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Dufour Effect on an Unsteady MHD Free Convective Flow Past a Vertical Porous Plate in the Presence of Thermal Radiation and Chemical Reaction

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Abstract:

The present paper is concerned to analyze the influence of chemical reaction and the combined effects of Dufour and thermal radiation on the unsteady MHD free convective boundary layer flow of a viscous incompressible fluid past a semi infinite vertical plate with time dependent suction. The non-dimensional governing equations are solved analytically using perturbation technique. The effects of various governing parameters on the velocity, temperature concentration, Skin friction coefficient, Nusselt number, Sherwood number are illustrated graphically and analyzed in detail.

Keywords: Chemical reaction, Thermal radiation, Porous medium, Dufour effect

Introduction:

The heat and mass transfer occur simultaneously in processes like the flow in a desert cooling, energy transfer in a wet cooling, evaporation at the surface of water body. The flows on MHD free convection attracted many researchers because of their wide range of applications viz. purification of crude oil, paper industry and textile industry. MHD is applied to study the stellar and solar structure, interstellar matter, radio propagation through the ionosphere etc. The effect of heat generation or absorption in moving fluids and heat transfer problems are important in view of several physical applications such as fluids undergoing exothermic or endothermic chemical reaction. The flows through porous media is a subject of most common interest area because of its importance in the flow of the oil through porous rocks, the filtration of solids from liquids, drugs permeation through human skin. Moreover, the flow through porous media occurs in the ground water hydrology, irrigation and drainage problem, soil erosion and tile drainage. Bejan and Khair (1985) considered combined heat and mass transfer on the free convection boundary layer flow in a porous medium. Chamkha (1999) discussed the effect of heat generation or absorption on hydromagnetic three dimensional free convection flows over a vertical stretching sheet. Hady et al. (2006) have reported that effect of heat generation on free convection flow along a vertical wavy surface embedded in electrically conducting fluid saturated porous media. Vidyasagar et al. (2012) has considered the effect of radiation on the free convective flow over a non isothermal stretching sheet embedded in a porous medium in the presence of magnetic field.

The study of heat and mass transfer problems with chemical reaction is of considerable importance in chemical and hydrometallurgical industries. Many authors investigated the effect of chemical reaction on different geometry of the problem. The effect of mass transfer flow past an impulsively started in infinite vertical plate with chemical reaction was studied by Das et al. (1994). MHD boundary layer flow with heat and mass transfer through a vertical porous surface with suction and chemical reaction has been investigated by Rajeswari et al. (2009). Vidyasagar (2013) has analyzed the radiation effect of Kuvshinshiki fluid on MHD free convection flow past a vertical porous plate with heat and mass transfer. Srinivasa Rao et al (2014) have investigated numerically the combined effects of viscous dissipation and suction on the steady free convective boundary layer flow in the presence of thermal radiation.

When the heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and driving potentials are of a more intricate nature. It is found that a heat flux can be generated not only by temperature gradients but by composition gradients as well. The heat flux that occurs due to composition gradient is called the Dufour effect or diffusion-thermo effect. Generally, the diffusion-thermo effects are of smaller order magnitude than the effects prescribed by Fourier’s or Fick’s laws and are often neglected in heat and mass transfer processes. However, for a special case, the Dufour effect was found to be of a considerable magnitude such that it cannot be neglected (Eckert and Drake 1972). Anghel and Takhar (2000) studied Dufour and Soret effect on free convection boundary layer over a vertical surface embedded in a porous medium. Raju et al. (2008) investigated soret effect due to natural convection between heated inclined plates. Srinivasa Rao et al (2014) presented the problem of heat and mass transfer on MHD boundary layer flow with suction by considering Soret and Dufour effects.

Abdus Sattar et al. (1996) investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Acharya et al. (1999) have reported the problem of heat and mass transfer over an accelerating surface with heat source in presence of suction and blowing. The unsteady free convective MHD flow with heat transfer past a semi-infinite vertical porous moving plate with variable suction has been studied by Kim (2000). Cookey et al. (2003) investigated the simultaneous effects of viscous dissipation and radiation on unsteady flow past an infinite vertical heated plate in a porous medium with time-dependent suction. Prakash and Ogulu (2006) studied unsteady two-dimensional flow of a radiating and chemically reacting MHD fluid with time dependent suction. Das et al. (2007) investigated numerically the unsteady free convective flow past an accelerated vertical plate with suction and heat flux. The effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction analyzed by Ibrahim et al. (2008). Ramachandra Prasad and Bhaskar Reddy (2008) presented radiation and mass transfer effects on an unsteady convection flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with viscous dissipation. Ambethkar (2009) investigated the heat and mass transfer effects of an unsteady MHD free convective flow past an infinite vertical plate with constant suction and heat source or sink. Das and Mitra (2009) discussed the unsteady mixed convective MHD flow and mass transfer past an accelerated infinite vertical plate with suction. Shanker et al. (2010) presented radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation/absorption. Anand Rao and Shivaiah (2011) analyzed the effect of heat source and suction on an unsteady MHD free convective flow past an infinite vertical porous plate in presence of chemical reaction. Raptis (2001) studied the heat transfer in a porous medium in the presence of radiation. Sugunamma et al (2013) studied the effect of chemical reaction on unsteady flow over a semi infinite vertical porous plate in presence of inclined magnetic field and radiation.

Thus motivated by the above investigations and applications mentioned, the objective of the present work is to analyze the Dufour effects on an unsteady two dimensional free convective flow past an infinite vertical porous plate under the influence of magnetic field, by taking into account the effect of thermal radiation, chemical reaction and radiation absorption.

FORMULATION OF THE PROBLEM

Consider the problem of unsteady free convective, viscous, incompressible electrically conducting and radiating fluid past a semi-infinite vertical porous moving plate embedded in a porous medium with time dependent suction in presence of chemical reaction and radiation absorption. Let the x'-axis is taken in the upward direction along the plate and y'-axis normal to it. A uniform magnetic field is applied in the transverse direction to the flow. We also considered the heat and mass transfer processes in the presence of Dufour effect. A homogeneous first order chemical reaction between fluid and the species concentration is considered, in which the rate of chemical reaction is directly proportional to the species concentration. All the fluid properties are assumed to be constant except that the influence of the density variation with temperature is considered only in the body force term. Since the plate is of infinite length, all the physical variables are function of y' and t' only. Under usual Boussinesq approximation the flow field is governed by the following equations.

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

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} + \beta_T\, g(T' - T_\infty) + \beta_C\, g\,(C' - C_\infty) - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K'}u' \tag{2}$$

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\alpha\frac{\partial^2 T'}{\partial y'^2}-\frac{1}{\rho c_p}\frac{\partial q_r'}{\partial y'}+Q_1(C'-C_\infty)-\frac{Q_0}{\rho c_p}(T'-T_\infty)+\frac{D_m K_T}{C_s C_p}\frac{\partial^2 C'}{\partial y'^2} \tag{3}$$

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D_m\frac{\partial^2 C}{\partial y^2}-K_r(C'-C_\infty) \tag{4}$$

where u′, v′ are the velocity components in x', y′ directions respectively. t′ is the time, g is the acceleration due to gravity, υ is the kinematic viscosity, ρ is the fluid density, σ is the electric conductivity of the fluid, B_0^2 constant transverse magnetic field, K′ is the permeability of the porous medium, β_T, β_c are the thermal and concentration expansion coefficients, T′ is the temperature of the fluid in the boundary layer, T_∞ is the temperature of the fluid far away from the plate, C′ is the species concentration in the boundary layer, C_∞ is the species concentration in the fluid far away from the plate, α is the thermal diffusivity, C_p is the specific heat at constant pressure, q_r' is the radiative heat flux, Q_1 is the radiation absorption parameter, Q_0 is the heat absorption, D_m is the mass diffusivity, K_T is the thermal diffusion ratio and C_s is the concentration susceptibility, K_r is the chemical reaction rate on the species concentration.

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

At $y'=0, \quad u'=u'_p, T'=T'_w, C'=C'_w$ (5a)

As $y'\to\infty, \quad u'=U'(t')=V_0(1+\varepsilon e^{\omega' t'}), \; T'\to T_\infty, \; C'\to C_\infty$ (5b)

where T'_w and C'_w are the wall dimensional temperature and concentration of the plate. The continuity equation (1) states that, the suction velocity at the plate is a constant or a function of time. So the suction velocity is assumed to be of the form

$$v'=-V_0(1+\varepsilon e^{\omega' t'}) \tag{6}$$

Where ε is small such that ε << 1 and V_0 is the mean suction velocity which is non-zero positive constant. The negative sign indicates that the suction is directed towards the plate.

By using the Rosseland approximation (Brewster 1992), we can write the radiative heat flux q_r as

$$q_r=-\frac{4\sigma_s}{3k_e}\frac{\partial T^4}{\partial y'} \tag{7}$$

where σ_s is the Stephen Boltzmann constant and k_e is the mean absorption coefficient.

We assume that the temperature differences within the flow are sufficiently small so that T^4 can be expanded in a Taylor series about free stream temperature T_∞, so that after neglecting higher order terms we have:

$$T^4=4T_\infty^3 T-3T_\infty^4 \tag{8}$$

Using equation (9) in the energy equation (3), we get

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2}-\frac{Q_o}{\rho C_p}(T'-T_\infty)+Q_1(C'-C_\infty)+\frac{16\sigma_s}{3k_e}\frac{T_\infty^3}{\rho C_p}\frac{\partial q_r}{\partial y}+\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C'}{\partial y'^2} \quad (9)$$

We introduce the following non-dimensional variables

$$y=\frac{V_0}{\nu}y',\ \omega=\frac{\nu}{V_0^2}\omega',\ u=\frac{u'}{V_0},v=\frac{v'}{V_0},\ t=\frac{V_0^2}{\nu}t',u_p=\frac{u_p'}{V_0},\theta=\frac{T'-T_\infty}{T_w'-T_\infty},C=\frac{C'-C_\infty}{C_w'-C_\infty},$$
$$U(t)=\frac{U'(t')}{V_0},Gr=\frac{\upsilon g\beta_T(T_w'-T_\infty)}{V_o^3},Gc=\frac{\upsilon g\beta_c(C_w'-C_\infty)}{V_o^3},M=\frac{\sigma B_0^2\upsilon}{\rho V_o^2},K=\frac{V_o^2k'}{\upsilon^2}$$
$$\gamma=\frac{K_r\upsilon}{V_o^2},Sc=\frac{\upsilon}{D},\xi=\frac{Q_o\upsilon}{\rho C_pV_o^2},Pr=\frac{\mu C_p}{k},Q_1=\frac{\upsilon Q_1(C_w'-C_\infty)}{(T_w'-T_\infty)V_o^2},N=\frac{kk_e}{4T_\infty^3\sigma_s} \quad (10)$$
$$D_f=\frac{D_mK_T(C_w'-C_\infty)}{\upsilon Cs\,Cp(T_w'-T_\infty)}$$

On substitution of equation (10) into equation (2), (4) and (9), we obtain the governing equations in non-dimensional form as

$$\frac{\partial u}{\partial t}-(1+\varepsilon e^{\omega t})\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\,\theta+Gc\,C-\left(M+\frac{1}{K}\right)u \quad (11a)$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon e^{\omega t})\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\left(1+\frac{4N}{3}\right)\frac{\partial^2 \theta}{\partial y^2}-\xi\,\theta+Q_1\,C+D_f\,\frac{\partial^2 C}{\partial y^2} \quad (11b)$$

$$\frac{\partial C}{\partial t}-(1+\varepsilon e^{\omega t})\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-\gamma\,C \quad (11c)$$

Where Gr, Gc, M, K, Pr, N, ξ, Q_1, D_f, Sc and γ are the thermal Grashof number, solutal Grashof number, Magnetic parameter, permeability parameter, Prandtl number, Radiation parameter, heat absorption parameter, radiation absorption parameter, Dufour number, Schmidt number and chemical reaction parameter respectively.

The corresponding boundary conditions are

$$u=u_p,\ \theta=1, C=1 \qquad at\ y=0$$
$$u\to 1+\varepsilon\,e^{\omega t},\ \theta\to 0,\ C\to 0 \qquad as\ y\to\infty \quad (12)$$

SOLUTION OF THE PROBLEM

Equations (11 a-c) are coupled, non linear partial differential equations which cannot be solved in closed form. So, in order to solve these equations we assume the velocity, temperature and concentration of the fluid in the neighborhood of the porous plate as

$$u(y,t) = u_o(y) + \varepsilon e^{\omega t} u_1(y) + O(\varepsilon^2) + \ldots\ldots\ldots\ldots$$
$$\theta(y,t) = \theta_o(y) + \varepsilon e^{\omega t} \theta_1(y) + O(\varepsilon^2) + \ldots\ldots\ldots\ldots \quad (13)$$
$$C(y,t) = C_o(y) + \varepsilon e^{\omega t} C_1(y) + O(\varepsilon^2) + \ldots\ldots\ldots\ldots$$

We now substitute equation (13) into equations (11a-c), and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we get

$$u_o'' + u_o' - R_1 u_o = -Gr\,\theta_o - Gc\,C_o \quad (14)$$
$$u_1'' + u_1' - R_2 u_1 = -u_o' - Gr\theta_1 - Gc\,C_1 \quad (15)$$
$$\left(1 + \frac{4N}{3}\right)\theta_o'' + \Pr\theta_o' - \Pr\xi\,\theta_o = -\Pr Q_1 C_o - \Pr D_f C_o'' \quad (16)$$
$$\left(1 + \frac{4N}{3}\right)\theta_1'' + \Pr\theta_1' - R_3 \Pr\theta_1 = -\Pr\theta_o' - \Pr Q_1 C_1 - \Pr D_f C_1'' \quad (17)$$
$$C_o'' + Sc\,C_o' - Sc\,\gamma\,C_o = 0 \quad (18)$$
$$C_1'' + Sc\,C_1' - Sc\,R_4\,C_1 = -Sc\,C_o' \quad (19)$$

The corresponding boundary conditions are

$$u_o = u_{p,}\; u_1 = 0,\; \theta_o = 1, \theta_1 = 0,\; C_o = 1,\; C_1 = 0 \quad at\;\; y = 0 \quad (20a)$$
$$u_o = 1,\; u_1 = 1,\; \theta_o \to 0,\; \theta_1 \to 0,\; C_o \to 0,\; C_1 \to 0 \quad as\;\; y \to \infty \quad (20b)$$

Solving the equations (14-19), subject to the boundary conditions (20a, b), we get the velocity, temperature and concentration distributions in the boundary layer as

$$u_o(y) = 1 + D_7\,e^{-m_1 y} + D_6\,e^{-m_4 y} + B_7 e^{-m_5 y}$$
$$u_1(y) = 1 + D_8 e^{-m_1 y} + D_9 e^{-m_2 y} + D_{10} e^{-m_3 y} + D_{11} e^{-m_4 y} + D_{12} e^{-m_5 y} + B_{13} e^{-m_6 y}$$
$$\theta_o(y) = (1 + D_2) e^{-m_3 y} - D_2 e^{-m_1 y}$$
$$\theta_1(y) = D_3\,e^{-m_1 y} + D_4 e^{-m_2 y} + D_5 e^{-m_3 y} + B_4 e^{-m_4 y}$$
$$C_o(y) = e^{-m_1 y}$$
$$C_1(y) = D_1(e^{-m_1 y} - e^{-m_2 y})$$

where the expressions for the constants are given in the Appendix

The Skin-Friction Coefficient (C_f), rate of heat transfer coefficient or Nusselt number (Nu) and rate of mass transfer coefficient or Sherwood number (Sh) at the plate are important physical parameters for this type of boundary layer flow.

The Skin-friction at the plate, which is in the non-dimensional form is given by

$$C_f = \left(\mu \frac{\partial u'}{\partial y'} \right)_{y'=0} = \left(\frac{\partial u}{\partial y} \right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon\, e^{\omega t} \frac{\partial u_1}{\partial y} \right)_{y=0}$$

The rate of heat transfer coefficient (Nusselt number)at the which is in non-dimensional form is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y} \right)_{y=0} = -\left(\frac{\partial \theta_0}{\partial y} + \varepsilon\, e^{\omega t} \frac{\partial \theta_1}{\partial y} \right)_{y=0}$$

The rate of mass transfer coefficient (Sherwood number) at the plate, which is in non-dimensional form is given by

$$Sh = -\left(\frac{\partial C}{\partial y} \right)_{y=0} = -\left(\frac{\partial C_0}{\partial y} + \varepsilon\, e^{\omega t} \frac{\partial C_1}{\partial y} \right)_{y=0}$$

Results and Discussions:

The problem of heat and mass transfer on unsteady free convective flow of a viscous incompressible, thermally radiating and chemically reaction in the presence of Dufour effect and heat absorption has been formulated and analyzed by using perturbation technique. The expressions for the velocity, temperature and concentration were obtained. The numerical values of velocity, temperature and concentration have been computed for different governing parameters such as M, K, Gr, Gc, N, ξ, Q_1, D_f, Pr, Sc and γ. In the present study the following default parametric values are taken. Gr= 4, Gc = 2, K =2, Sc = 0.2, t =1, ω = 0.1, Pr = 0.71, N = 2, D_f =1, Q_1 = 2, ε = 0.2, u_p = 0.5, t =1, γ = 0.2, ξ =2. All the graphs correspond to these values unless indicated on the appropriate graph.

The velocity profiles for different values of thermal Grashof Number (Gr) are given in Fig. 1. The thermal Grashof Number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. It is observed that the velocity flow field decreases due to increase in the Gr. Here the positive value of Gr corresponds to cooling of the surface. In addition, the curve shows that the peak values of the velocity increases rapidly as Gr increases and then decreases to the free stream velocity.

Fig 2 depicts the effect of mass Grashof number (Gc) on velocity profiles. The mass Grashof number Gc defines the ratio of the species buoyancy force to the viscous hydrodynamic force. It is noticed that buoyancy effect due to mass transfer enhances the velocity.

Fig 3 illustrates the velocity temperature profiles for different values of Magnetic Parameter (M). The numerical results show that velocity decreases as the existence of magnetic field becomes stronger. This is due to the fact that the application of transverse magnetic field setup a Lorentz force which has tendency to retard the fluid motion.

The effect of the Radiation parameter N on the velocity is shown in the Fig 4. The radiation parameter N defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is noticed that an increase in the radiation parameter results in decreasing velocity.

Figs 5 and 6 represent the velocity profile in the boundary layer for various values of the Porous parameter (K) and Dufour number (D_f). It can be clearly seen from this figure that the effect of Porous parameter slightly affect the fluid Velocity. As the values of K increases, the fluid velocity increases. The effect of Dufour number is more on velocity field when compared with K.

The variation in temperature profiles for different values of radiation absorption parameter (Q_1) is plotted in Fig 7. The temperature is found to increase with increase in Q_1. Moreover, the thermal boundary layer thickness increases with increase in Q_1 is noted.

The influence of the Dufour number (D_f) on the temperature is given in Fig 8. Physically, the Dufour term that appears in the temperature equation measures the contribution of concentration gradient to thermal energy flux in the flow domain. It plays an important role in enhancing the flow velocity and the ability to increase the thermal energy in the boundary layer. Due to this reason the temperature profile increases with the increase in D_f.

Fig 9 demonstrate the effects of heat absorption parameter (ξ) on the temperature field. The heat absorption parameter measures the amount of heat flux absorbed by the fluid particles. It is shown that the temperature is decreased by an increase in the heat absorption by the fluid. From Fig 10, it is further observed that increase in the radiation parameter increases the temperature distribution in the thermal boundary layer.

The temperature profiles for different Prandtl number (Pr) are given in Fig 11. Prandtl number is the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity. It can be seen that an increase in the Prandtl number leads to decrease in the temperature field. Also, the temperature field falls more rapidly for water (i.e Pr = 7) in comparison to air (i.e Pr = 0.71).

In Figs 12 and 13, the concentration profiles are presented for different values Schmidt number and chemical reaction. Schmidt number is the ratio of the momentum diffusivity to the mass (species) diffusivity. It is observed that the species concentration decreases with the increase in Sc. Physically this shows that an increase in Sc causes a decrease in the molecular diffusion D. As the fluid flow is subjected to a first order chemical reaction it reduces the fluid concentration i.e. concentration profile decreases with increase in chemical reaction parameter.

The effects of M, K, N, Sc and D_f on the skin friction coefficient (C_f) are presented in Figs 14 to 18. An increase in M and Sc decreases skin friction coefficient whereas an increase in K, N and D_f increases the skin friction coefficient. It is also observed that C_f increases as t increases.

Figs 19 to 22 represent the variation of rate of heat transfer (Nu) for different values of Pr, N, ξ, D_f. It depicts that, as Pr, ξ increases Nusselt number increases. A reverse trend is notices in the case of N and D_f

Figs 23 to 25 highlight the mass transfer results for different values of Q_1, Sc, γ. Sherwood number increase with Sc and decreases with γ.

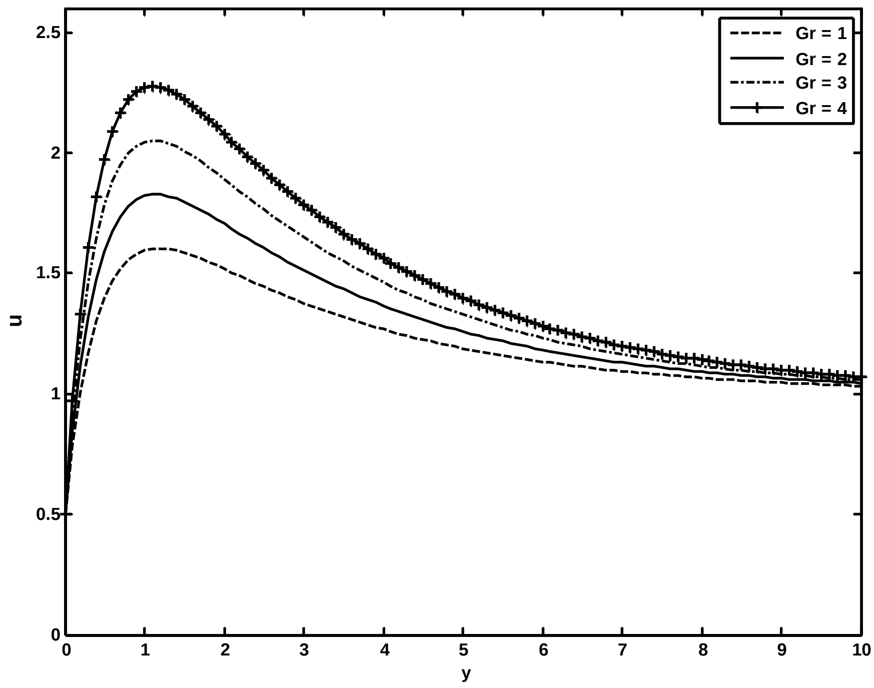

Fig 1. Velocity Profiles for different values of Gr

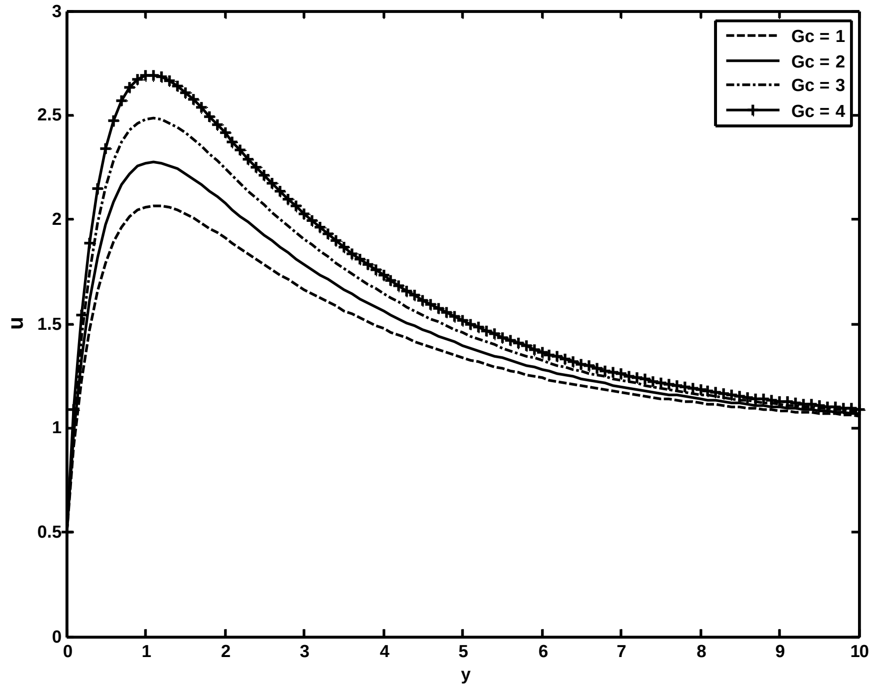

Fig 2. Velocity Profiles for different values of Gc

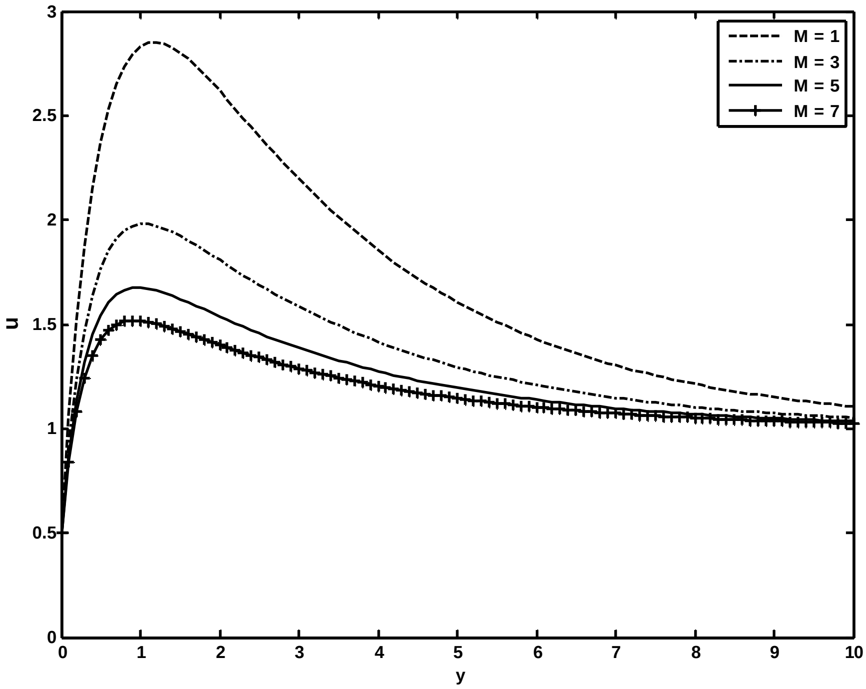

Fig 3. Velocity Profiles for different values of M

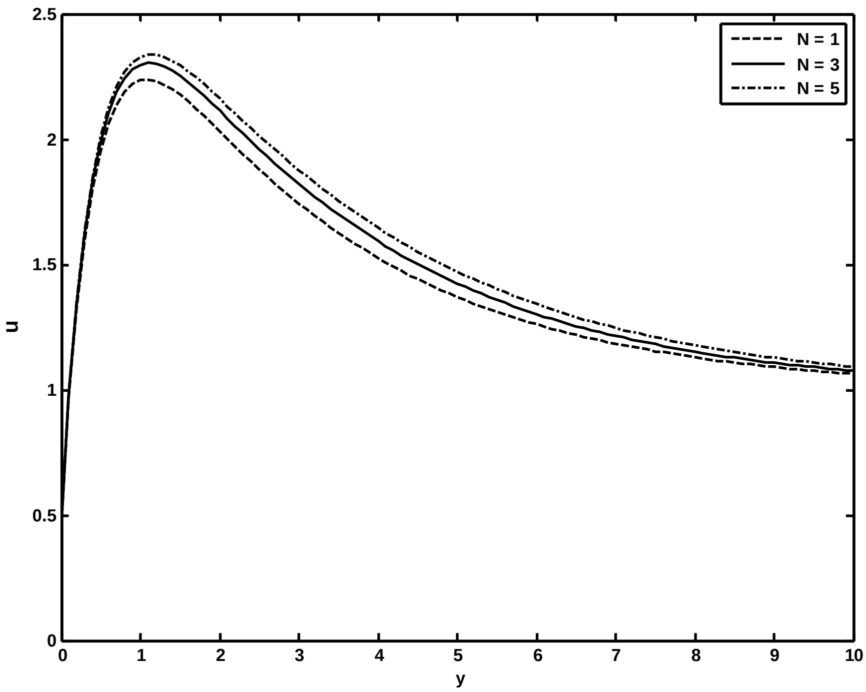

Fig 4. Velocity Profiles for different values of N

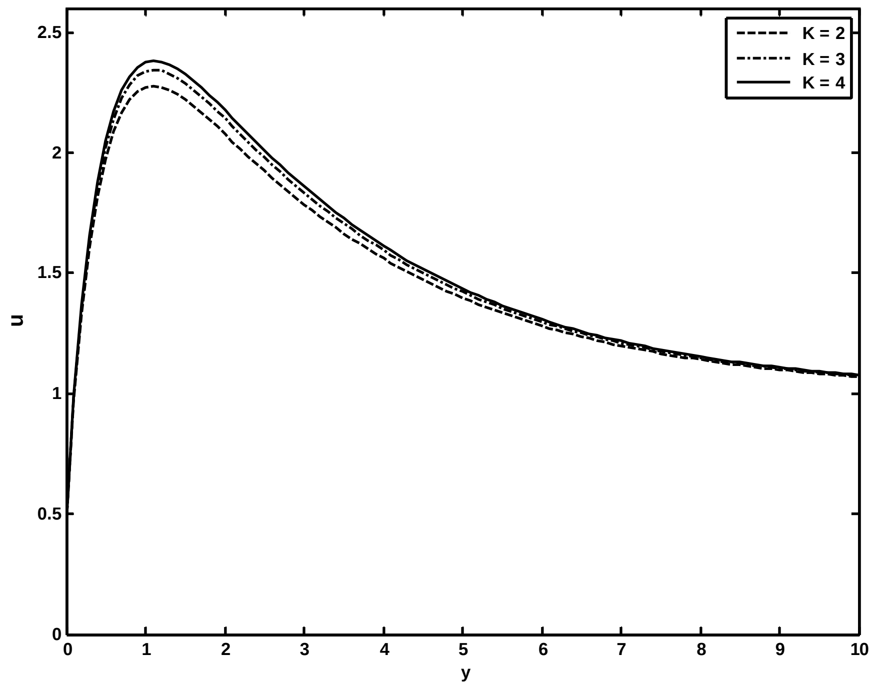

Fig 5. Velocity Profiles for different values of K

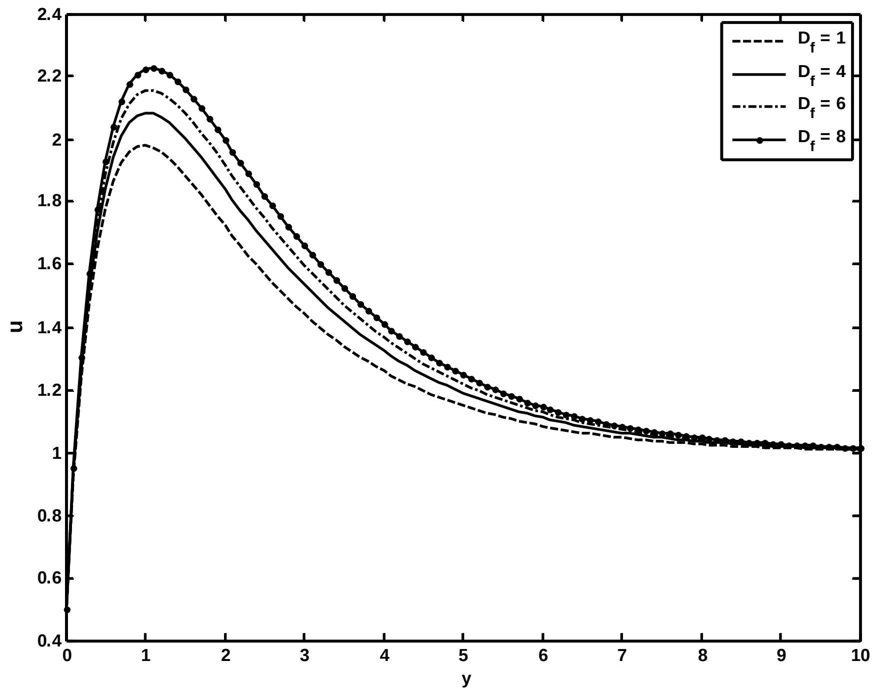

Fig 6. Velocity Profiles for different values of D_f

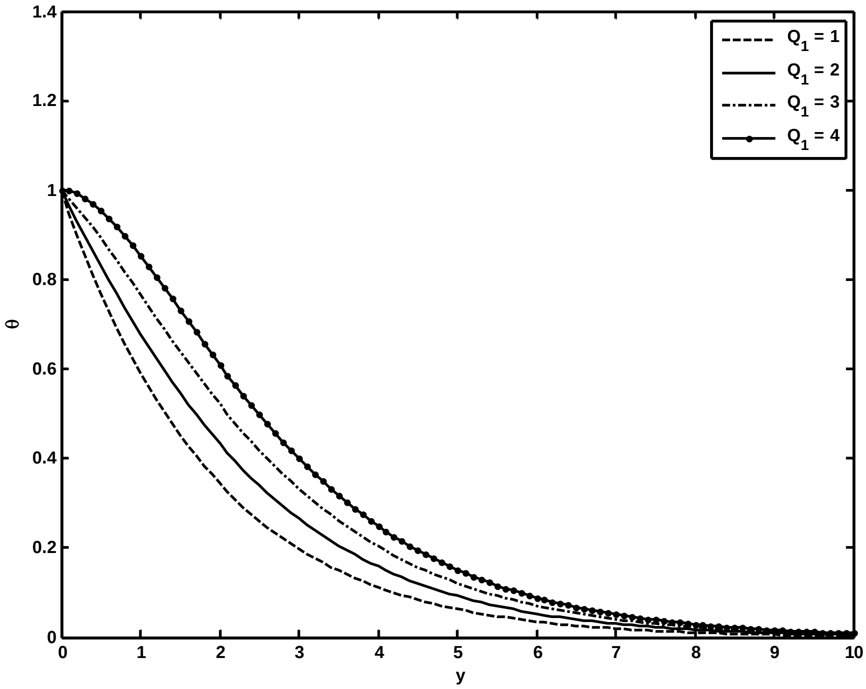

Fig 7. Temperature Profiles for different values of Q_1

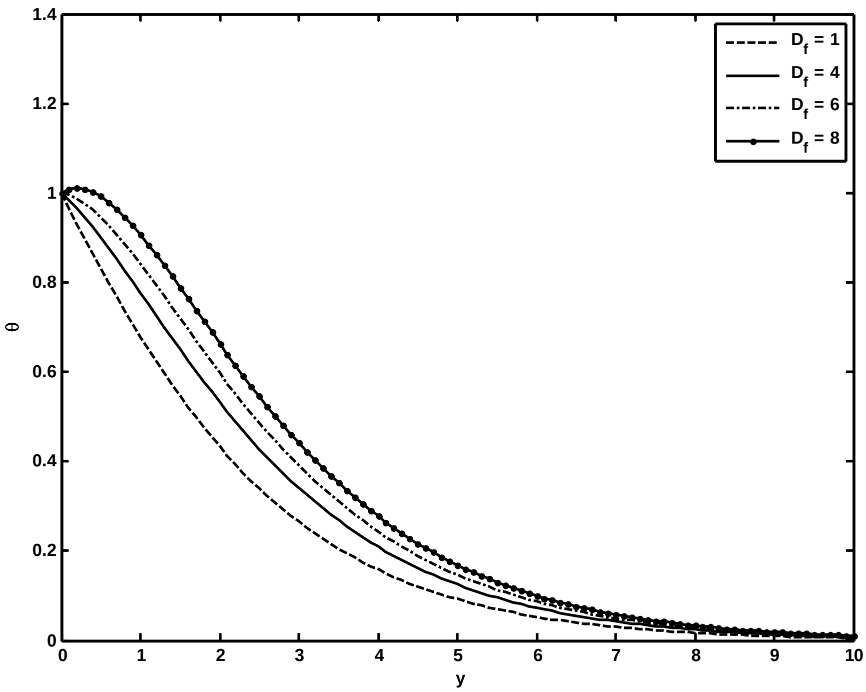

Fig 8. Temperature Profiles for different values of D_f

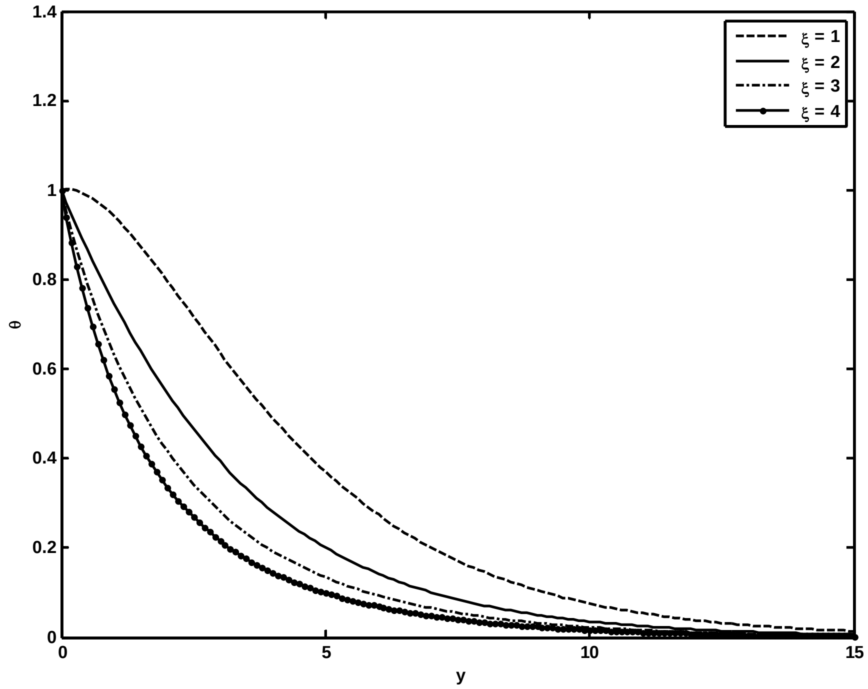

Fig 9. Temperature Profiles for different values of ξ

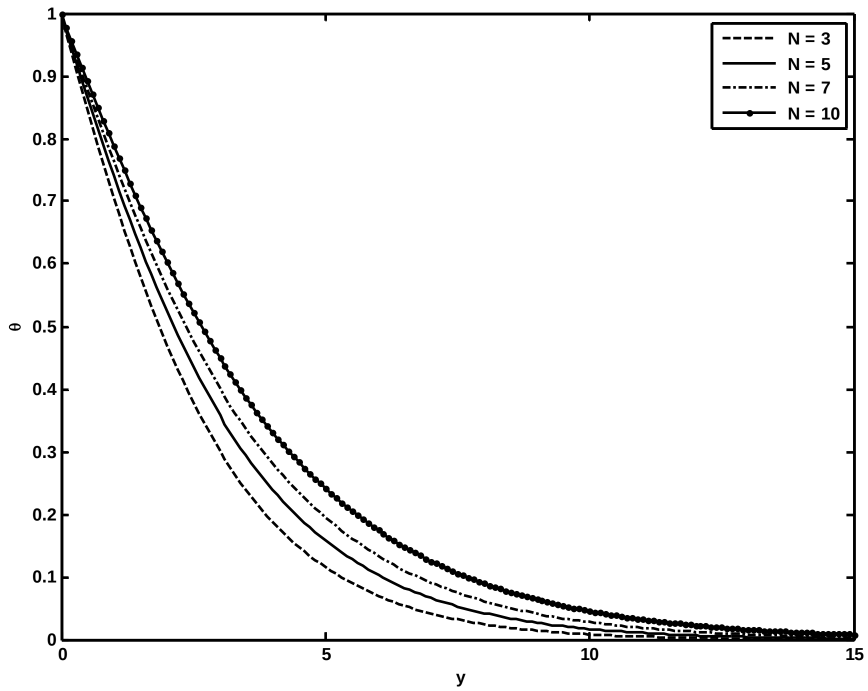

Fig 10. Temperature Profiles for different values of N

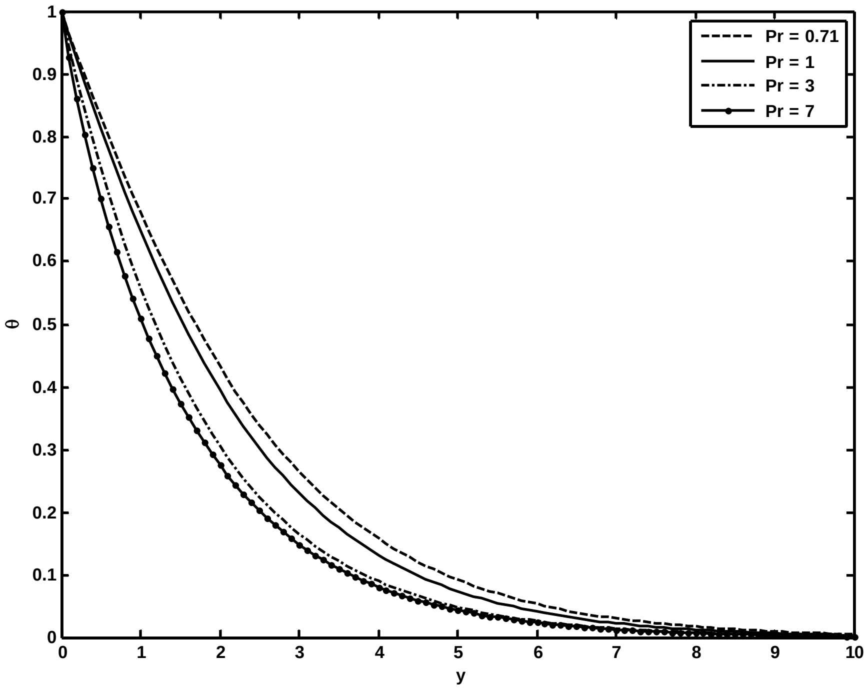

Fig 11. Temperature Profiles for different values of Pr

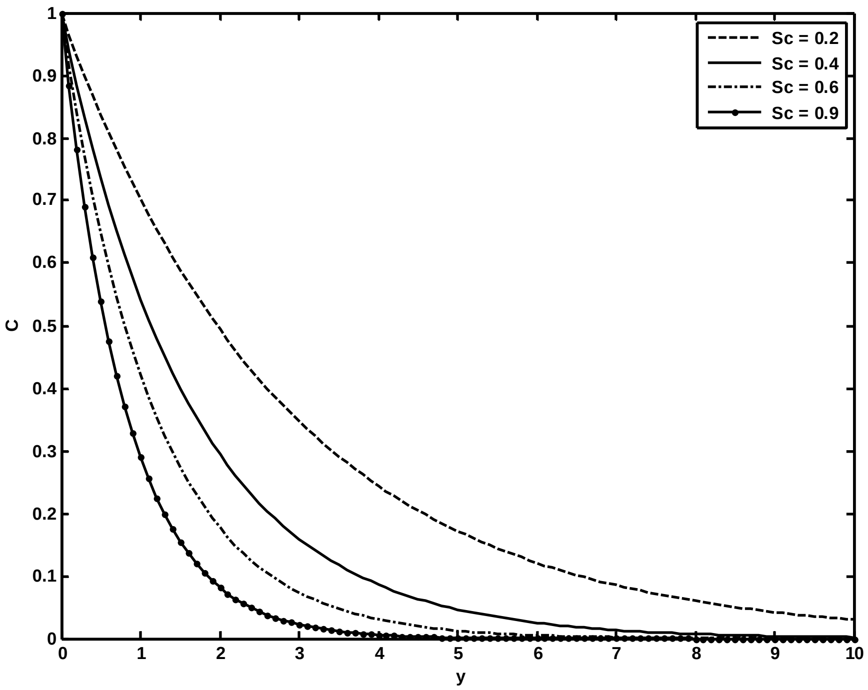

Fig 12. Concentration Profiles for different values of Sc

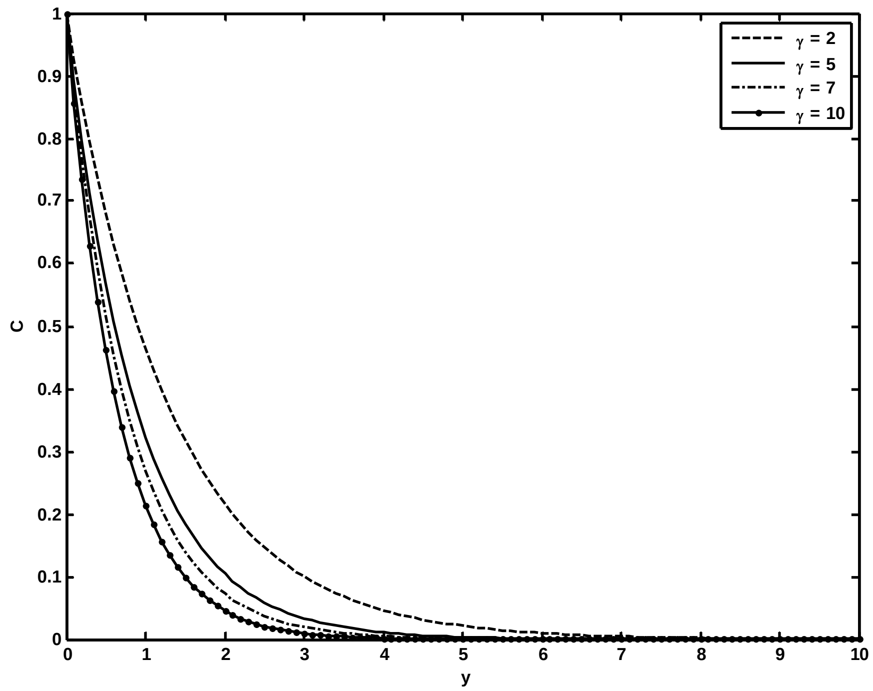

Fig 13. Concentration Profiles for different values of γ

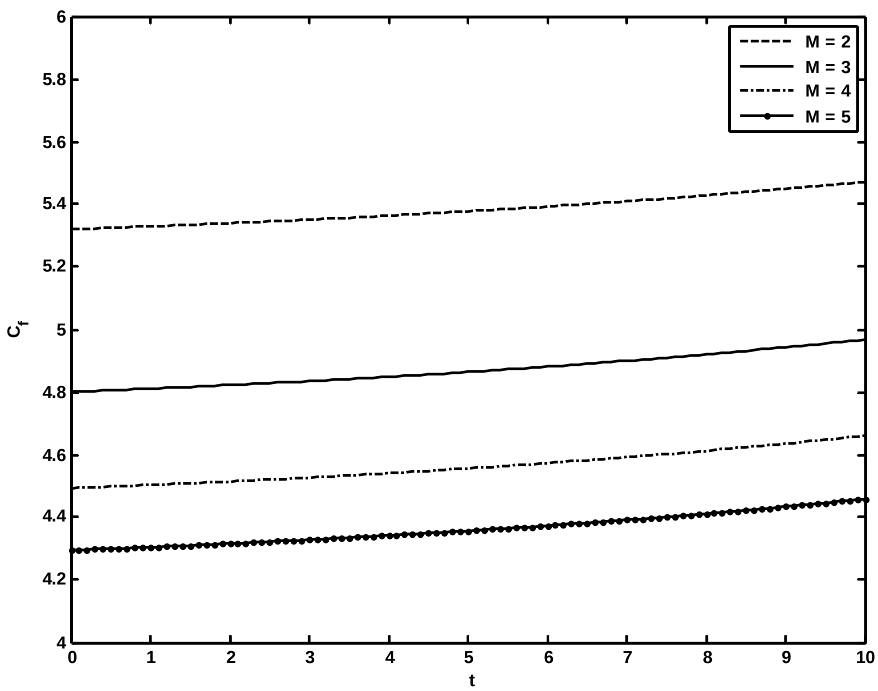

Fig 14. Skin friction Coefficient for different values of M

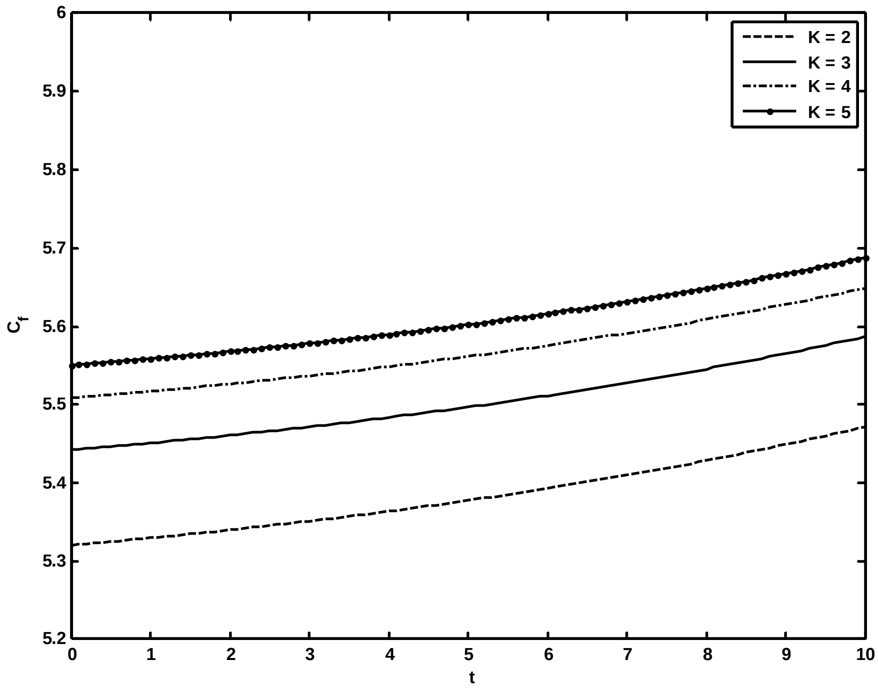

Fig 15. Skin friction Coefficient for different values of K

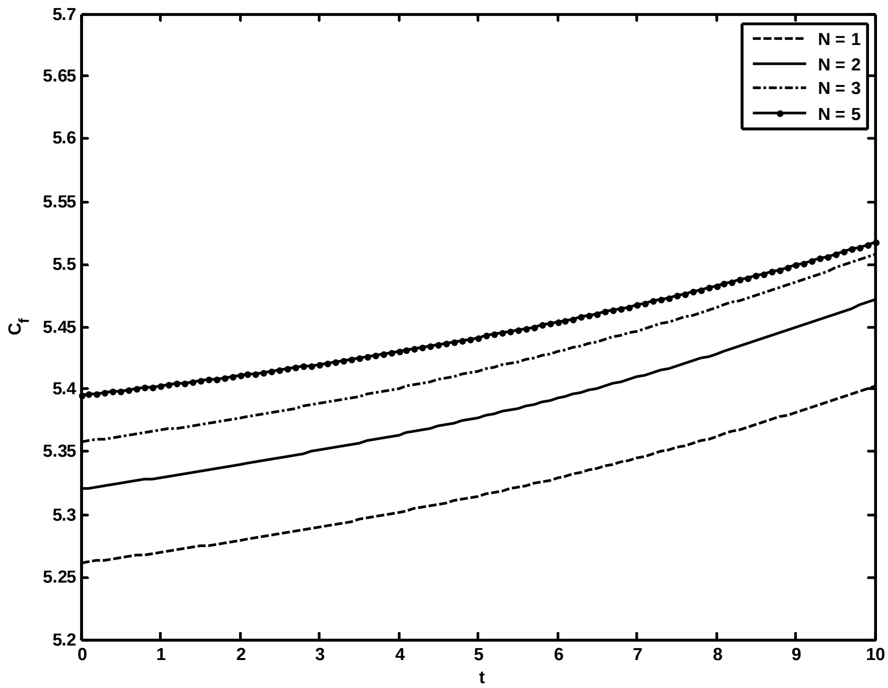

Fig 16. Skin friction Coefficient for different values of N

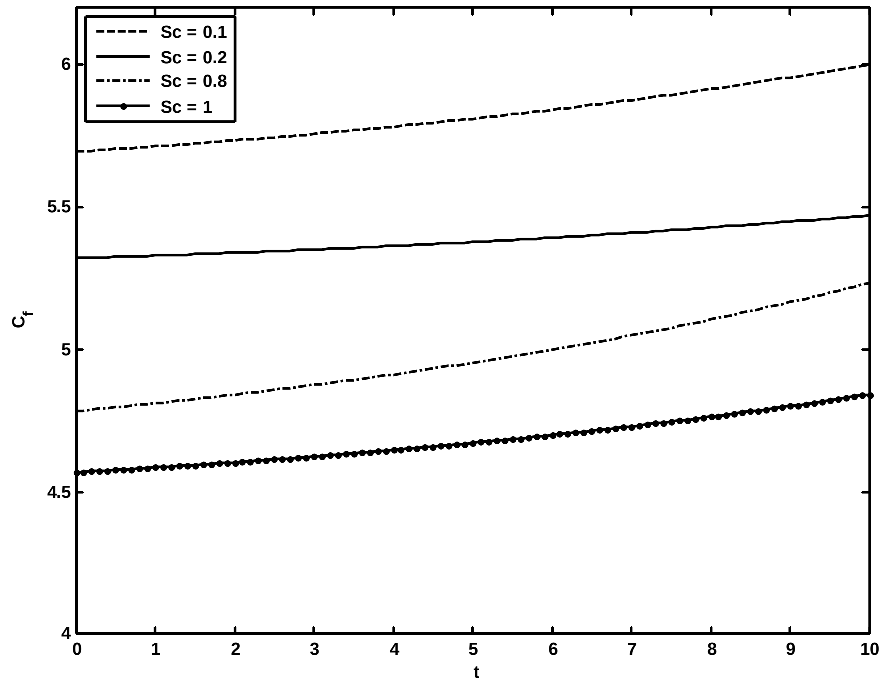

Fig 17. Skin friction Coefficient for different values of Sc

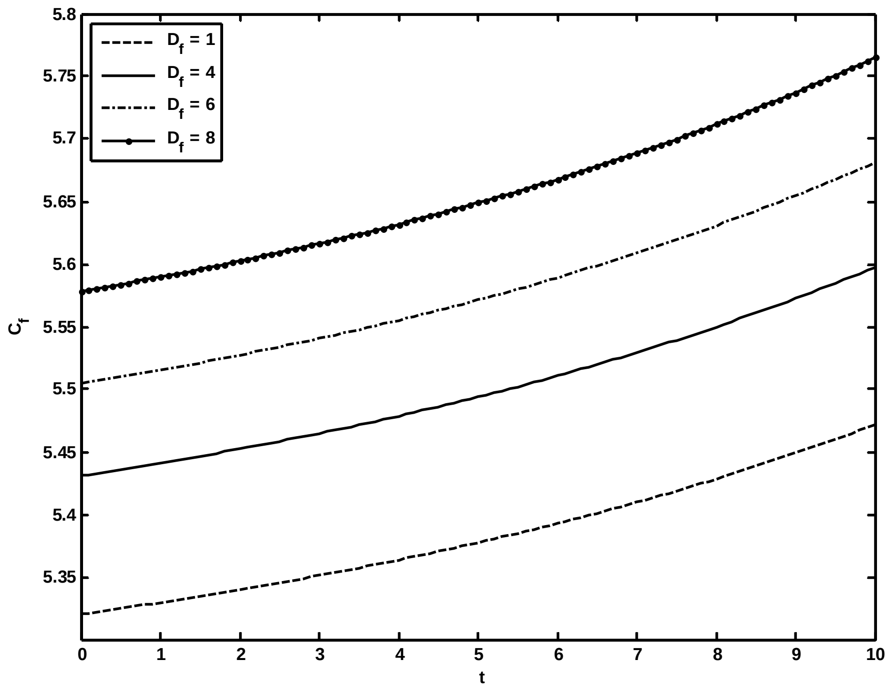

Fig 18. Skin friction Coefficient for different values of D_f

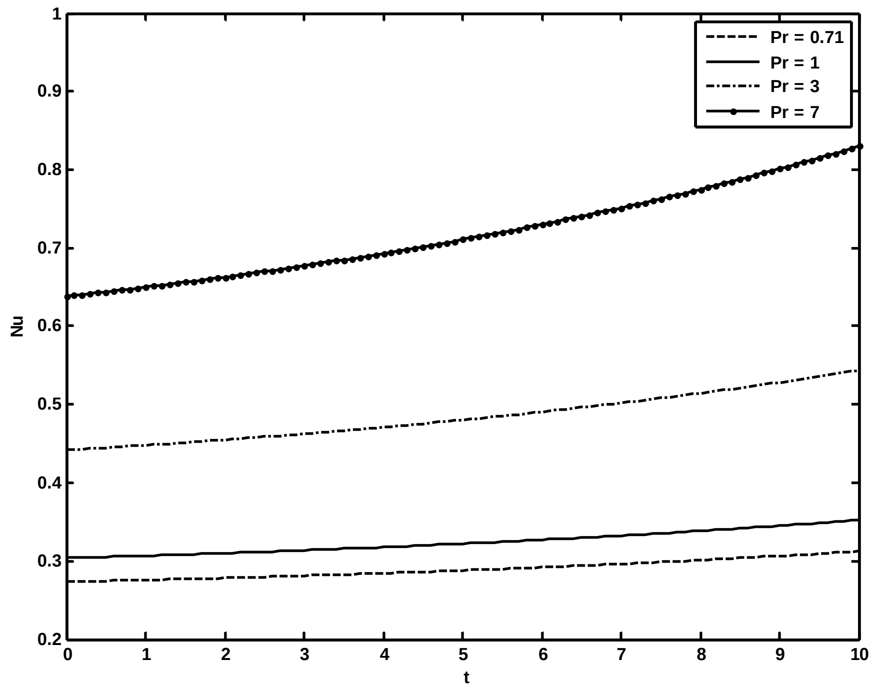

Fig 19. Nusselt Number for different values of Pr

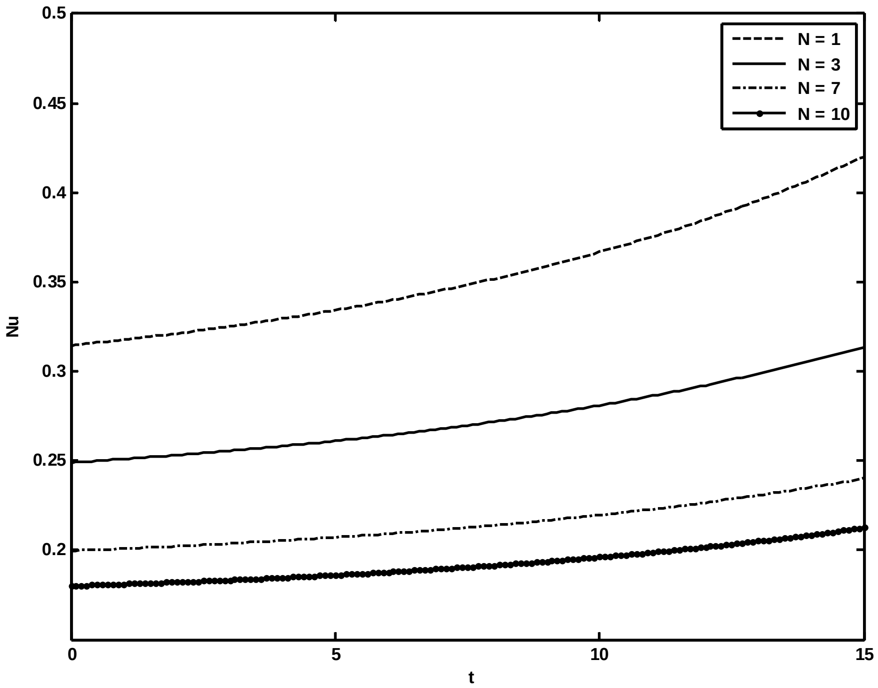

Fig 20. Nusselt Number for different values of N

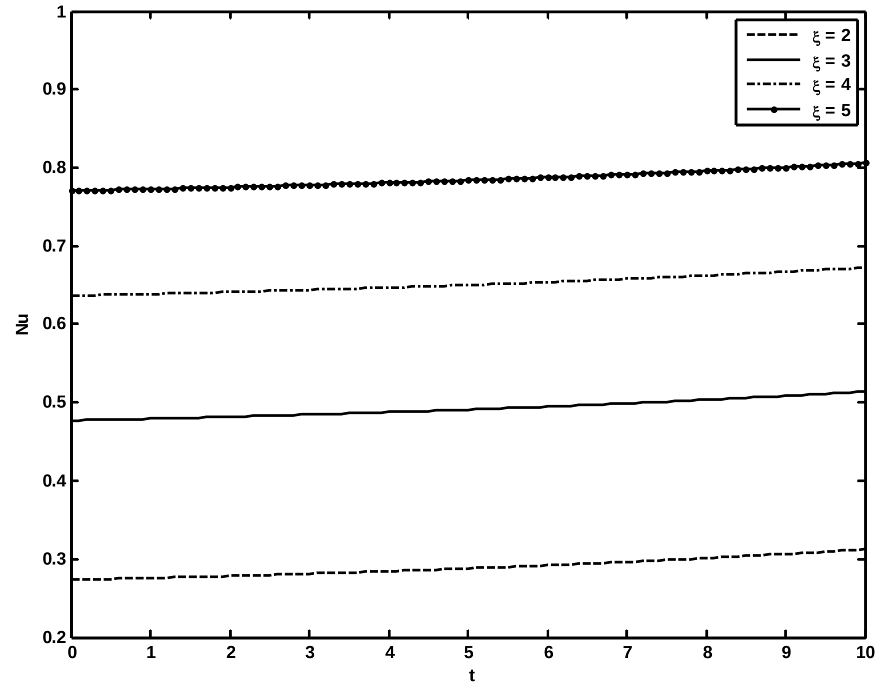

Fig 21. Nusselt Number for different values of ξ

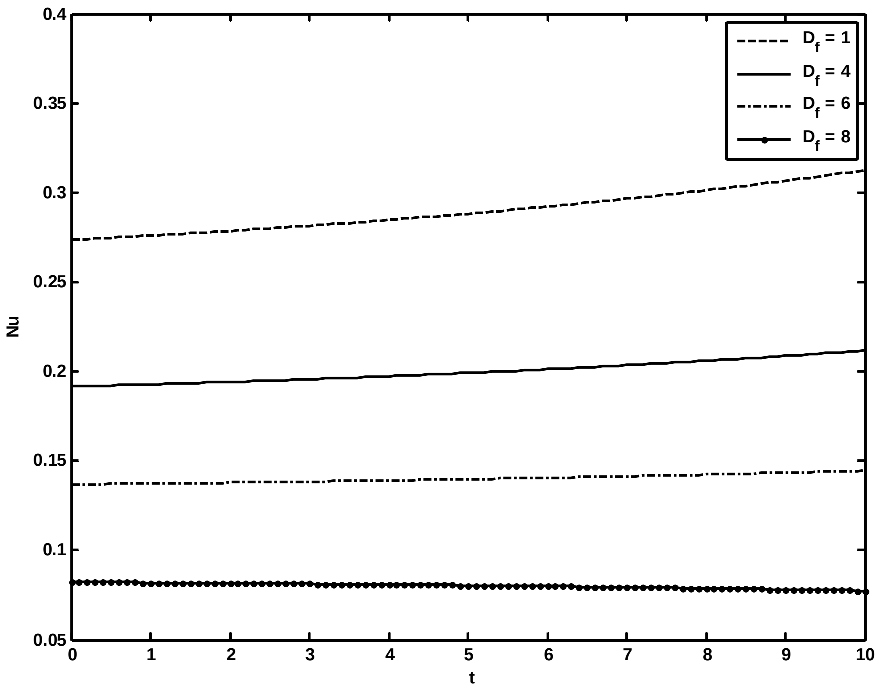

Fig 22. Nusselt Number for different values of D_f

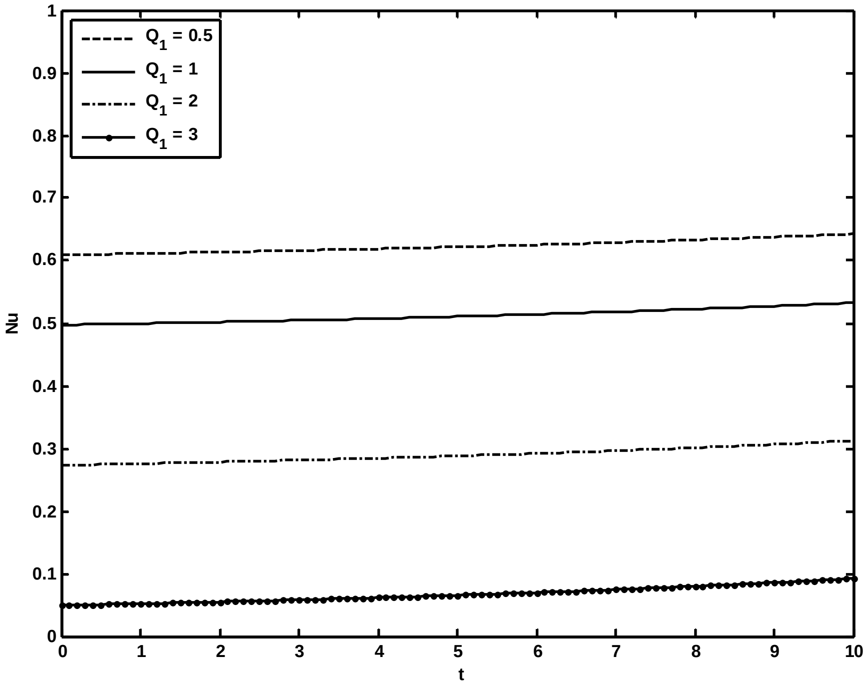

Fig 23. Nusselt Number for different values of Q_1

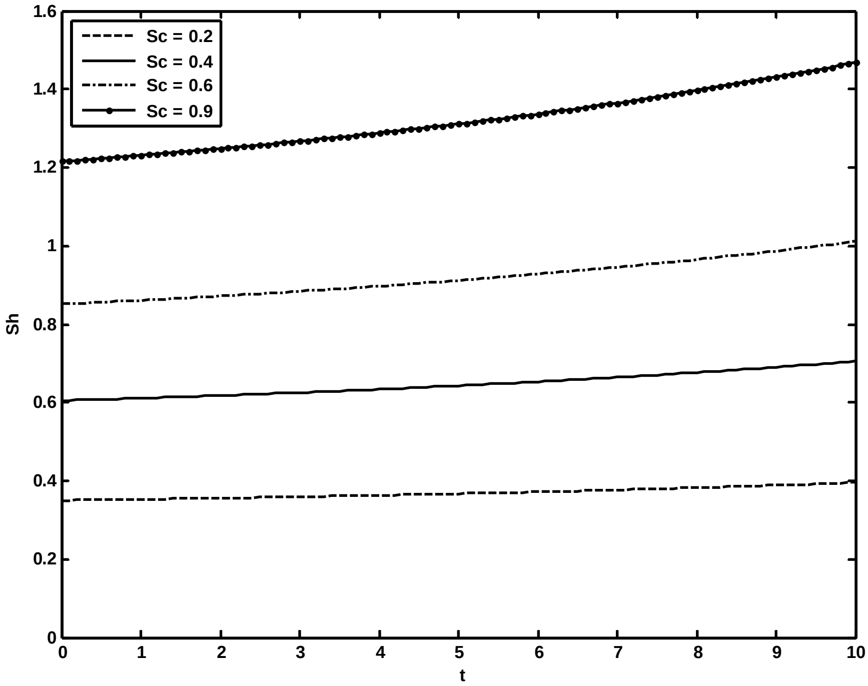

Fig 24. Sherwood Number for different values of Sc

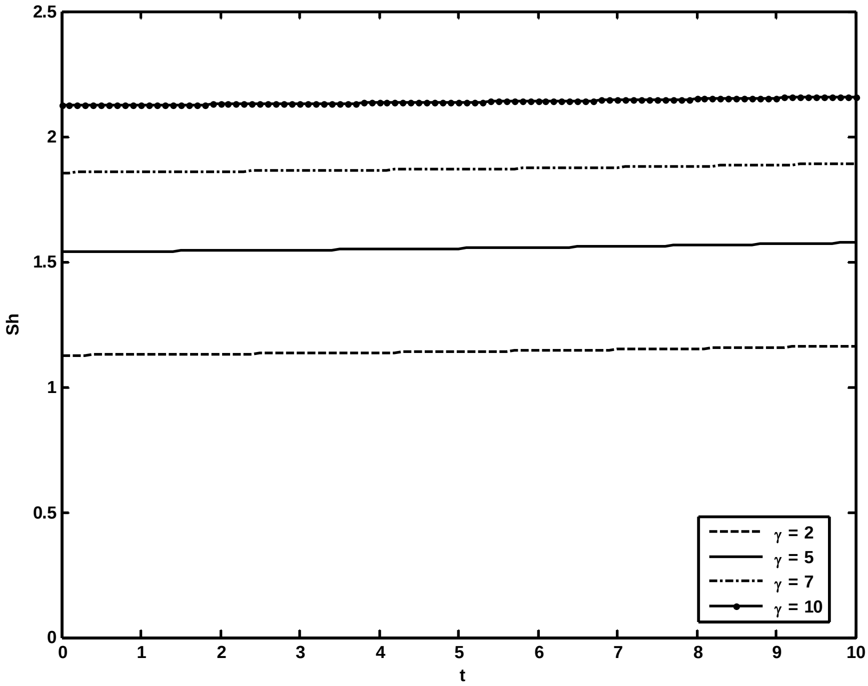

Fig 25. Sherwood Number for different values of γ

Conclusions

We considered the two dimensional unsteady free convective flow under the influence of magnetic field, radiation, heat absorption and chemical reaction. Dufour effects also considered. The partial differential equations are solved by perturbation technique. From this investigation the following conclusions are drawn

1. Increase in the Magnetic parameter, velocity profiles decreases.
2. Velocity and temperature increases with the increase of Dufour number
3. The temperature profiles are decreasing with the increase in Prandtl number
4. The presence of chemical reaction reduces the Concentration profiles
5. The skin friction coefficient increases by increasing Dufour number where as Nu decreases

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Appendix

$$A=1+\frac{4N}{3}\ ,\ R_1=M+\frac{1}{K},\ R_2=R_1+\omega,\ R_3=\xi+\omega,\ R_4=\gamma+\omega$$

$$m_1=\frac{1}{2}\left[Sc+\sqrt{Sc^2+4Sc\gamma}\right],\ m_2=\frac{1}{2}\left[Sc+\sqrt{Sc^2+4ScR_4}\right],$$

$$m_3=\frac{1}{2A}\left[\Pr+\sqrt{\Pr^2+4A\Pr\xi}\right],\ m_4=\frac{1}{2A}\left[\Pr+\sqrt{\Pr^2+4A\Pr R_3}\right],$$

$$m_5=\frac{1}{2}\left[1+\sqrt{1+4R_1}\right],\ m_6=\frac{1}{2}\left[1+\sqrt{1+4R_2}\right]$$

$$D_1=\frac{-Sc\ m_1}{m_1^2-Sc\ m_1-R_4\ Sc},\ D_2=\frac{Q_1\Pr+D_f\ \Pr m_1^2}{Am_1^2-\Pr\ m_1-\Pr\xi},$$

$$B_1=Q_1\Pr D_1-m_1\Pr D_2+\Pr D_1\ D_f\ m_1^2\ ,\ B_2=Q_1\Pr D_1+\Pr D_1\ D_f\ m_2^2\ ,$$

$$B_3=(1+D_2)\,m_3\Pr$$

$$D_3=\frac{B_1}{Am_1^2-\Pr\ m_1-\Pr R_3},\ D_4=\frac{-B_2}{Am_2^2-\Pr\ m_2-\Pr R_3},\ D_5=\frac{B_3}{Am_3^2-\Pr\ m_3-\Pr R_3},$$

$$B_4=-D_3-D_4-D_5\ ,\ B_5=-Gr\,(1+D_2),\ B_6=GrD_2-Gc$$

$$D_6=\frac{B_5}{m_3^2-m_3-R_1},\ D_7=\frac{B_6}{m_1^2-m_1-R_1},\ B_7=u_p-1-D_6-D_7\ ,$$

$$B_8=m_1D_7-D_3\,Gr+Gc\,D_1\ ,\ B_9=D_4\,Gr-Gc\,D_1\ ,\ B_{10}=m_3D_6-D_5\,Gr\ ,\ B_8=B_4\,Gr$$

$$D_8=\frac{B_8}{m_1^2-m_1-R_2},\ D_9=\frac{B_9}{m_2^2-m_2-R_2},\ D_{10}=\frac{B_{10}}{m_3^2-m_3-R_2},\ D_{11}=\frac{B_{11}}{m_4^2-m_4-R_2}$$

$$D_{12}=\frac{B_{12}}{m_5^2-m_5-R_2}\ ,\ B_{13}=-(D_8+D_9+D_{10}+D_{11}+D_{12})$$