameter on the temperature is illustrated in Figure 17. It is observed that, the temperature decreases with decrease in the suction parameter.

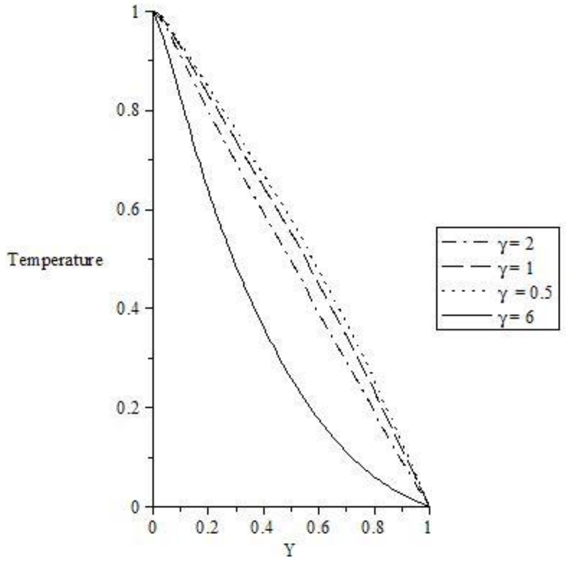

Figure 17: Temperature Profiles for Different Values of γ .

Figure 18 represents the effect of constant η on the temperature. It is noted that, the temperature rises when the constant is higher.

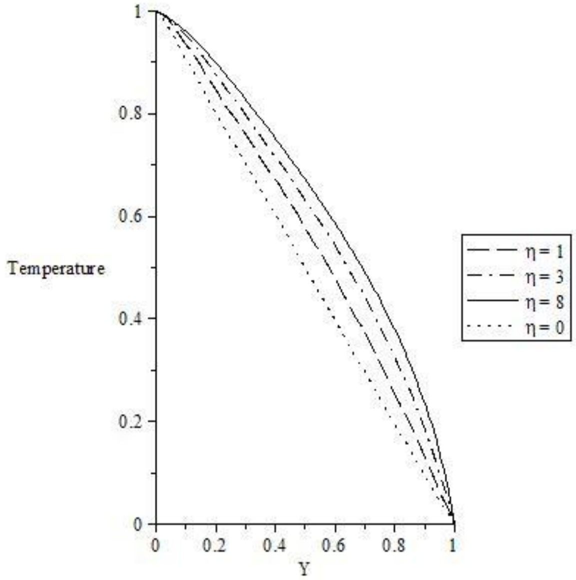

Figure 18: Temperature Profiles for Different Values of η .

Influence of radiation parameter on the temperature is shown in Figure 19. It is clear that the temperature decreases as the radiation parameter is increased.

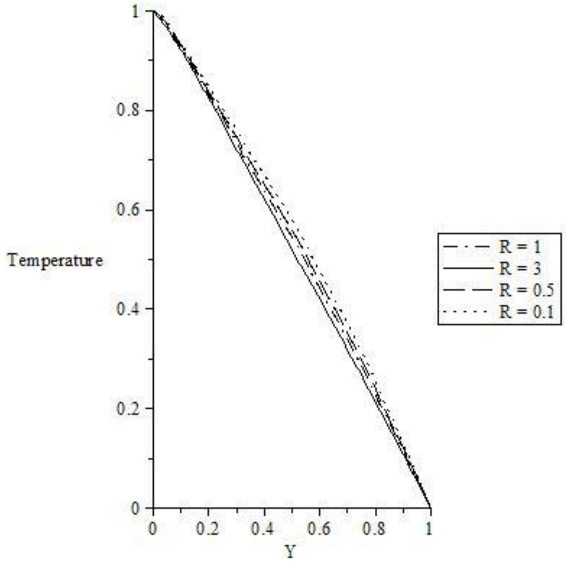

Figure 19: Temperature Profiles for Different Values of R.

In Figure 20, it is shown that, the temperature increases with increasing time.

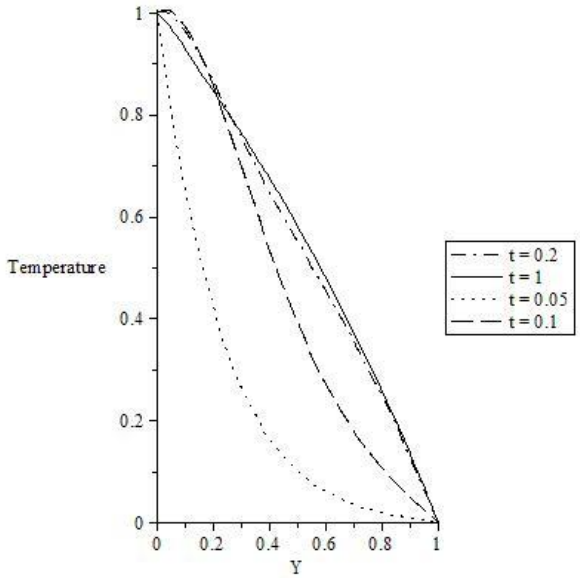

Figure 20: Temperature Profiles for Different Values of t.

Figure 21 illustrates the variation of temperature for different values of Dufour number, it is clear that the temperature increases with increase in Du.

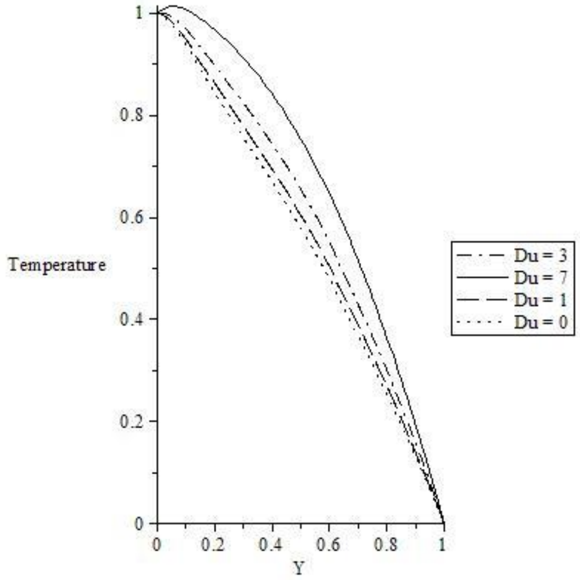

Figure 21: Temperature Profiles for Different Values of Du.

Concentration Profiles

Figures 22 to 26 depict the concentration profiles.

Effects of Schmidt number on the concentration is presented in Figure 22. It is noted that, the concentration is lower due to increasing Schmidt number. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reduction in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

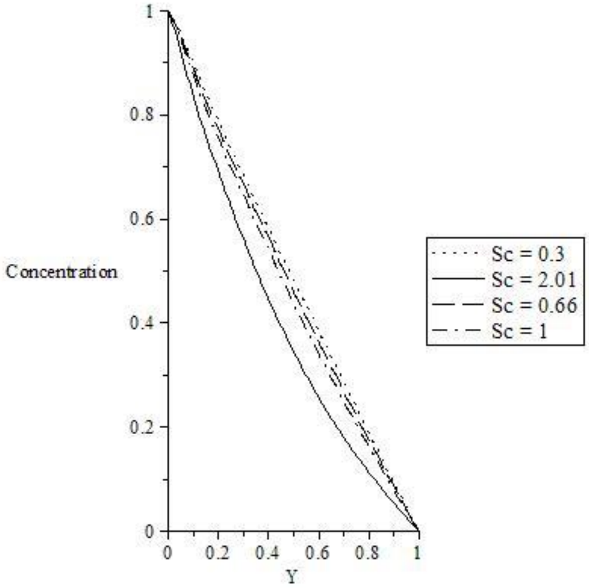

Figure 22: Concentration Profiles for different values of Sc.

In Figure 23, the influence of chemical absorption on the concentration is shown. It is demonstrated that. The concentration is higher as the chemical absorption number is increased.

Figure 24 displays the variation of suction parameter on the concentration. It is seen that, the concentration deceases with decreasing suction parameter.

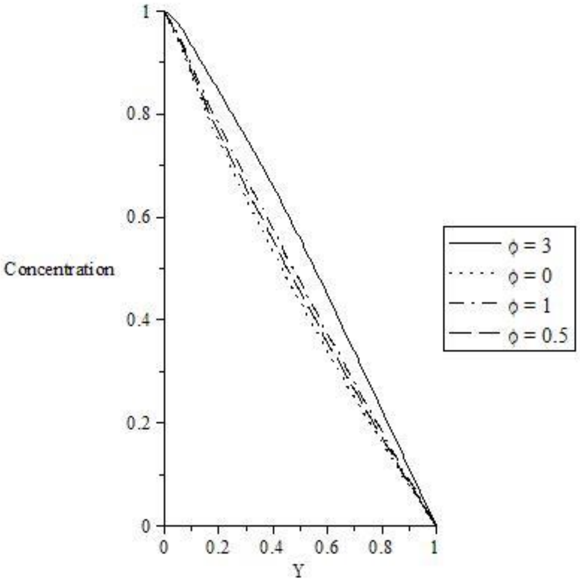

Figure 23: Concentration Profiles for Different Values of ϕ .

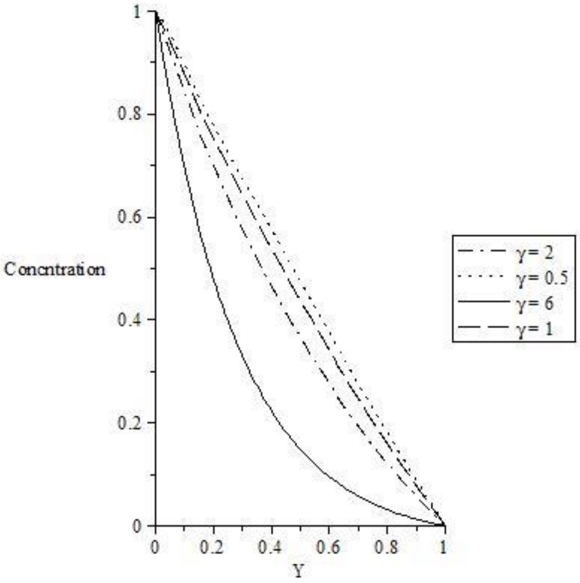

Figure 24: Concentration Profiles for Different Values of γ .

In Figure 25, It is observed that the concentration falls with an increase in the chemical reaction parameter.

The concentration rises with increase in time as depicted in Figure 26.

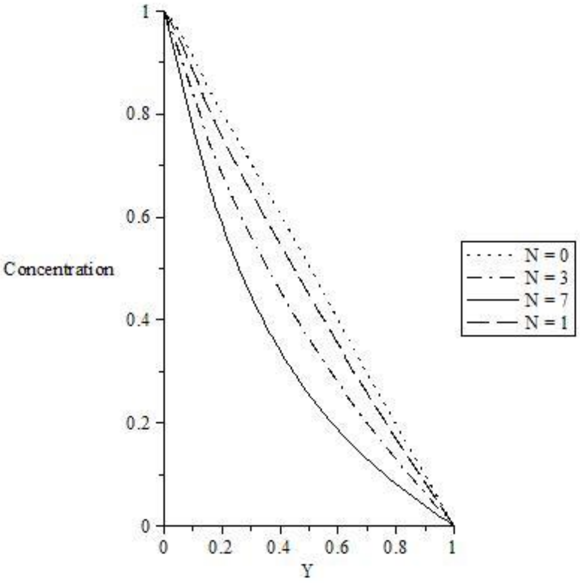

Figure 25: Concentration Profiles for Different Values of N.

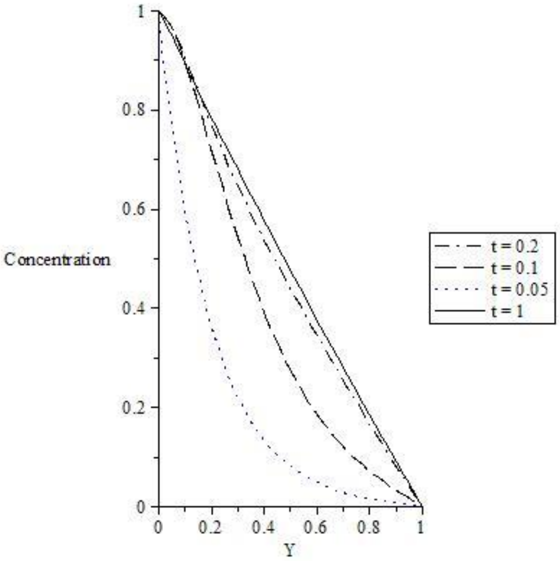

Figure 26: Concentration Profiles for Different Values of t.

CONCLUSIONS

The present numerical study has been carried out for radiation effect of Jeffery fluid on heat and mass transfer past a finite vertical porous plate with chemical reaction, Dufour, and variable thermal conductivity.

The equations governing the flow in dimensionless forms have been solved using implicit finite difference schemes of Crank-Nicolson type. The conclusions of the study are as follows:

- The velocity becomes higher when Gr, Gc, Ec, Du, Sr, S, η, t and λ_1 is increased. Also, decreases of Pr, Sc, M, R, N, γ and K lead to sharp fall in the velocity of the boundary layer.
- An increase in the heat generation, Dufour number, and time increases the thermal boundary layer while increased values of Prandtl number, radiation and suction lowers the temperature of the fluid.
- The concentration rises with increase in the values of chemical absorption parameter and time, and decreases with increasing values of chemical reaction parameter and Schmidt number Sc, and suction.

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SUGGESTED CITATION

Omokhuale, E. and I.J. Uwanta. 2016. “Radiation Effect of Jeffery Fluid on Heat and Mass Transfer in a Vertical Channel with Chemical Absorption, Dufour and Variable Thermal Conductivity”. *Pacific Journal of Science and Technology*. 17(2):45-58.

Pacific Journal of Science and Technology