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Original Article

Impact of Radiation and Newtonian Heating on Double Diffusive Convective Flow Past a Surface in the Presence of Chemical Reaction

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Abstract - *The heat and mass transfer characteristics of the unsteady radiative boundary layer flow of a chemically reacting fluid past an infinite vertical oscillating plate are taken into account in this study. Exact solutions obtained by Laplace transform technique in this paper are interpreted graphically to examine the effects of various pertinent parameters. Graph results are presented for temperature, velocity, skin friction. The physical aspects of the problem are also discussed.*

Keywords *- Chemical reaction, Free convection, Mass transfer, Newtonian heating, Radiation.*

1. Introduction

Heat and mass transfer analysis has its application in various fields including automobile, steam-electric power generation, energy systems. Muthucumaraswamy Rajamanickam et. al. [1] investigated effects of heat and mass transfer on flow past an oscillating vertical plate. Harir Kataria et.al. [2] considered Heat and mass transfer flow past an oscillating vertical plate embedded in porous medium. Muthucumaraswamy R. et. al. [3] pionered unsteady flow past a vertical plate with variable temperature and uniform mass flux. Chaudhary et.al.[4,5] analyzed heat and mass transfer flow past an infinite vertical plate with different physical conditions. Heat and mass transfer effects on free convection flow past a surface is investigated by Jhansi Rani et. al. [6] and Veera Krishna et.al. [7]. Heat transfer past a porous plate is studied by Ameer et. al.[8].

Recently, Newtonian heating is studied by many researchers instead of constant surface temperature because in many physical situations constant temperature assumption at surface fails to work. Newtonian heating is defined as the process in which internal resistance is negligible as compared to surface resistance. The applications of Newtonian heating include heat exchanger, conjugate heat transfer around fins etc. Abid Hussanan et.al. [9] analyzed natural convection flow past an oscillating plate with Newtonian heating. Bijjula Prabhakar Ready et. al. [10] and Das et. al. [11] pioneered Newtonian Heating Effect on flow past a Plate. Effects of Newtonian heating on moving vertical plate is investigated by Dolat Khan et.al.[12].

At high operating temperature, radiation effect can be quite significant. Nuclear power plants, gas turbines, satellites and space vehicles are examples of such engineering areas where radiation is important. MHD natural convective fluid flow past a vertical plate embedded in porous medium with radiation is analyzed by Reddy.et.al.[13]. Mixed convection flow past a surface with radiation is studied by Bakier et.al.[14] and Badruddin et. al. [15]. Radiation effects on flow past a plate pioneered by Venkateswara Raju et.al.[16] and Ananda Reddy et.al.[17]. An exact solution of natural convective and radiating effects on flow past a plate is analyzed by Chaudhary et.al. [18].

Chemical reactions are used in the field of Psychrometer to measure humidity, paper production, glass blowing. Radiation and chemical reaction effects on flow past a infinite vertical plate is analyzed by Shankar Goud et.al.[19]. Lalitha et. al. [20] and Sakthikala et.al.[21] considered laminar free convection flow with radiation and chemical effects past a plate. Rajput et. al. [22] investigated effects of radiation and chemical reaction on flow past a vertical plate. Effects of radiation on chemically reacting fluid flow past a vertical plate is studied by Veeresh et. al. [23]. Arulmozhil et. al. [24] investigated heat and mass transfer analysis of radiative and chemically reactive effects over an infinite moving vertical plate. Influence of Newtonian heating and radiation on chemically reactive fluid flow past an accelerated surface by Laplace transform technique is analyzed by Arpita [25].

2. Mathematical Analysis

Consider unsteady two-dimensional flow of an incompressible and electrically conducting viscous fluid along an infinite vertical plate. The x'-axis is taken on the infinite plate and parallel to the free stream velocity and y'-axis normal to it. Initially, the plate and the fluid are at same temperature T'_∞ with concentration level C'_∞ at all points. At time t' > 0, It starts oscillating with a velocity $U_R \cos \omega' t'$ in its own plane. At the same time, the heat transfer from plate to the fluid is directly proportional to the local surface temperature T' and the plate concentration is raised linearly with respect to time. It is assumed that there exist a homogeneous chemical reaction of first order with constant rate K_l between the diffusing species and the fluid. Since the plate is infinite in extent therefore the flow variables are the functions of y' and t' only. The fluid is considered to be gray absorbing-emitting radiation but non scattering medium. The radiative heat flux in the x'-direction is considered negligible in comparison with of y'-direction. Then neglecting viscous dissipation and assuming variation of density in the body force term (Boussinesq's approximation), the problem can be governed by the following set of equations:

$$\frac{\partial T'}{\partial t'} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \tag{1}$$

$$\frac{\partial C'}{\partial t'} = D\,\frac{\partial^2 C'}{\partial y'^2} - k_l C' \tag{2}$$

$$\frac{\partial u'}{\partial t'} = \nu\,\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta_c(C' - C'_\infty) \tag{3}$$

with following initial and boundary conditions

$$u' = 0\,,\; T' = T'_\infty, C' = C'_\infty \text{ for all } y', t' \le 0 \tag{4}$$

$$u' = u_R\,cos(\omega' t')\,, \frac{\partial T'}{\partial y'} = -h_s T' C' \quad = C'_\infty + (C'_W - C'_\infty)\frac{u_R^2 t}{\upsilon} at y' = 0, t' > 0$$

$$u' \to 0, T' \to T'_\infty, C' \quad \to C'_\infty as y'' \to \infty, t' > 0$$

The radiative heat flux term, by using the Rosseland's approximation is given by

$$q_r = -\frac{4\sigma'}{3\kappa^*}\frac{\partial T'^4}{\partial y'} \tag{5}$$

where U_R is reference velocity, g is gravitational acceleration, C_p is specific heat at constant pressure, D is mass diffusivity, β is thermal expansion coefficient, β_C is concentration expansion coefficient, ρ is density, κ is thermal conductivity of fluid, κ^* is mean absorption coefficient, ν is kinematic viscosity and , q_r is radiative heat flux, σ' is Stefan-Boltzmann Constant. We assume that the temperature differences within the flow are such that T'4 may be expressed as a linear function of the temperature T'. This is accomplished by expanding T'4in a Taylor series about T'_∞ and neglecting higher-order terms

$$T'^4 \simeq 4\,T'^3_\infty T' - 3T'^4_\infty \tag{6}$$

using Equations (5) and (6), Equation (1) gives

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa\frac{\partial^2 T'}{\partial y'^2} + \frac{16\sigma' T'^3_\infty}{3\kappa^*}\frac{\partial^2 T'}{\partial y'^2} \tag{7}$$

Introducing the following dimensionless quantities

$$\omega = \omega' t_R\; t = \frac{t'}{t_R}, y = \frac{y'}{L_R}, u = \frac{u'}{U_R}, k = \frac{U_R^2 k_l}{\nu^2}$$

$$Pr = \frac{\mu C_P}{\kappa}, Sc = \frac{\nu}{D}, \theta = \frac{T' - T'_\infty}{T'_\infty}, G = \frac{g\beta_T T'_\infty \nu}{U_R^3}$$

$$C = \frac{C' - C'_\infty}{C'_W - C'_\infty}, Gm = \frac{\nu g\beta_C(C'_W - C'_\infty)}{U_R^3}, k = \frac{\nu k_l}{U_R^2}, R = \frac{\kappa^*\kappa}{4\sigma' T'^3_\infty}$$

$$\Delta T = T'_w - T'_\infty,\ U_R = (\nu g\beta \Delta t)^{\frac{1}{3}}, L_R = \left(\frac{g\beta\Delta T}{\nu^2}\right)^{-1/3}, t_R = (g\beta\Delta T)^{-2/3}\nu^{1/3} \quad (8)$$

where L_R is reference length, t_R is reference time, ω is frequency of oscillation, Gm is modified Grashof number, Pr is Prandtl number, Sc is Schmidt number and u is dimensionless velocity component, θ is dimensionless temperature, C is dimensionless concentration, μ is viscosity of fluid, t is time in dimensionless coordinate, R is radiation parameter and k is chemical reaction parameter.

On solving Equations (7), (2) and (3) by Laplace-transform, we get

$$\theta = exp(-2\gamma\eta\sqrt{t} + b^2 t)erfc(\eta\sqrt{a} - b\sqrt{t}) - erfc(\eta\sqrt{a}) \quad (9)$$

$$C = \frac{t}{2}\{exp(2\eta\sqrt{kSct})erfc(\eta\sqrt{Sc} + \sqrt{kt}) + exp(-2\eta\sqrt{kSct})erfc(\eta\sqrt{Sc} - \sqrt{kt})\}$$
$$\frac{\eta\sqrt{Sct}}{2\sqrt{k}}\{exp(2\eta\sqrt{kSct})erfc(\eta\sqrt{Sc} + \sqrt{kt}) + exp(-2\eta\sqrt{kSct})erfc(\eta\sqrt{Sc} - \sqrt{kt})\} \quad (10)$$

For Pr =Sc ≠ 1

$$u = \frac{\exp(i\omega t)}{4}\{\exp(2\eta\sqrt{i\omega t})\mathrm{erfc}(\eta + \sqrt{i\omega t}) + \exp(-2\eta\sqrt{i\omega t})\mathrm{erfc}(\eta - \sqrt{i\omega t})\}$$
$$+\frac{\exp(-i\omega t)}{4}\{\exp(2\eta\sqrt{-i\omega t})\mathrm{erfc}(\eta + \sqrt{-i\omega t}) + \exp(-2\eta\sqrt{-i\omega t})\mathrm{erfc}(\eta - \sqrt{-i\omega t})\}$$
$$+\frac{Gb}{a-1}\left\{\frac{1}{4\sqrt{\pi t}}exp(-\eta^2) + b\,exp(b^2 t - 2b\eta\sqrt{t})erfc(\eta - b\sqrt{t})\right\}$$
$$-\frac{Gb}{a-1}\left\{\frac{1}{4\sqrt{\pi t}}exp(-\eta^2 a) + b\,exp(b^2 t - 2\gamma\eta\sqrt{t})erfc(\eta\sqrt{a} - b\sqrt{t})\right\}$$
$$+\frac{Gm}{kSc}\left\{t(1+2\eta^2)erfc(\eta) - \frac{2\eta e^{-\eta^2}}{\sqrt{\pi}}\right\} + \frac{Gm(1-Sc)}{k^2Sc^2}erfc(\eta)$$
$$+\frac{Gm(1-Sc)}{2k^2Sc^2}exp\left(\frac{kSct}{1-Sc}\right)\left\{exp\left(2\eta\sqrt{\frac{kSct}{1-Sc}}\right)erfc\left(\eta\sqrt{Sc} + \sqrt{\frac{kt}{1-Sc}}\right) + exp\left(-2\eta\sqrt{\frac{kSct}{1-Sc}}\right)erfc\left(\eta\sqrt{Sc} - \sqrt{\frac{kt}{1-Sc}}\right)\right\}$$
$$-\frac{Gmt}{2kSc}\{exp(2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} + \sqrt{kt}) + exp(-2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} - \sqrt{kt})\}$$
$$+\frac{Gm\eta}{2kSc}\sqrt{\frac{tSc}{k}}\{exp(2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} + \sqrt{kt}) - exp(-2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} - \sqrt{kt})\}$$
$$-\frac{Gm(1-Sc)}{2k^2Sc^2}\{exp(2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} + \sqrt{kt}) + exp(-2\eta\sqrt{kSct})\,erfc(\eta\sqrt{Sc} - \sqrt{kt})\} \quad (11)$$

$$b = \frac{\gamma}{\sqrt{a}}, \rightleftarrows\rightleftarrows\ a = \frac{Pr}{1+R\frac{y}{2\sqrt{t}}\frac{kSc}{1-Sc}}$$

3. Skin-Friction

From velocity field, skin-friction at the plate in non dimensional form is expressed as:

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0}$$
$$\frac{exp(i\omega t)}{2\sqrt{t}}\left(\sqrt{i\omega t}erf(\sqrt{i\omega t})\right) + \frac{exp(-i\omega t)}{2\sqrt{t}}\left(\sqrt{-i\omega t}erf(\sqrt{-i\omega t})\right) + \frac{1}{\sqrt{\pi t}} + \frac{Gb}{a-1}\left\{\frac{b}{\sqrt{\pi t}} + b^2\,exp(b^2 t)\,erfc(-b\sqrt{t})\right\}$$

$$+\frac{Gm(1-Sc)}{k^2Sc^2}\left(exp\left(\frac{kSct}{1-Sc}\right)\right)\sqrt{\frac{kSc}{1-Sc}}\left(erf\left(\sqrt{\frac{kSct}{1-Sc}}\right)+erf\left(\sqrt{\frac{kt}{1-Sc}}\right)\right)$$

$$+\frac{Gm(1-Sc)}{k^2Sc^2\sqrt{\pi t}}-\frac{Gb^3\sqrt{a}}{(a-1)}e^{b^2t}erfc(-b\sqrt{t})-\frac{Gb^2}{(a-1)}e^{b^2t}\sqrt{\frac{a}{\pi t}}$$

$$-\frac{Gmt}{kSc}\left\{\sqrt{kSc}\,erf(\sqrt{kt})+\sqrt{\frac{Sc}{\pi t}}e^{-kt}\right\}$$

$$-\frac{Gm(1-Sc)}{k^2Sc^2}\left\{\sqrt{kSc}\,erf(\sqrt{kt})\right\}+\frac{Gm}{2k^{\frac{3}{2}}\sqrt{Sc}} \tag{12}$$

4. Discussion

Figures 1 & 2 elucidate the effects of Pr and ϒ on temperature profile respectively. It is observed that temperature is maximum at the plate then decreases to zero far away from the plate. Further, thickness of thermal boundary layer decreases with a rise in Pr. This is due to the fact that thermal conductivity of fluid decreases with increasing Pr, results a decrease in thermal boundary layer thickness. It is also noticed that it decreases steeply for Pr = 7 than that of Pr = 0.71. Further, an increase in Newtonian heating parameter ϒ increases the thermal boundary layer thickness as a result the surface temperature of the plate increases.

Figure 3 reveals the effect of ωt and Pr on the velocity. It is obvious from the figure 3 that the velocity increases and reaches its maximum value in the vicinity of the plate ($\eta \le 0.5$) and then tends to zero asymptotically. It is also observed that both the velocity and the penetration for Pr = 0.71 is higher than that of Pr = 7. Physically, it is possible because fluids with high Prandtl number have high viscosity and hence move slowly. It is also noticed that the velocity decrease with an increase in ωt. Figure 4 indicates the effect of G and ϒ on velocity profile for Pr=7 and Pr=0.71. It is clear from figure that velocity is equal to time t at the plate then increases to maximum value after that it decreases to zero value for Pr=0.71 but for Pr=7 the same shape of profile is found in reverse direction. Further, magnitude of velocity for Pr=0.71 is higher than that of Pr=7. Physically, it is true because fluids with high Prandtl number have high viscosity and hence move slowly. Moreover, the magnitude of velocity increases with an increase in value of G due to mass buoyant effect of G. Moreover, the magnitude of velocity increases with an increase in the value of ϒ.

Figure 5 represents the effects of parameters Sc, k, Gm, ωt on skin friction at the plate at different values of t. It is noticed that skin- friction decreases with an increase in time and for ωt=0 it becomes negative means separation of boundary later occurs for higher values of t (t>0.3). The figure shows that skin friction grow more for heavier particles (Sc=0.96) than for lighter particles. Physically, it is correct since an increase in Sc serves to increase momentum boundary layer thickness. Further, it decreases with an increase in value of Gm and marginally increases with an increase in k.

References

[1] Muthucumaraswamy Rajamanickam and A. Vijayalakshmi, “Effect of Heat and Mass Transfer on Flow Past a Oscillating Vertical Plate with Variable Temperature,” *International Journal of Applied Mathematics and Mechanics*, vol. 4, no.1, pp. 59-65, 2008.

[2] Harir Kataria, Harshad and R. Patel, “Heat and Mass Transfer in Magnetohydrodynamic (MHD) Casson Fluid Flow Past Over an Oscillating Vertical Plate Embedded in Porous Medium with Ramped Wall Temperature,” *Propulsion and Power Research*, vol. 7, no. 3, pp. 257- 267, 2018.

[3] R. Muthucumaraswamy and B. Saravanan, “Finite Difference Solution of Unsteady Flow Past an Oscillating Semi Infinite Vertical Plate with Variable Surface Temperature and Uniform Mass Flux,” *International Journal of Applied Mechanics and Engineering*, vol. 19, pp. 709- 724, 2014.

[4] R. C. Chaudhary and Arpita Jain, “Influence of Periodic Temperature on Transient Natural Convection Flow of an Elastico-Viscous Fluid Past a Uniformly Accelerated Plate,” *Journal of Engineering Physics and Thermophysics*, vol. 82, no. 3, pp. 476-487, 2009.

[5] R. C. Chaudhary and Arpita Jain, “An Exact Solution of Magnetohydrodynamic Convection Flow Past an Accelerated Surface Embedded in Porous Medium,” *International Journal of Heat and Mass Transfer*, vol.53, no. 7-8, pp. 1609- 1611, 2010.

[6] K. Jhansi Rani, G. V. Ramana Reddy, Ch. V. Ramana Murthy and M. V. Ramana Murthy, “Heat and Mass Transfer Effects on MHD Free Convection Flow Over an Inclined Plate Embedded in a Porous Medium,” *International Journal of Chemical Science*, vol. 13, no. 4, pp. 1998-201, 2015.

[7] M. Veera Krishna and P. V. S. Anand, “Heat and Mass Transfer on Free Convective Flow of a Micropolar Fluid Through a Porous Surface with Inclined Magnetic Field and Hall Effects,” *Special Topics Rev Porous Media*, vol. 10, no. 3, pp. 203-223, 2019.

[8] N. Ameer Ahammad, Irfan Anjum Badruddin, Sarfaraz Kamangar, H.M.T. Khaleed, C. Ahamed Saleel and Teuku Meurah Indra Mahlia, "Heat Transfer and Entropy in a Vertical Porous Plate Subjected to Suction Velocity and MHD," *MDPI Entropy*, vol. 23, no. 1069, pp. 1-23, 2021.

[9] Abid Hussanan, M. Imran, Farhad Ali and Ilyas Khan, "Natural Convection Flow Past an Oscillating Plate with Newtonian Heating," *Heat Transfer Research*, vol. 45, no. 2, pp. 119-135, 2014.

[10] Bijjula Prabhakar Ready and L. Sademaki Joseph, "A Numerical Study on Newtonian Heating Effect on Heat Absorbing MHD Casson Flow of Dissipative Fluid Past an Scillating Vertical Porous Plate," *International Journal of Mathematics and Mathematical Sciences*, vol. 2, pp. 1-16, 2022.

[11] M. Das, R. Mahato and R. Nandkeolyar, "Newtonian Heating Effect on Unsteady Hydromagnetic Casson Fluid Flow Past a Flat Plate with Heat and Mass Transfer," *Alexandria Engineering Journal*, vol. 54, no. 4, pp. 871-879, 2015.

[12] Dolat Khan, Arshad Khan, Ilyas Khan, Farhad Ali, Faizan ul Karim and I. Tlili, "Effects of Relative Magnetic Field, Chemical Reaction, Heat Generation and Newtonian Heating on Convection Flow of Casson Fluid Over a Moving Vertical Plate Embedded in a Porous Medium," *Scientific Reports*, vol. 9, pp. 1-18, 2019.

[13] P. C. Reddy, M. C. Raju and G. S. S, "MHD Natural Convective Heat Generation/Absorbing and Radiation Fluid Past a Vertical Plate Embedded in Porous Medium-An Exact Solution," *Journal of Serbian Society of Computational Mechanics*, vol. 12, no. 2, pp. 106-127, 2018.

[14] A. Bakier, "Thermal Radiation Effect on Mixed Convection From Vertical Surfaces in Saturated Porous Media," *International Communications in Heat and Mass Transfer*, vol. 28, pp. 119–126, 2001.

[15] I. A. Badruddin, Z. A. Zainal, P. A. A. Narayana, K. N. Seetharamu and L. W. Siew, "Free Convection and Radiation Characteristics for a Vertical Plate Embedded in a Porous Medium," *International Journal for Numerical Methods in Engineering*, vol. 65, pp. 2265–2278, 2006.

[16] K. Venkateswara Raju, A. Parandhama, M.C. Raju and K. Ramesh Babu, "Unsteady MHD Free Convection Jeffery Fluid Flow of Radiating and Reacting Past a Vertical Porous Plate in Slip-Flow Regime with Heat Source," *Frontiers in Heat and Mass Transfer*, pp. 10-25, 2018. DOI: http://dx.doi.org/10.5098/hmt.10.25

[17] N. Ananda Reddy, P. Chandra Reddy, M.C. Raju and S.V.K. Varma, "Radiation and Dufour Effects on Laminar Flow of a Rotating Fluid Past a Porous Plate in Conducting Field," *Frontiers in Heat and Mass Transfer*, pp. 1-7, 2018.
Doi: http://dx.doi.org/10.5098/hmt.10.4

[18] R. C. Chaudhary and Arpita Jain, "Unsteady Free Convection Flow Past an Oscillating Plate with Constant Mass Flux in the Presence of Radiation," *Acta Techn CSAV*, vol. 52, pp. 93-108, 2007.

[19] B. Shankar Goud and M. N. Rajashekar, "Soret, Dufour and Radiation Effects on an Unsteady Mass Transfer Flow Through a Highly Porosity Bounded by a Vertical Infinite Moving Plate in the Presence of the Heat Generation and Chemical Reaction," *International Journal of Mathematics Trends and Technology*, vol. 39, No. 3, pp. 218-226, 2016.

[20] P. Lalitha and S. Vijaya Kumar Varma, "Thermal Radiation and Chemical Reaction Effects on Unsteady Laminar Hydromagnetic Free Convective Flow of Oldroyd Fluid Through Porous Medium Along a Moving Vertical Plate with Thermal Diffusion," *International Journal of Mathematics Trends and Technology*, vol. 51, no. 1, pp. 43-51, 2017.

[21] R. Sakthikala and S. Prahala, "Unsteady MHD Free Convection Flow of a Viscous Dissipative Kuvshinski Fluid Past an Infinite Vertical Porous Plate in the Presence of Thermal Radiation and Chemical Effects*," International Journal of Mathematics Trends and Technology*, vol. 53, no. 4, pp. 284-292, 2018.

[22] U. S. Rajput and Gaurav Kumar, "Effects of Radiation and Chemical Reaction on MHD Flow Past a Vertical Plate with Variable Temperature and Mass Diffusion," *Journal of Naval Architecture and Marine Engineering*, vol. 16, pp. 99-108, 2019.

[23] C. Veeresh, M.C. Raju, S. V. K. Varm and A. G. Vigaya Kumar, "Effects of Thermal Diffusion and Radiation on Magnetohydrodynamic Chemically Reacting Fluid Flow Past a Vertical Plate in Slip Flow Regime," *Journal of Computational and Applied Mechanics*, vol. 52, no. 2, 2019.

[24] S. Arulmozhi, K. Sukkiramathi, S. S. Santra, R. Edwan, Unai Femandez –Gamiz and Samad Noeiaghdam, "Heat and Mass Transfer Analysis of Radiative and Chemically Reactive Effects on MHD Nanofluid Over an Infinite Moving Vertical Plate," *Results in Engineering*, vol. 14, pp. 1-9, 2022.

[25] Arpita Jain, "Radiation and Chemical Reaction Effects on Unsteady Double Diffusive Convective Flow Past an Oscillating Surface with Constant Heat Flux," *ISRN Chemical Engineering*, pp. 1-8, 2013. Doi: dx.doi.org/10.1155/2013/846826

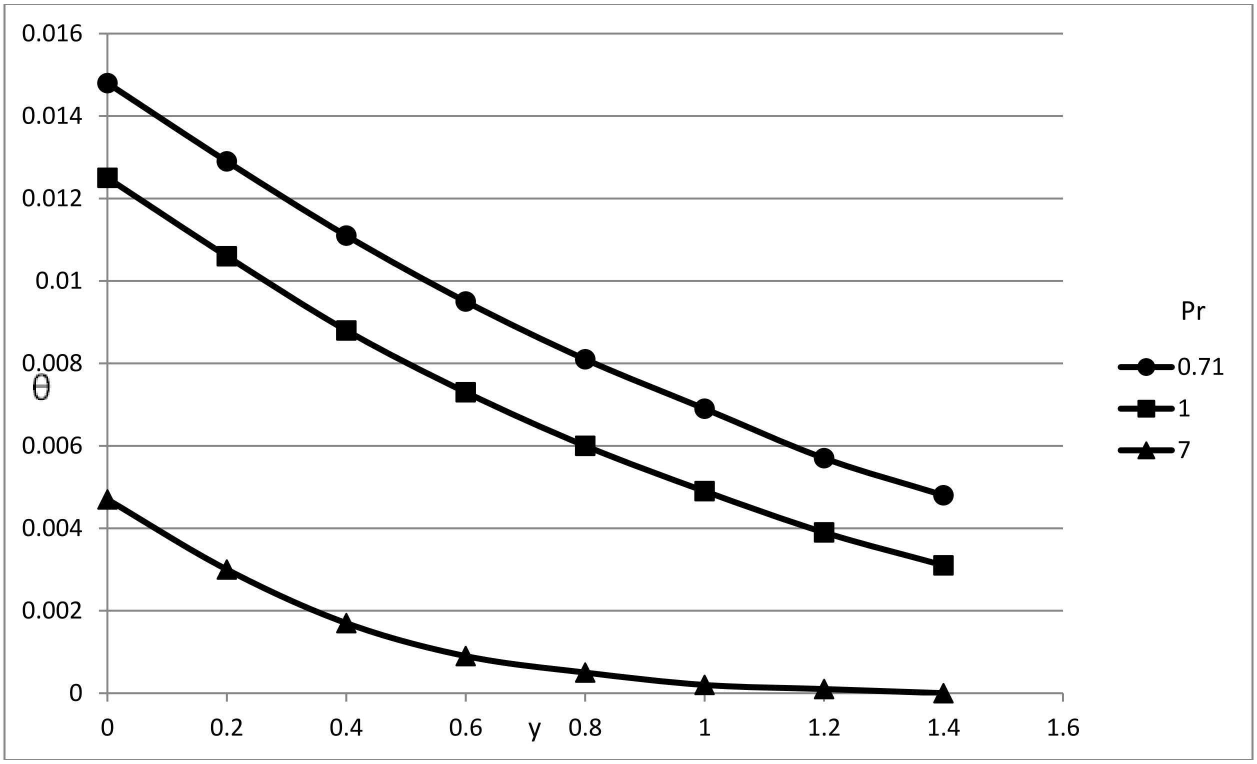

Fig. 1 Temperature profile ϒ=1, R=1, t=0.2

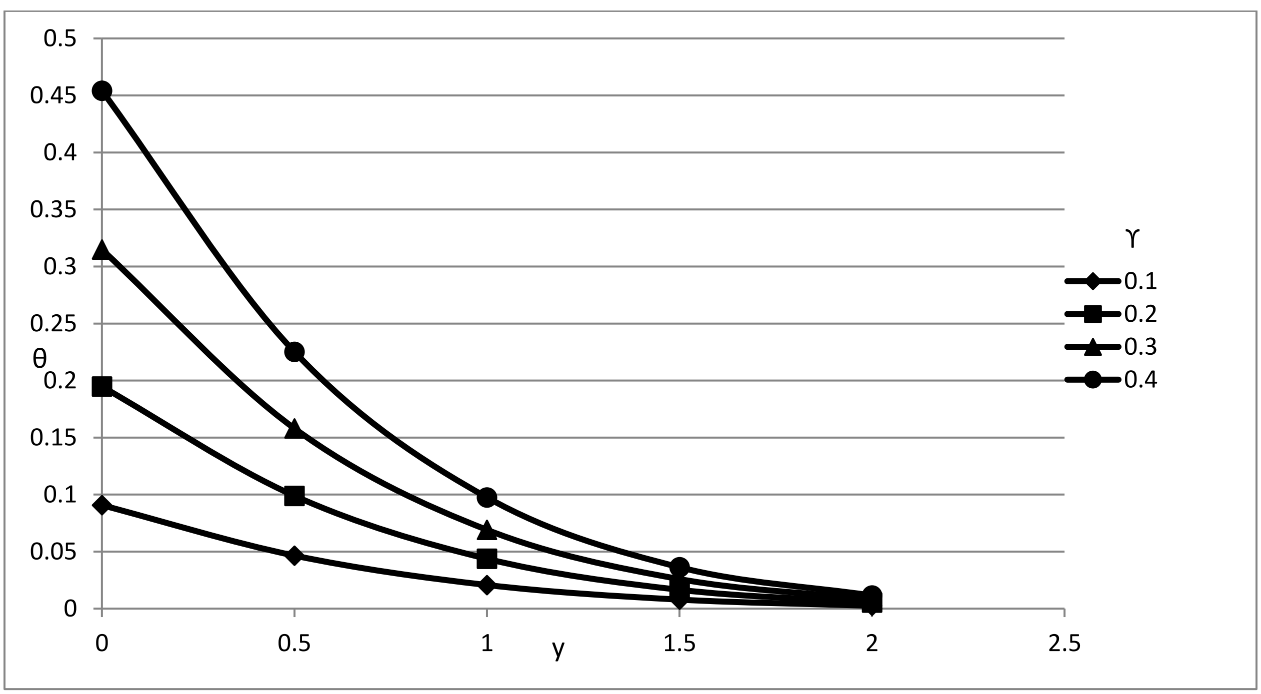

Fig. 2 Temperature profile t=0.2, Pr=0.71, R=1

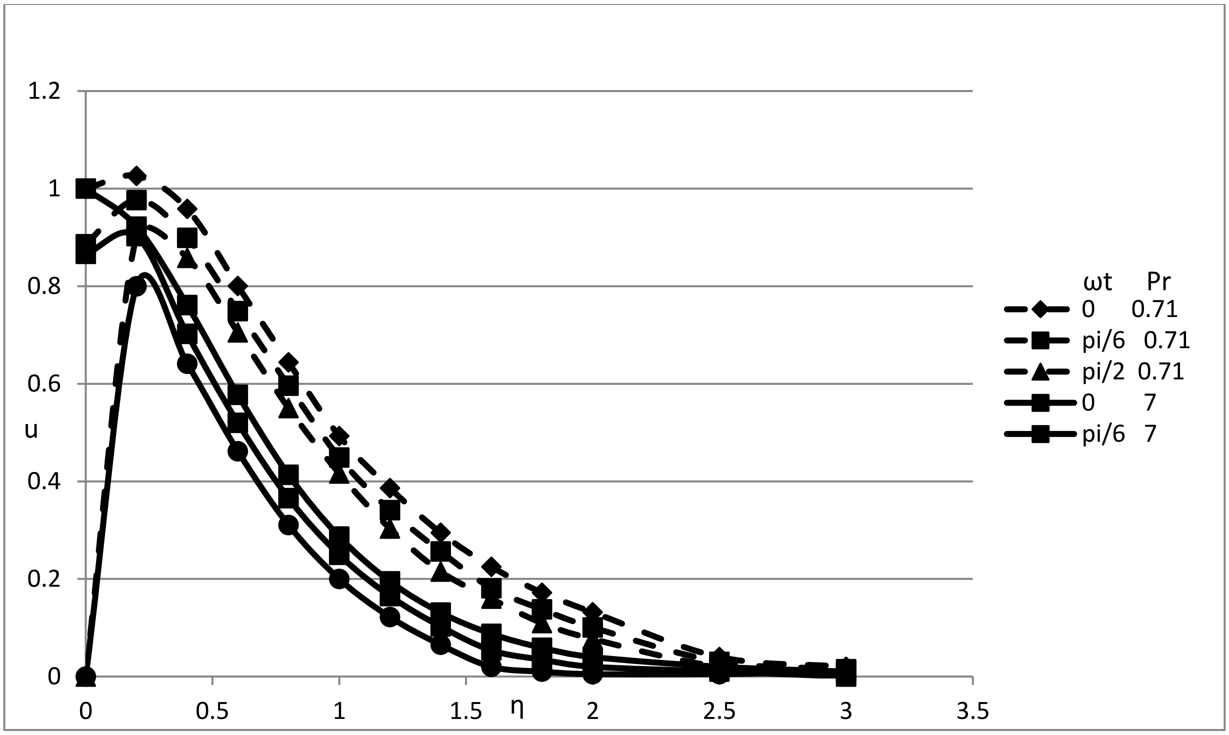

Fig. 3 Velocity profile for sc=0.22, t=0.2, R=4, k=0.2, ϒ=1, G=5, Gm=2

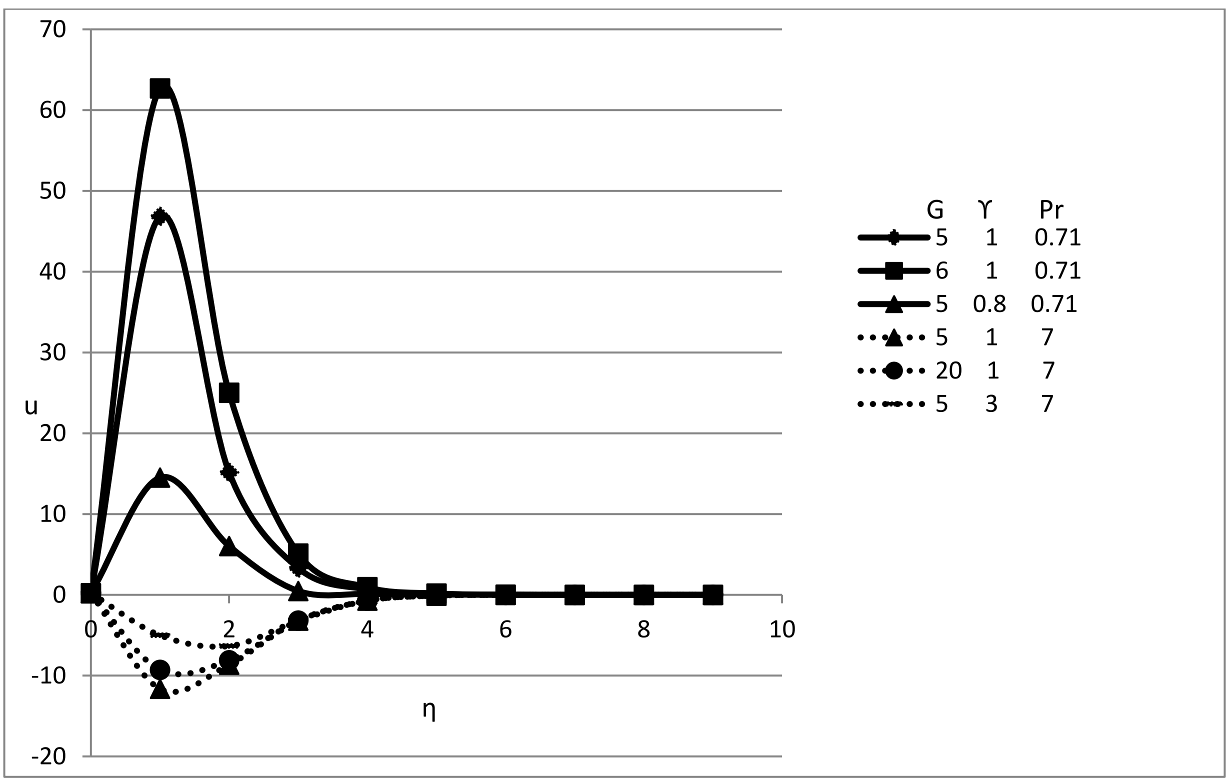

Fig. 4 Velocity profile R=1, k=0.2, t=0.2, Sc=0.22, Gm=2, ωt=pi/4

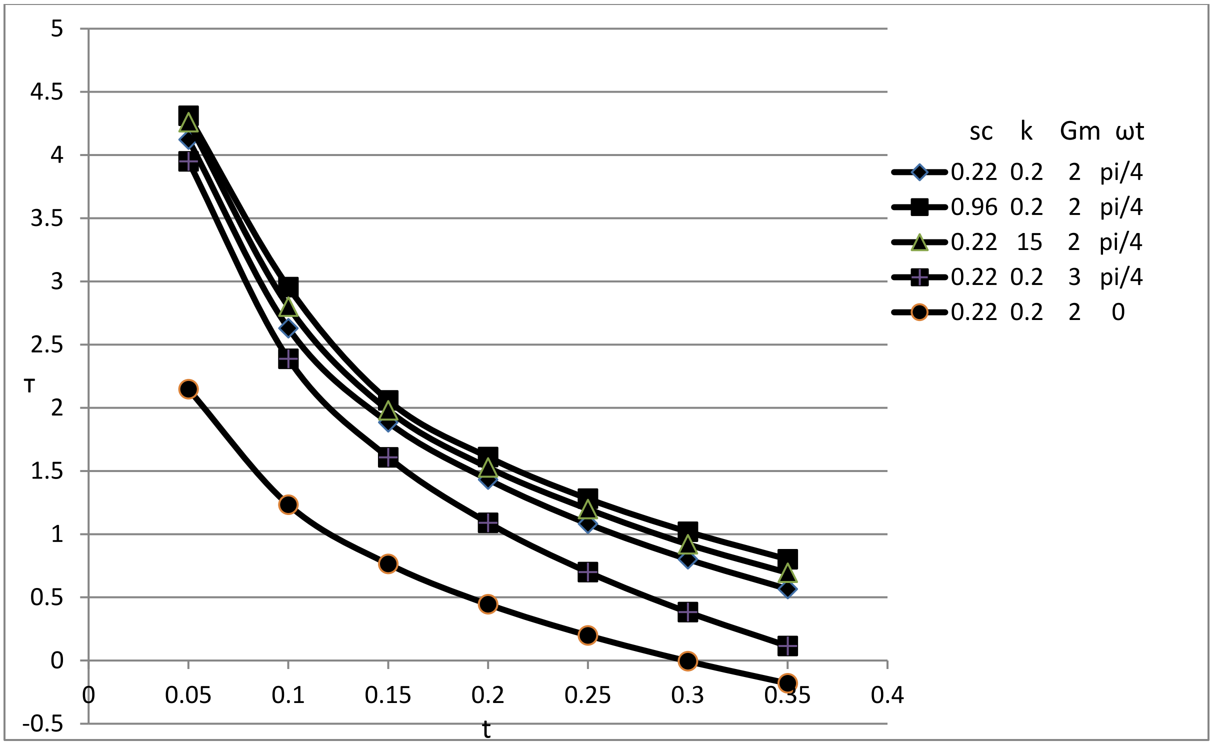

Fig. 5 Skin friction for R=4, G=5, ϒ=0.2, Pr=7