International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.7, pp : 894-898 1 July 2014

Effects of Chemical Reaction and Thermal Diffusion on Mixed Convective Mass Transfer Flow in Permeable Media with Heat Generation/Absorption

Sanjib Sengupta
Department of Mathematics, Assam University, Silchar, Assam, India.
sanjib_aus2009@rediffmail.com

Abstract: ***The present paper analytically deals with two dimensional steady incompressible viscous flow of Newtonian fluid past a permeable plate immersed in Darcian porous media in presence of first order chemical reaction, thermal diffusion (Soret) and heat generation / absorption effects. The primary velocity is found to increase due to increase in parametric values of thermal diffusion, permeability parameter, while the increase in Schmidt number and chemical reaction parameter decrease the flow rate. It is also seen that, the mass transfer rate accelerates under the influence of Schmidt number and chemical reaction parameter, whereas the skin-friction increases as thermal diffusion parameter increases and decreases due to increase in chemical reaction parameter.***

Key words: Mixed convection, chemical reaction, thermal diffusion, heat source.

1. Introduction:

The theory of heat and mass transfer flow with mixed convection is constantly developing due to its importance in space technology, meteorological sciences and particularly in nuclear reactors. The process of convection heat transfer associated with a heated/cooled vertical plate is one of the fundamental problems in heat and mass transfer studies and thus extensive research has been done in this field by the researchers. If, a free convective flow is accompanied by an external flow, it is commonly called as mixed convection. Chamkha et al. [6] studied the effects of localized heating (cooling), suction (injection), buoyancy forces and magnetic field for the mixed convection flow on a heated vertical plate. Abdelkhalek [1] considered the MHD mixed convective stagnation point flow impinging on a heated vertical semi-infinite permeable surface. Aydin and Kaya [4] studied the mixed convection of viscous dissipating fluid about a vertical plate. Sengupta [11] investigated the case of radiative mixed convective mass transfer flow in presence of thermal diffusion and heat generation.

The theory of heat and mass transfer with chemical reaction is of considerable importance in the chemical and hydrometallurgical industries. Chambre and Young [5] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Muthucumaraswamy [9] considered the effects of chemical reaction on a moving isothermal surface with suction. Akyildiz et al. [3] studied the diffusion of chemically reactive species in a porous medium over a stretching sheet. Very recently, Sengupta and Sen [12] investigated first order chemical reaction effect on a free convective absorbing fluid in presence of heat sink and uniform heat flux.

It is observed that, a mass flux may be generated by the effects of both concentration gradients as well as by the temperature gradients. Mass flux influenced by temperature gradient is termed as Soret or thermal diffusion effect. The pioneering work in Soret effect was made by Eckert and Drake [7]. Notable contributions in thermo – diffusion effects are also made by researchers like, Afify [2] and Hayat et al. [8] etc. Sengupta [10] considered the influence of thermal diffusion effect on a free convective mass transfer flow with heat sink.

The objective of the present paper is to investigate the effects of first order chemical reaction on a steady two-dimensional mixed convective flow of a laminar incompressible viscous Newtonian fluid in presence of thermal diffusion and heat generation / absorption.

2. Mathematical Formulation and Solution of the Problem:

The flow field is considered to be steady, laminar and two-dimensional, whereas the fluid and the porous media are in local thermo-dynamical equilibrium. A co-ordinate system ($\bar{x}$, $\bar{y}$) has been introduced, with its $\bar{x}$ -axis along the length of the infinite plate in the upward vertical direction and $\bar{y}$ -axis perpendicular to the plate towards the fluid region. The plate is subjected to a constant suction velocity. Using Boussinesq approximation, a two- dimensional fully developed fluid model has been established in terms of a system of coupled partial differential equations, combined with two-point semi-open boundary conditions as:

Continuity Equation

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \quad (1)$$

Momentum Equation

$$\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + \nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + g\beta(\bar{T}-\bar{T}_\infty) + g\beta^*(\bar{C}-\bar{C}_\infty) - \frac{\nu\bar{u}}{\bar{K}} \quad (2)$$

Energy Equation

$$\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}} = \frac{k}{\rho c_p}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + \frac{\bar{Q}_l}{\rho c_p}(\bar{T}-\bar{T}_\infty) \quad (3)$$

Species Continuity Equation

$$\bar{v}\frac{\partial \bar{C}}{\partial \bar{y}} = D_M\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} + D_T\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - K_l(\bar{C}-\bar{C}_\infty) \quad (4)$$

Subject to the relevant boundary conditions as :

$$\bar{u}=0,\ \bar{v}=V_0,\ \bar{T}=\bar{T}_w,\ \bar{C}=\bar{C}_w,\ at\ \bar{y}=0 \quad (5.1)$$

$$\bar{u}\to\bar{U},\ \bar{v}=0\ \ \bar{T}\to\bar{T}_\infty, \bar{C}\to\bar{C}_\infty,\ at\ \bar{y}=0 \quad (5.2)$$

Using Bernoulli's pressure equation, the total (mechanical) pressure of the flow field can be quantified as:

$$-\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} = \frac{\nu \bar{U}}{\bar{K}} \quad (6)$$

By virtue of (6), equation (2) can recast as:

$$\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \nu \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + g\beta(\bar{T} - \bar{T}_\infty) + g\beta^*(\bar{C} - \bar{C}_\infty) + \frac{\nu}{\bar{K}}(U_0 - u) \quad (7)$$

The constant suction velocity can be considered as:

$$\bar{v}(t) = -V_0 \ , (V_0 > 0) \quad (8)$$

Introduce the following non-dimensional quantities as:

$$y = \frac{\bar{y}V_0}{\nu},\ U_0 = \frac{\bar{U}}{V_0}\ \ u = \frac{\bar{u}}{U_0},\ v = \frac{\bar{v}}{V_0},\ \theta = \frac{\bar{T} - \bar{T}_\infty}{\bar{T}_w - \bar{T}_\infty},$$

$$,\phi = \frac{\bar{C} - \bar{C}_\infty}{\bar{C}_w - \bar{C}_\infty}, Gr = \frac{g\beta\nu(\bar{T}_w - \bar{T}_\infty)}{V_0^3}, Sc = \frac{\nu}{D_M}\ \ Gm = \frac{g\beta\nu(\bar{C}_w - \bar{C}_\infty)}{V_0^3}$$

$$,\ K = \frac{V_0^2 \bar{K}}{\nu^2},\ \Pr = \frac{\nu\rho c_p}{k},\ Sr = \frac{D_T(\bar{T}_w - \bar{T}_\infty)}{\nu(\bar{C}_w - \bar{C}_\infty)},$$

$$Q_0 = \frac{\bar{Q}_l \nu^2}{k V_0^2}\ \ , F = \frac{\bar{K}_l \nu}{V_0^2}$$

The non-dimensional form of equations (7), (3) and (4) is,

$$\frac{d^2u}{dy^2} + \frac{du}{dy} - \frac{u}{K} = -\frac{U_0}{K} - Gr\theta - Gm\phi \quad (9)$$

$$\frac{d^2\theta}{dy^2} + \Pr\frac{d\theta}{dy} + Q_0\theta = 0 \quad (10)$$

$$\frac{d^2\phi}{dy^2} + Sc\frac{d\phi}{dy} - FSc\phi = -SrSc\theta \quad (11)$$

The corresponding non-dimensional initio - boundary conditions are:

$$u(0) = 0,\ \theta(0) = 1,\ \phi(0) = 1, \quad (12.1)$$

$$u(\infty) \to 1,\ \theta(\infty) \to 0,\ \phi(\infty) \to 0 \quad (12.2)$$

The exact analytical solution of equations (9) - (11) subject to (12.1) - (12.2) is thus calculated as:

$$\theta(y) = \exp(-\xi_1 y) \quad (13)$$

$$\phi(y) = \eta_1 \exp(-\xi_1 y) + \eta_2 \exp(-\xi_2 y) \quad (14)$$

$$u(y) = U_0 + \eta_3 \exp(-\xi_1 y) + \eta_4 \exp(-\xi_2 y) \quad (15)$$

Skin-friction at the plate:

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \xi_1\eta_3 + \xi_2\eta_4 \quad (16)$$

Nusselt number at the plate:

$$Nu = -\frac{1}{\Pr}\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \frac{\xi_1}{\Pr} \quad (17)$$

Sherwood number at the plate:

$$Sh = -\frac{1}{Sc}\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = \frac{1}{Sc}(\xi_1\eta_1 + \xi_2\eta_2) \quad (18)$$

Where, $\xi_1 = \frac{\Pr + \sqrt{\Pr^2 - 4Q_0}}{2}, (\Pr^2 > 4Q_0)$, $\xi_2 = \frac{Sc + \sqrt{Sc^2 + 4FSc}}{2}$,

$\eta_1 = -\frac{SrSc}{\xi_1^2 - Sc\xi_1 - FSc}$, $\eta_2 = 1 - \eta_1$, $\eta_3 = -\frac{Gr + \eta_1 Gm}{\xi_1^2 - \xi_1 - \frac{1}{K}}$, $\eta_4 = -\frac{Gm(1+\eta_1)}{\xi_2^2 - \xi_2 - \frac{1}{K}}$

3. Results and discussion:

The problem of two- dimensional steady flow of a viscous chemically heat generation/absorption fluid in porous media with thermal diffusion in presence of a uniform free stream motion is considered for this discussion. The parametric influence of various physical parameters on the velocity, temperature and concentration profiles as well as on the skin-friction, Nusselt and Sherwood numbers are presented graphically through graphs 1-8 and in tables 1 and 2.

Figure1 shows the parametric effect of Prandtl number (Pr) on the temperature profiles (θ , Q_0) for a fixed normal distance y = 0.02. The temperature is found to decrease due to increase in Pr for different range of values of Q_0. When $Q_0 \epsilon$ [-5, 1), the temperature initially increases due to increase in Pr, thereafter for $Q_0 \epsilon$ [1, 5], the temperature attains a steady state. Figure 2 represents the influence of Schmidt number (Sc) on the concentration profiles (ϕ, F) for a set of fixed values of Pr=0.71, Q_0 =0.1, Sr=0.5, y=0.01. Due to increase in Sc, the mass diffusivity decreases, results of which the thickness of the solutal boundary layer decreases and thus the concentration near the plate surface drops. Further it is also seen that, as F increases, the concentration near the plate falls, indicating across movement of fluid particles from the plate (higher concentration zone) to the free stream region (lower concentration zone). Figures 3 to 5 depict how the flow rate are being influenced by the presence of parameters like, Soret number (Sr), free stream velocity (U_0) and the permeability parameter (K) against normal distance (y) and for a set of fixed values of Pr=0.71, Q_0 =0.1, Sc=0.74, F=0.3, Gr=5.0, Gm=2.0 as well as Sr = 0.5(for fig. 2, 3), U_0 =0.5(for fig. 1, 3) and K=0.5(for fig. 1, 2). It is observed that, the flow rate accelerates due to increase in values of Sr, U_0 and K respectively. Due to increase in Sr, the mass buoyancy forces increase which accelerates the flow rate and thus increase the value of u. Again, due to increase in U_0, an additional fluid velocity is acquired by the fluid particles inside the momentum boundary layer, which increases the kinetic energy thereby increase the flow rate and the value of u. Also as the values of K increase, the frictional force decreases, this increases the flow rate and the fluid velocity u. The effect of Schmidt number (Sc) on the velocity profiles (u, F) for a set of fixed values of Pr=0.71, Q_0 =0.1, Gr=5.0, Gm=2.0, Sr = 0.5, U_0 =0.5, K=0.5 and y=0.01 is depicted in figure 6. As the mass diffusivity decreases due to increase in values of Sc, the concentration of fluid particles near the plate drops, which results in decreasing the effect of mass buoyancy forces and thus decrease the fluid velocity u. Figure 7 shows the influence of Prandtl number (Pr) on the Nusselt number profiles (Nu , Q_0). When Q_0 ϵ [-1, 0), the Nusselt number *is found decreasing due to increase in values of Pr, while for Q_0 ϵ [0, 1], an opposite trend has observed. Figure 8 represents how the Sherwood number is being influenced due to change in values of Schmidt number (Sc) against chemical reaction parameter (F). As the values of Sc increase, the value of Sh decreases while, Sh is found increasing due to increase in values of F. Table 1 presents numerically the variation of ϕ for parametric variation in values of Soret number (Sr) against chemical reaction parameter (F) and for a set of fixed values of Pr=0.71,Sc=0.6, Q_0 =0.1 and y=0.01. It is clearly seen that, the concentration rises due to increase in values of Sr, while reversed effect has been observed due to increase in values of F. The change in values of Soret number (Sr) for relative change in values of chemical reaction parameter (F) on the skin-friction is depicted numerically in table 2. The skin-frictional effect is found increasing due to increase in Sr, but a reversed phenomenon is observed as the values of F increase.*

4. Conclusion:

The significant outcome of the study is highlighted as follows:

- *The temperature decreases due to increase in Prandtl number, while the temperature increases in presence of heat absorption parameter and achieves steady state in presence of heat generation parameter.*
- *The concentration increases as Soret number increases, while concentration drops due to increase in Schmidt number and chemical reaction parameter.*
- *The velocity of flow increases as Soret number, free stream velocity and permeability parameters increase, while the increase in Schmidt number and chemical reaction parameter is found to decrease the fluid velocity.*
- *The Nusselt number first decreases and thereafter it is found increasing due to increase in values of Prandtl number, but Nusselt number decreases as heat generation / absorption parameter increases.*
- *The Sherwood number decreases as Schmidt number increases while reversed phenomenon is observed due to increase in values of chemical reaction parameter.*
- *The skin-friction increases as Soret number increases, while an opposite phenomenon has been observed due to increase in values of chemical reaction parameter.*

References

i. M.M. Abdelkhalek (2006): The skin friction in the MHD mixed convection stagnation point with mass transfer. Int. Commun. Heat Mass, 33, pp 249–258.

ii. A.A. Afify, (2009): Similarity solution in MHD: Effects of thermal diffusion and diffusion- thermo on free convective heat and mass transfer over a stretching surface considering suction or injection. Comm. in Non-linear Sciences and numerical simulations, 14, pp 2202-2214.

iii. III. F.T. Akyildiz, H. Bellout, K. Vajravelu (2006): Diffusion of chemically reactive species in a porous medium over a stretching sheet. J. Math Anal Appl., 320, pp 322–39.

iv. O. Aydin and A. Kaya (2007) : Mixed convection of a viscous dissipating fluid about a vertical flat plate, Appl. Math. Model 31, pp 843–853.

v. P.L. Chambre and J. D Young (1958): On the diffusion of a chemically reactive species in a laminar boundary layer flow. The Physics of Fluids, 1, pp 48-54.

vi. A.J. Chamkha, H.S.Takhar and G. Nat (2004): Mixed convection flow over a vertical plate with localized heating (cooling), magnetic field and suction (injection). Heat Mass Transfer, 40 pp 835–841.

vii. E. R. G. Eckert and R. M. Drake (1972): Analysis of heat and mass transfer, Hemisphere Pub. Corp., Washington, D.C.

viii. T. Hayat, M. Mustafa and I. Pop (2010): Heat and mass transfer for Soret and Dufour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with viscoelastic fluid. Commun Nonlinear Sci Numer Simul, 15, pp 1183–1196.

ix. R. Muthecumaraswamy (2002): Effects of a chemical reaction on a moving isothermal surface with suction. Acta Mechanica 155, pp 65-72.

x. S. Sengupta (2011): Thermal diffusion effect of free convection mass transfer flow past a uniformly accelerated porous plate with heat sink. International Journal of Mathematical Archive, 2, pp 1266-1273.

xi. S. Sengupta (2012): Radiative mixed convection mass transfer flow past an iso-thermal porous plate embedded in a permeable medium in presence of thermal diffusion and heat generation. International Journal of Computer Applications, 40, pp 17-22.

xii. S.Sengupta, and M. Sen (2013) Free convective heat and mass tyransfer flow past an oscillating plate with heat generation, thermal radiation and thermo-diffusion effects, JP J. of heat and mass transfer, 8(2), pp 187-210.

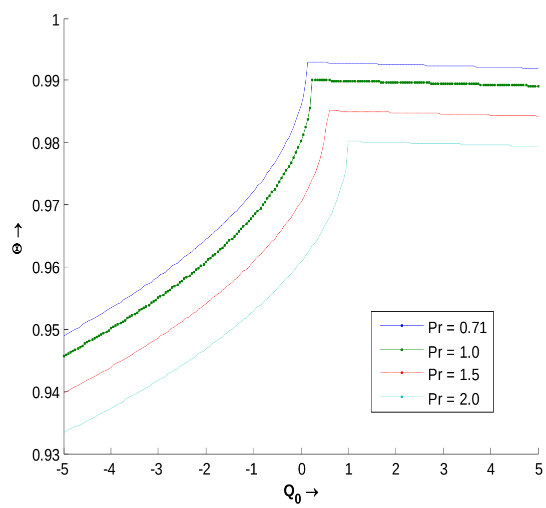


Figure1: Temperature versus heat absorption / generation parameter for arbitrary values of Prandtl number.

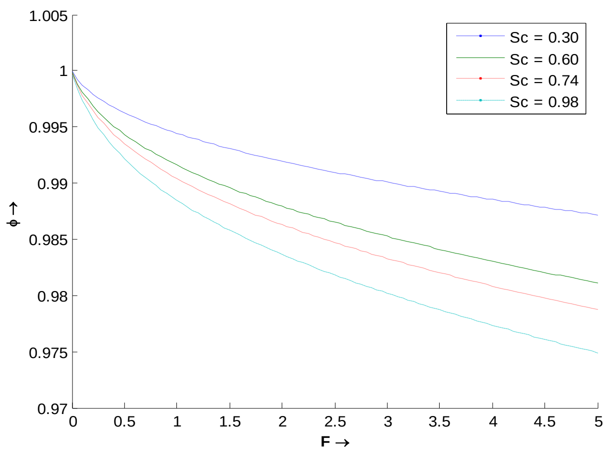


Figure 2: Concentration versus chemical reaction against arbitrary values of Schmidt number .

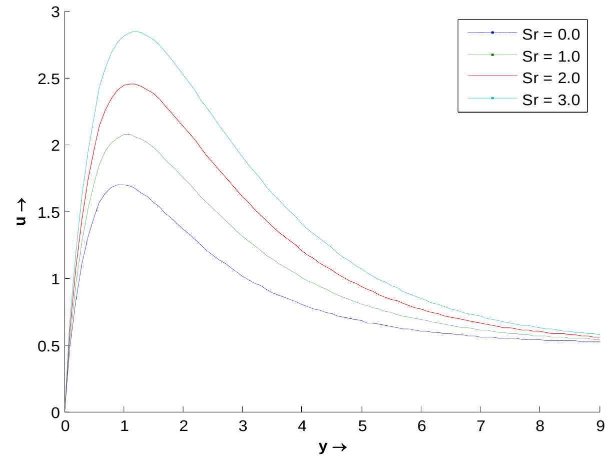
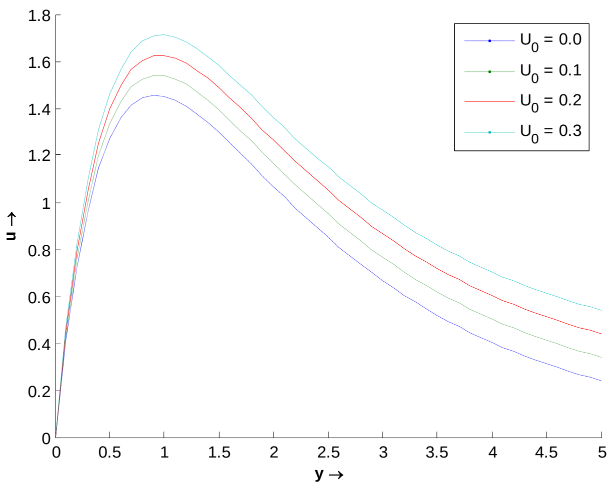


Figure 3: Velocity versus normal distance against arbitrary fixed values of Soret number.



Figiure 4: Velocity versus normal distance against arbitrary fixed values of free stream velocity.

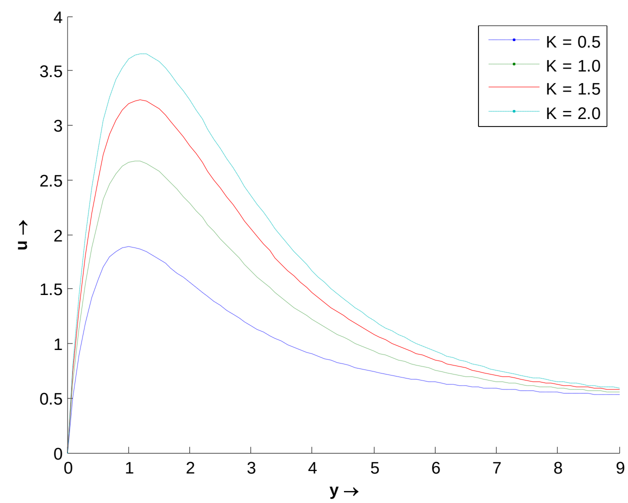


Figure 5: Velocity versus normal distance against arbitrary fixed values of permeability.

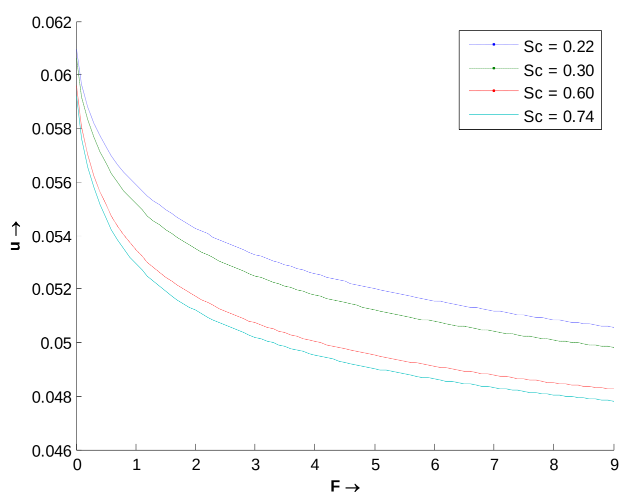
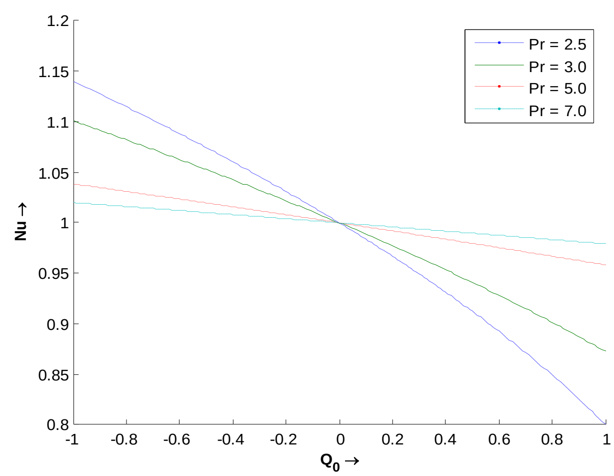
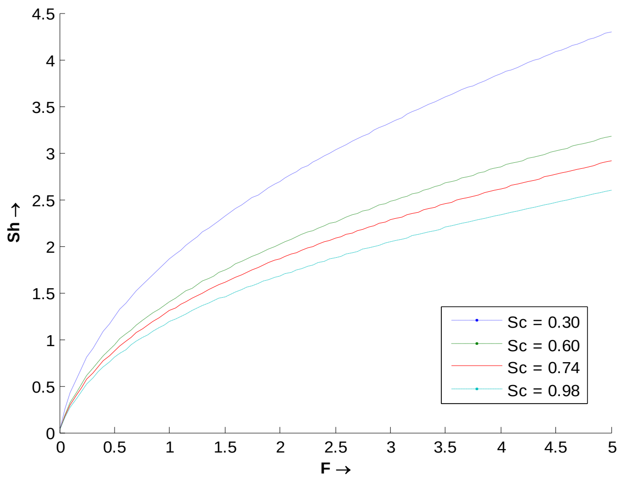


Figure 6: Velocity versus normal distance against arbitrary fixed values of Schmidt number.



Figiure 7: Nusselt number versus heat absorption / generation parameter for arbitrary values of Prandtl number.

International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.7, pp : 894-898 1 July 2014



Figiure 8: Sherwood number versus chemical reaction parameter for arbitrary values of Schmidt number.

Table1.The numerical values of concentration against heat generation parameter for different values of Soret number.

F	Sr= 0.0	Sr = 0.2	Sr = 0.4	Sr = 0.6
0.0	0.9940	0.9963	0.9986	1.0010
0.5	0.9908	0.9922	0.9936	0.9950
1.0	0.9888	0.9899	0.9910	0.9922
1.5	0.9871	0.9881	0.9891	0.9901
2.0	0.9857	0.9866	0.9875	0.9884
2.5	0.9845	0.9853	0.9861	0.9869
3.0	0.9834	0.9841	0.9849	0.9856
3.5	0.9824	0.9831	0.9838	0.9845
4.0	0.9814	0.9821	0.9827	0.9834
4.5	0.9805	0.9811	0.9817	0.9824
5.0	0.9796	0.9802	0.9808	0.9814

Table2.The numerical values of skin-friction against chemical reaction parameter for different values of Soret number.

F	Sr= 0.0	Sr = 0.5	Sr = 1.0	Sr = 1.5
0.0	5.4469	5.9901	6.5333	7.0765
0.5	5.2581	5.5312	5.8043	6.0774
1.0	5.1646	5.3600	5.5554	5.7509
1.5	5.1017	5.2571	5.4125	5.5679
2.0	5.0546	5.1849	5.3152	5.4455
2.5	5.0170	5.1298	5.2427	5.3555
3.0	4.9859	5.0858	5.1857	5.2856
3.5	4.9594	5.0493	5.1391	5.2290
4.0	4.9365	5.0183	5.1001	5.1819
4.5	4.9163	4.9915	5.0666	5.1418
5.0	4.8983	4.9679	5.0376	5.1072