RADIATION EFFECT ON SLIP FLOW REGIME WITH HEAT GENERATION

D Chenna Kesavaiah[1], Ikramuddin Sohail Md[2], R S Jahagirdar[3]

[1]Department of Humanities & Science, K G Reddy College of Engineering & Technology, Chilkur, Moinabad, R R Dist, Pin – 501 504, TS, India
[2,3]Department of Mechanical Engineering, K G Reddy College of Engineering & Technology, Chilkur, Moinabad, R R Dist, Pin – 501 504, TS, India

Abstract - ***This paper analyze the radiation effects on MHD unsteady free convective viscous incompressible flow past a vertical porous plate flat plate periodic temperature in slip-flow regimen with heat generation has been discussed. The governing partial differential equations are solved by using perturbation technique. Assuming variable suction at the porous plate, analytical expression for flow characteristic is obtained and thermal radiation is included. The effects of various flow parameters on the transient velocity and transient temperature are discussed with help of graphs and analytical solutions are derived for transient velocity, skin-friction and rate of heat transfer. The results are shown in figures followed by a quantitative discussion.***

Keywords: ***Radiation, Free convection MHD and Heat generation***

I. INTRODUCTION

Natural convection is mechanism or type of heat transport in which the fluid motion is not generated by any external source (like a pump, fan, suction device etc), but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat and by thermal expansion becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current; this process transfer heat energy from the bottom of the convection cell to top. The driving force for natural is buoyancy, a result of differences in fluid density. Because of this, the presence of a proper acceleration such as arises from resistance of gravity or an equivalent force (arising from acceleration, centrifugal force or Coriolis Effect) is essential for natural convection. Free convection flow of MHD fluid has attracted many researchers in view of its numerous applications in geophysics, astrophysics, metal forming, aerodynamics, boundary layer control energy generators accelerators, aerodynamics heating, polymer technology, meteorology, continuous casting wire and glass fiber drawing. Petroleum industry, magnetohydrodynamic power generators and pumps, purification of crude oil, and in material processing such as extrusion. In many engineering applications, transient free convection flow occurs as such a flow acts as a cooling device. However, free-convection flow is enhanced by superimposing oscillating temperature on the mean plate temperature. Again transient natural convection is of interest in the early stage of melting adjacent to heated surface or in transient heating of insulating air gaps by heat input at the start-up of furnaces. The effect of free convection flow of a viscous incompressible fluid past an infinite vertical plate has many important technological applications in the astrophysical, geophysical and engineering problems. Anwer [1] studied MHD unsteady free convection flow past a vertical porous plate. The transient free convection flow past an infinite vertical plate with periodic temperature variation was studied analytically by Das *et al.* [5]. Hossain *et al.* [6] investigated the effect of a fluctuating surface temperature and concentration on natural convection flow from a vertical flat plate. Chenna Kesavaiah and Satyanarayana [8] MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction.

The study of MHD plays an important role in agriculture, astrophysics, hot gases ionization (i.e. high temperature, low density), sun and stars, solar corona, solar wind and flares, mass ejection, fusion, cooling of fusion reactors, star formation, engineering and petroleum industries. The problem of free convection under the influence of a magnetic field has attracted the interest of many researchers in view of its applications in geophysics and astrophysics. Chandran *et al.* [3] investigated analytically natural convective flow of a viscous incompressible fluid past an infinite vertical plate by deriving an exact solution when the wall temperature has a continuous ramped profile with respect to time. Taneja and Jain [7] looked at the Unsteady MHD flow in a porous medium in the presence of radiative heat where they obtained expressions for the velocity, temperature and rate of heat transfer. The study of fluid flow in porous media in the presence of radiative heat is of paramount importance in geothermal engineering and in astrophysics hence a lot of works have been reported in the literature. The free convective heat transfer on a vertical semi-infinite plate has been investigated by Berezovsky *et al.* [2]. Chenna Kesavaiah and Sudhakaraiah [9] Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption. Srinathuni Lavanya and Chenna Kesavaiah [10] Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, Ch Kesavaiah et.al [11] analyzed effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, Karunakar Reddy et.al. [12] Convective heat and mass transfer flow from a vertical surface with radiation, chemical reaction and heat source/absorption, Chenna Kesavaiah Sudhakaraiah [13] Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, Chenna Kesavaiah et.al. [14] MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects. Recently some of the author's studies; Mallikarjuna Reddy et.al. [15] Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, Chenna Kesavaiah and Jahagirdar [16] MHD Free Convective Flow through Porous Medium under the Effects of Radiation and Chemical reaction, Chenna Kesavaiah and Jahagirdar [17] Radiation absorption and chemical reaction effects on MHD flow through porous medium past an exponentially accelerated inclined plate.

In spite of all these studies, the unsteady MHD free convective heat transfer in the presence of radiation has received little attention. Hence, the objective of this paper is to study the radiation effects of variable suction on transient free convection flow past an infinite vertical plate in slip-flow regime with heat generation, when the temperature of the plate oscillates in time about a constant mean. The governing equation solve by using perturbation technique. The influence of the various parameters entering into the problem on the velocity field, temperature field discussed with the help of graphs and the analytical solution derived for skin friction and Nusselt number is extensively.

II. FORMULATION OF THE PROBLEM

An unsteady free convective flow of a viscous incompressible fluid past an infinite vertical porous flat plate in slip-flow regime in the presence of radiating heat transfer with variable suction $V^* = -V_0^*\left(1+\varepsilon A e^{i\omega^* t^*}\right)$ is considered. Also it is assumed that the temperature of the plate oscillates in time about a nonzero constant mean. We introduce a co-ordinate system with wall lying vertically in $x^* - y^*$ plane. The $x^* -$axis is taken in vertically upward direction along the vertical porous plate and $y^* - axis$ is taken normal to the plate. Since the plate is considered infinite in the x*-direction, hence all physical quantities will be independent of x^*. Under these assumption, the physical variables are function of x^* and t^* only. The physical configuration of the problem is given in figure (1).

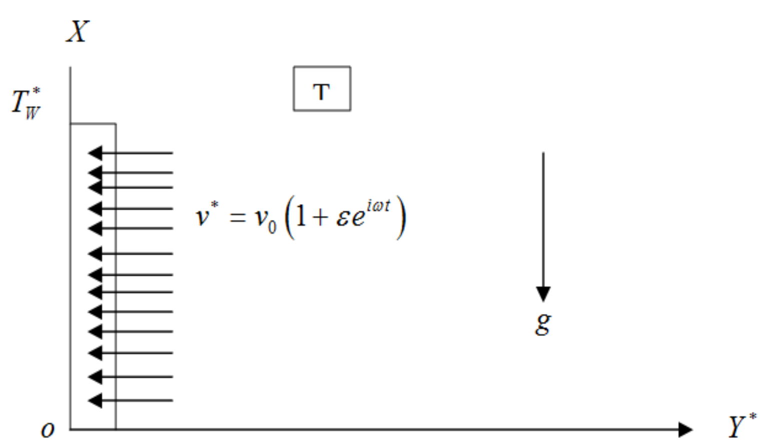

Figure (1): The physical configuration of the problem

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:

$$\frac{\partial u^*}{\partial t^*}-V_0^*\left(1+\varepsilon Ae^{i\omega^* t^*}\right)\frac{\partial u^*}{\partial y^*}=\rho g\,\beta\left(T^*-T_\infty^*\right)+\nu\frac{\partial^2 u^*}{\partial y^{*2}}-\sigma B_0^2 u^* \quad (1)$$

$$\rho C_p\left[\frac{\partial T^*}{\partial t^*}-V_0^*\left(1+\varepsilon Ae^{i\omega^* t^*}\right)\frac{\partial T^*}{\partial y^*}\right]=k\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{\partial q_r^*}{\partial y^*}-Q\left(T^*-T_\infty^*\right) \quad (2)$$

The boundary conditions of the problem are:

$$u^*=L^*\left(\frac{\partial u^*}{\partial y^*}\right),T^*=T_\omega^*+\varepsilon\left(T^*-T_\omega^*\right)e^{i\omega^* t^*} \quad at\ y^*=0$$
$$u^*\to 0,T^*\to T_\omega^* \quad as\ y^*\to\infty \quad (3)$$

We now introduce the following non-dimensional quantities into equations (1) to (2)

$$y=\frac{y^* V_0^*}{\nu},t=\frac{t^* V_0^*}{4\nu},\omega=\frac{4\nu\omega^*}{V_0^2},u=\frac{u^*}{V_0},\theta=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*},\Pr=\frac{V_0^* L^*}{\nu},R=\frac{4\nu I'}{V_0^{*2}}$$

$$Gr=\frac{g\beta\nu\left(T_w^*-T_\infty^*\right)}{V_0^3},\quad \Pr=\frac{\mu C_p}{k},\quad M=\frac{\sigma B_0^2\nu}{V_0^2},\quad \phi=\frac{Q_0\nu}{\rho C_p V_0^{*2}}$$

The radiative heat flux is given by Cogly [4]

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

where $I=\int_0^\infty K\frac{\partial e_{b\lambda}}{\partial T^*}d\lambda,\ K_{\lambda w}-$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function.

where Gr is Grashof number, $\Pr$ is Prandtl number, M is Magnetic parameter, H is Rarefaction parameter R is Radiation parameter ϕ is heat source parameter, A is the suction parameter, $\nu-$ is kinematics viscosity, $\omega-$ is the frequency, ρ is the density, g - is the acceleration due to gravity, β is coefficient of thermal expansion, T^* is the temperature and C_p is the specific heat at constant pressure. The $(*)$ stands for dimensional quantities. The subscript (∞) denotes the free stream condition. Using equation (4) in equation (2) then equations (1) and (2) reduce to the following non dimensional form:

$$\frac{1}{4}\frac{\partial u}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial u}{\partial y}=Gr\theta+\nu\frac{\partial^2 u}{\partial y^2}-Mu \quad (5)$$

$$\frac{1}{4}\frac{\partial\theta}{\partial t}-\left(1+\varepsilon Ae^{i\omega t}\right)\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-R\theta-\phi\theta \quad (6)$$

The boundary conditions to the problem in the dimensionless form are

$$u=h\left(\frac{\partial u}{\partial y}\right),\theta=1+\varepsilon e^{i\omega t} \quad at\ y=0$$
$$u\to 0,\theta\to 0 \quad as\ y\to\infty \quad (7)$$

III. SOLUTION OF THE PROBLEM

Assuming the small amplitude oscillations $(\varepsilon<<1)$, we can represent the velocity u and temperature θ, near the plate as:

$$u(y,t)=u_0(y)+\varepsilon e^{i\omega t}u_1(y)$$
$$\theta(y,t)=\theta_0(y)+\varepsilon e^{i\omega t}\theta_1(y) \quad (8)$$

Substituting (8) in (5) and (6), and comparing the coefficients of identical powers of e neglecting those of $\varepsilon^2,\varepsilon^3,ect.$, we get

$$u_0''+u_0'-Mu_0=-Gr\,\theta_0 \quad (9)$$

$$u_1''+u_1'-N_1 u_1=-A\,u_0'-Gr\,\theta_1 \quad (10)$$

$$\theta_0'' + \Pr\theta_0' - N_2\theta_0 = 0 \tag{11}$$

$$\theta_1'' + \Pr\theta_1' - N_3 \Pr\theta_1 = A\Pr\theta_0' \tag{12}$$

where $N_1 = \left(\frac{1}{4}i\omega + M\right), N_2 = (R-\phi), N_3 = \left(R + \phi + \frac{i\omega}{4}\right)$

The corresponding boundary conditions reduce to

$$u_0 = h\left(\frac{\partial u_0}{\partial y}\right), u_1 = h\left(\frac{\partial u_1}{\partial y}\right), \theta_0 = 1,\ \theta_1 = 1 \quad at\ y = 0$$

$$u_0 = 0, u_1 = 0, \theta_0 = 0, \theta_1 = 0 \quad as\ y \to \infty \tag{13}$$

where primes denote differentiation with respect to $'y'$. Solving the set of equations (9) – (12) under the boundary conditions (13) we get

$$\theta_0(y) = e^{m2y} \tag{14}$$

$$u_0(y) = A_1e^{m2y} + A_3e^{m4y} \tag{15}$$

$$\theta_1(y) = B_1e^{m2y} + B_2e^{m6y} \tag{16}$$

$$u_1(y) = A_4e^{m4y} + A_5e^{m2y} + A_9e^{m8y} + B_3e^{m6y} + B_4e^{m2y} \tag{17}$$

Substituting equation (14) to (17) in equations (8), we get the expression for the velocity and the temperature profiles. The velocity and the temperature can now be expressed in terms of fluctuating parts as:
where

$$u(y,t) = U_r + iU_i = A_4e^{m4y} + A_5e^{m2y} + A_9e^{m8y} + B_3e^{m6y} + B_4e^{m2y} \tag{18}$$

$$\theta(y,t) = T_r + iT_i = B_1e^{m2y} + B_2e^{m6y} \tag{19}$$

From equation (18) and (19) for $\omega t = \frac{\pi}{2}$ we can now obtain the following expressions for the transient velocity and temperature profiles as:

$$u\left(y, \frac{\pi}{2\omega}\right) = u_0(y) - \varepsilon U_i \tag{20}$$

$$\theta\left(y, \frac{\pi}{2\omega}\right) = \theta_0(y) - \varepsilon T_i \tag{21}$$

IV. RESULTS AND DISCUSSION

In order to point out the effect of variable suction and oscillating plate temperature on the transient velocity and temperature in slip flow regime, the following discussion are set out. The transient mean velocity, mean temperature profiles are shown in figures 2(a) & 2(b). It is observed from this figure that transient mean velocity increases with increasing the Radiation parameter R, while reverse effect observed in transient mean temperature profiles. Furthermore the transient mean velocity increases in the vicinity of the plate and then decreases far away from the plate. Figures 3(a) & 3(b) depicts the effect of Prandtl number (Pr), it observe that decreases with increasing Prandtl number (Pr) in both the cases. The transient mean velocity, mean temperature profiles are given in figures 4(a) & 4(b). It may be observed from this figure that transient mean velocity and mean temperature decreases with increasing heat generation parameter (ϕ) in both. The transient mean temperature decreases rapidly for $\Pr = 7.0$ (water) than Pr = $\Pr = 0.71$ (air) in the vicinity of the plate. The transient mean temperature for different values of Grashof number (Gr) is described in figure (5). It is observed that an increasing Gr leads to rise in the values of transient temperature. In addition, the curves show that the peak value of velocity increases rapidly near the wall of the porous plate as Grashof number increases, and then decays to the relevant free stream velocity. Figure (6) shows the variation of temperature profiles for different values of heat generation parameter (ϕ). It is seen from this figure that transient temperature profiles decreasing of heat generation parameter (ϕ)

Typical variation of transient temperature profiles along the spanwise coordinate y are shown in figure (7) for different values of Prandtl number$\left(\Pr\right)$. The results show that an increase of Prandtl number heat generation parameter $\left(\Pr\right)$ results in a decreasing in thermal boundary layer thickness and more uniform transient temperature distribution across the boundary layer. The reason is that smaller values of $\Pr$ are equivalent to increasing the thermal conductivities, and therefore, heat is able to differ away from the heated surface more rapidly than for higher values of $\Pr$. Hence, the boundary layer thicker and the rate of heat transfer is reduced, for gradient have been reduced. The effect of radiation parameter $\left(R\right)$ on the transient temperature profiles are presented in figure (8) from this figure we observe that, as the value of R increases the transient temperature profiles decreases, with an increasing in the thermal boundary layer thickness.

Skin-friction

The dimensionless shearing stress on the surface of a body, due to a fluid motion, is known as skin-friction and is defined by the Newton's law of viscosity

$$\tau_x^{\ *} = \mu\left(\frac{\partial u^*}{\partial y^*}\right)$$

Substituting equations (14) and (17) into equation (8) we can calculate the shearing stress component in dimensionless from as

$$\tau_x = \frac{\tau_x^{\ *}}{\rho V_0^{\ 2}} = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0} = \tau_m + \varepsilon\left|B\right|\cos\left(\omega t + \alpha\right)$$

where $\tau_m =$ mean skin friction

$$u_0\left(y\right) = A_1 m_2 + A_3 m_4;\ \left|B\right| = \sqrt{B_r^{\ 2} + B_i^{\ 2}};\tan\alpha = {B_i}/{B_r}$$

$$B = B_r + iB_i = u_1\left(y\right) = m_8 A_9 + A_4 m_4 + A_5 m_2 + B_3 m_6 + B_4 m_2$$

Coefficient of Heat Transfer

In the dynamics of viscous fluid one is not much interested to know all the details of the velocity and temperature fields but would certainly like to know quantity of heat exchange between the body and the fluid. Since at the boundary the heat exchanged between the fluid and the body is only due to conduction, according to Fourier's law, we have

$$q_w^{\ *} = k\left(\frac{\partial T^*}{\partial y^*}\right)_{y^*=0}$$

where y^* is the direction of the normal to the surface of the body. Substituting equations (14) and (17) into (8), we can calculate the dimensionless coefficient of heat transfer which is generally known as the Nusselt number $\left(Nu\right)$ as follows

$$Nu = \frac{q_w^{\ *}}{\rho V_0^{\ *} C_p\left(T_w^{\ *} - T_\infty^{\ *}\right)} = \frac{1}{\Pr}\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = 1 + \varepsilon\left|H\right|\cos\left(\omega t + \delta\right)$$

where

$$\left|H\right| = \sqrt{H_r^{\ 2} + H_i^{\ 2}};\tan\alpha = {H_i}/{H_r};H = H_r + H_i = B_1 m_6 + B_3 m_2$$

V. CONCLUSIONS

1. It is observed from this figure that transient mean velocity increases with increasing the Radiation parameter (R).
2. The variation of temperature profiles for different values of heat generation parameter (ϕ). It is seen from this figure that transient temperature profiles decreasing of heat generation parameter (ϕ)
3. The transient mean temperature for different values of Grashof number (Gr) is described. It is observed that an increasing Gr leads to rise in the values of transient temperature.
4. For different values of Prandtl number $(\Pr)$. The results show that an increase of Prandtl number $(\Pr)$ results in a decreasing in thermal boundary layer thickness and more uniform transient temperature distribution across the boundary layer.

APPENDIX

$$N_1 = \left(\frac{1}{4} + i\omega + M\right), N_2 = \Pr\left(R - \phi\right), N_3 = \left(R + \frac{i\omega}{4} + \phi\right)$$

$$m_2 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4N_2}}{2}\right), \quad m_4 = -\left(\frac{1 + \sqrt{1 + 4M}}{2}\right), \quad m_6 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\Pr N_3}}{2}\right)$$

$$m_8 = -\left(\frac{1 + \sqrt{1 + 4N_1}}{2}\right), A_2 = h\left[m_4\left(A_2 - A_1\right)m_4 A_1\right], A_3 = A_2 - A_1, A_4 = -\frac{Am_4 A_3}{m_4^{\ 2} + m_4 - N_1}$$

$$A_5 = -\frac{Am_2 A_1}{m_2^{\ 2} + m_2 - N_1}, \ B_1 = -\frac{A\Pr m_2}{m_2^{\ 2} + \Pr m_2 - \Pr N_3}, B_2 = 1 - B_1, B_3 = -\frac{GrB_2}{m_6^{\ 2} + m_6 - N_1},$$

$$B_4 = -\frac{GrB_1}{m_2^{\ 2} + m_2 - N_1}$$

REFERENCES

[1] Anwar K (1998): MHD unsteady free convection flow past a vertical porous plate, *ZAMM*, 78, pp. 255-270.

[2] Berezovsky A A, Martynenko O G and Sokovishin Yu A (1977): Free convective heat transfer on a vertical semi infinite plate, *J. Engng. Phys*., 33, pp. 32-39

[3] Chandran P, Sacheti N C and Singh A K (2005). Natural convection near a vertical plate with ramped wall temperature, *Heat Mass Transfer*, 41, pp. 459

[4] Cogly A C, Vincentry W C and Gilles S E (1968). A Differential approximation for radiative transfer in a non-gray gas near equilibrium, *AIAA Journal*, 6: pp. 551-555

[5] Das U N, Deka R K and Soundalgekar V M (1999): Transient free convection flow past an infinite vertical plate with periodic temperature variation, *J. Heat Transfer, (ASME)*, 121, pp. 1091-1094

[6] Hossain M A, Hussain S and Rees D A S (2001): Influence of fluctuating surface temperature and concentration on natural convection flow from a vertical flat plate, ZAMM, 81, pp. 699-709

[7] Taneja R and Jain N C (2002): Unsteady MHD flow with radiation through porous medium in slip flow regime, *Modeling Simulation & Control B AMSE* vol. 71, no. 8, p.23

[8] D Chenna Kesavaiah, P V Satyanarayana (2013): MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, *Indian Journal of Applied Research, Vol. 3 (7*), pp. 310-314

[9] D Chenna Kesavaiah and A Sudhakaraiah (2014): Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, *Scholars Journal of Engineering and Technology, 2(2B):* pp. 219-225

[10] Srinathuni Lavanya and D Chenna Kesavaiah (2017): Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, International Journal of Pure and Applied Researches, Vol. 3(1), pp. 43-56

[11] D Ch Kesavaiah, P V Satyanarayana and S Venkataramana (2011): Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, *Int. J. of Appl. Math and Mech. Vol. 7 (1),* pp. 52-69

[12] S Karunakar Reddy, D Chenna Kesavaiah and M N Raja Shekar (2013): Convective heat and mass transfer flow from a vertical surface with radiation, chemical reaction and heat source/absorption, *International Journal of Scientific Engineering and Technology*, *Vol.* 2 (5), pp : 351-361

[13] D Chenna Kesavaiah and A Sudhakaraiah (2014): Effects of Heat and Mass Flux to MHD Flow in Vertical Surface with Radiation Absorption, *Scholars Journal of Engineering and Technology, 2(2B):* pp. 219-225

[14] D Chenna Kesavaiah , Ikramuddin Sohail Md , R S Jahagirdar **(**2018): MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects, *Suraj Punj Journal For Multidisciplinary Research*, Vol. 8 (11), pp. 46-62

[15] B Mallikarjuna Reddy, D Chenna Kesavaiah and G V Ramana Reddy (2018): Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, *ARPN Journal of Engineering and Applied Sciences*, Vol. 13 (22), pp. 8863-8872

[16] D Chenna Kesavaiah and R S Jahagirdar (2018): MHD Free Convective Flow through Porous Medium under the Effects of Radiation and Chemical reaction, *Journal of Applied Science and Computations*, Vol.5 (10), pp. 1125-1140

[17] D Chenna Kesavaiah and R S Jahagirdar (2018): Radiation absorption and chemical reaction effects on MHD flow through porous medium past an exponentially accelerated inclined plate, *International Journal for Research in Applied Science & Engineering Technology*, Vol. 6 (6), pp. 1370-1381

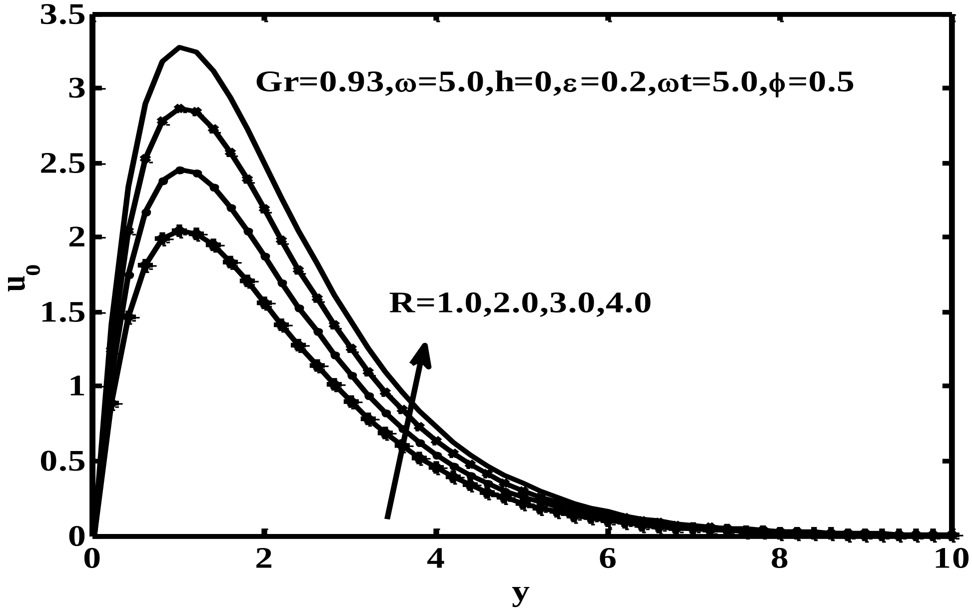

Figure 2(a). The transient mean velocity profiles

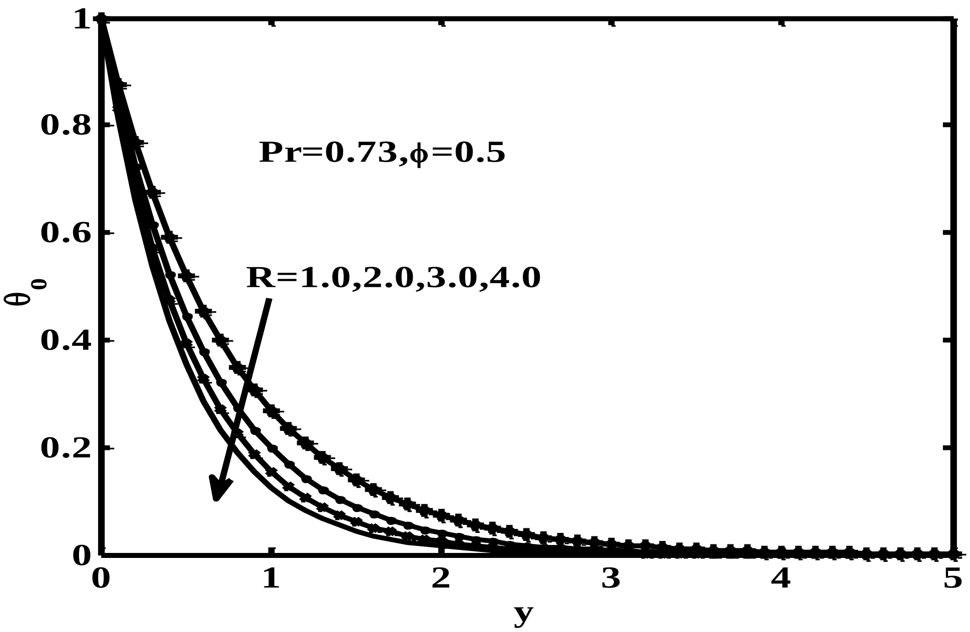

Figure 2(b). The trainsient mean temperature profiles

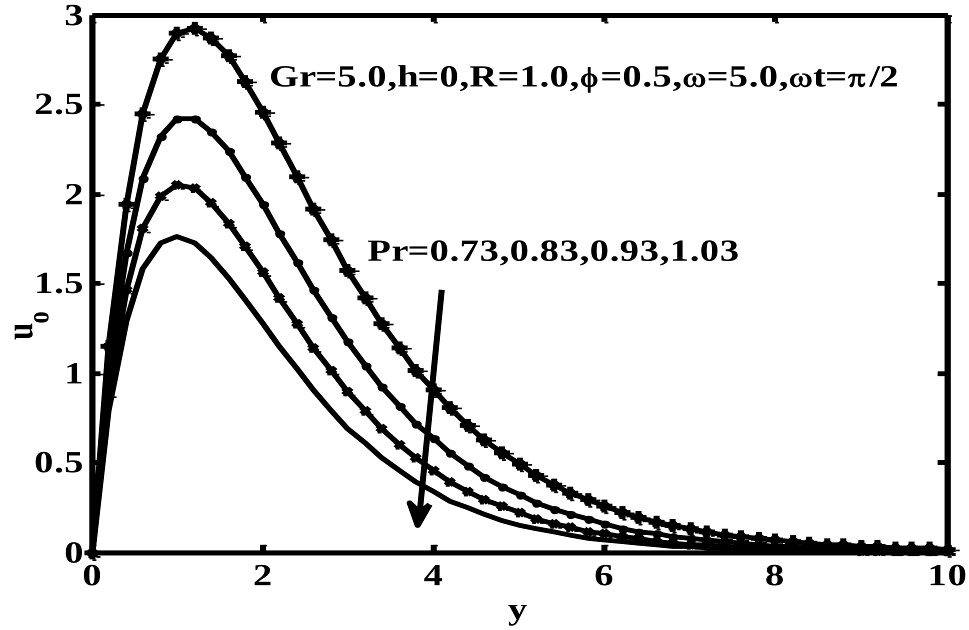

Figure 3(a). The Transient mean velocity profiles

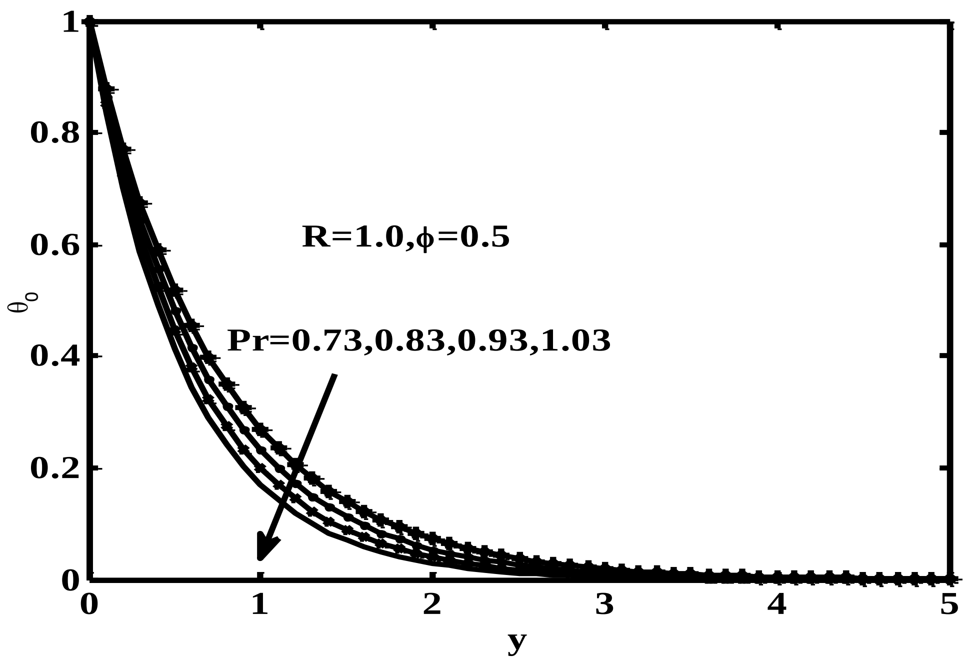

Figure 3(b). The trainsient mean temperature profiles

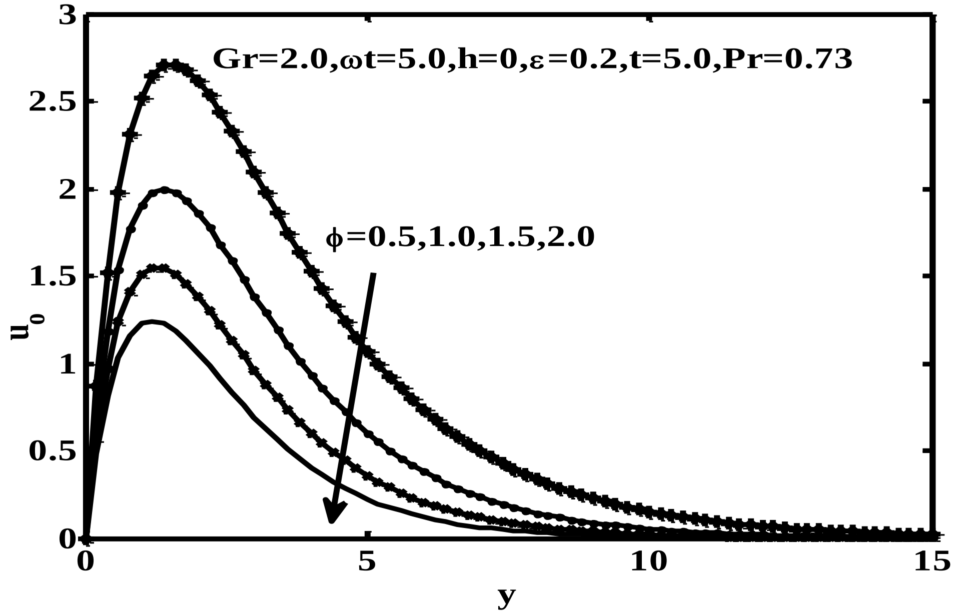

Figure 4(a) . The transient mean velocity profiles

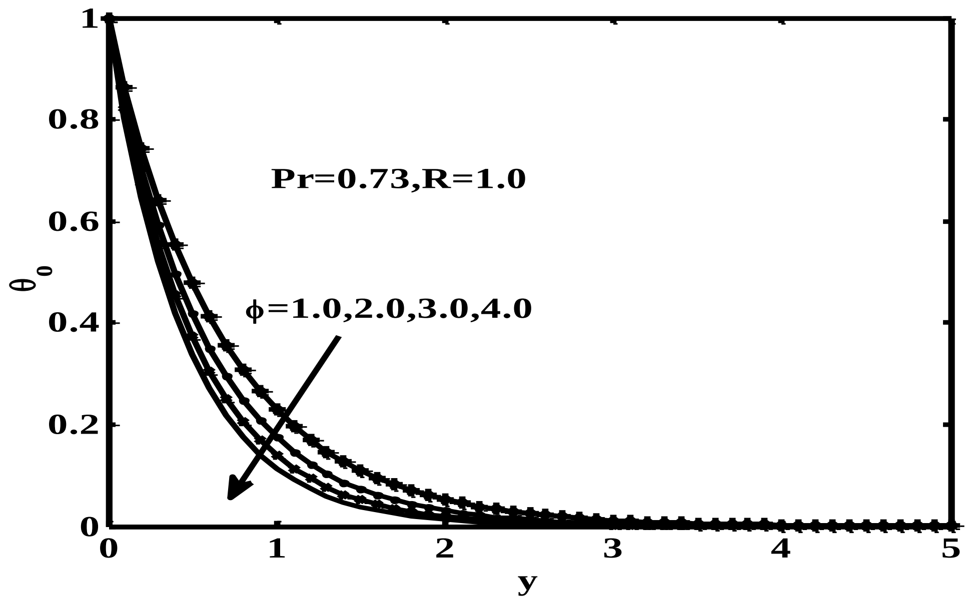

Figure 4(b). The trainsient mean temperature profiles

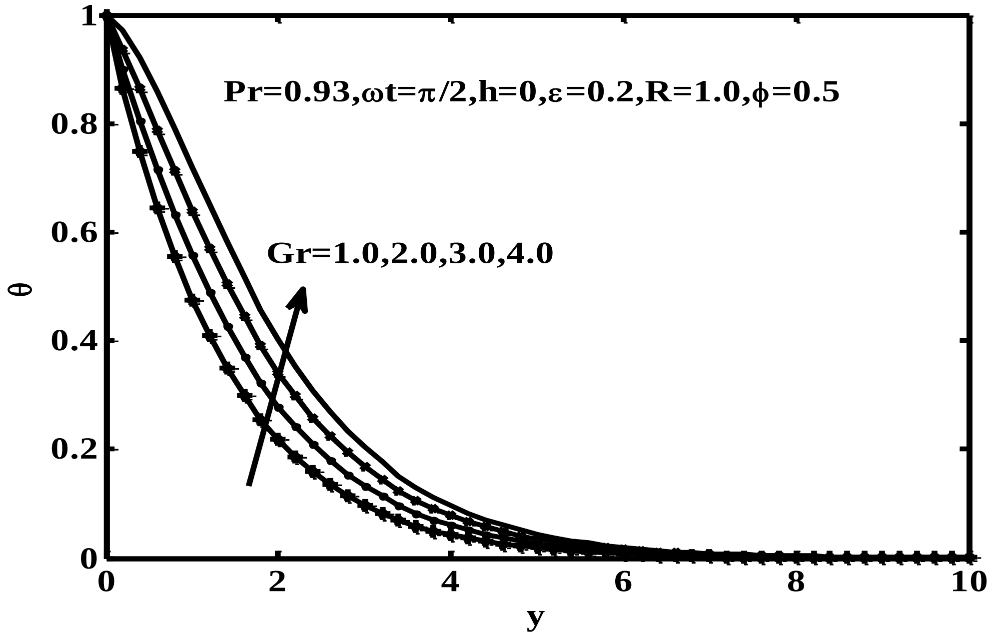

Figure 5. The transient temperature profiles

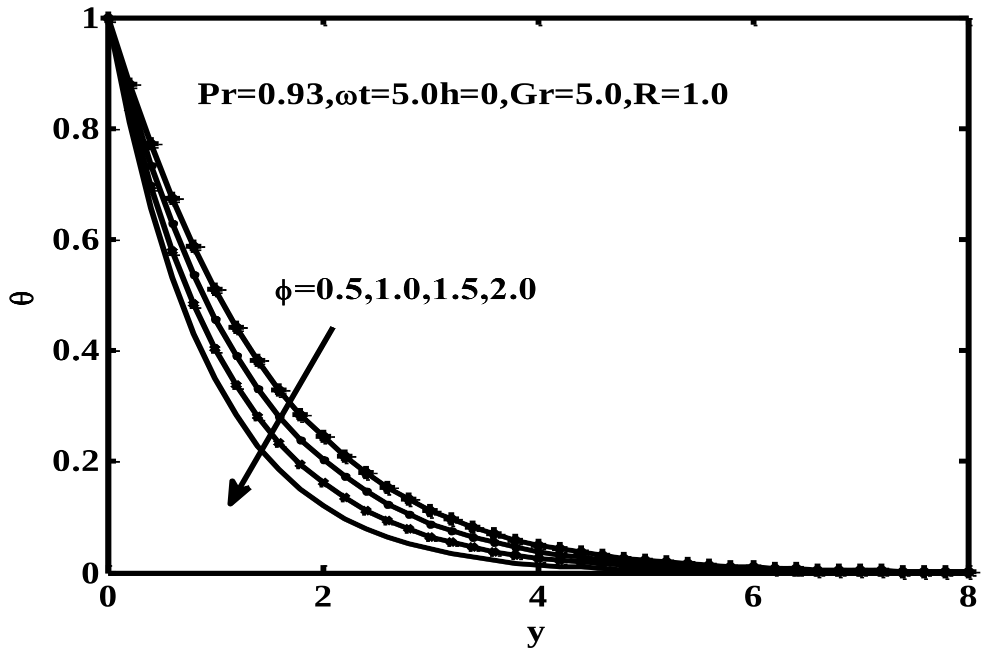

Figure 6. The transient temperature profiles

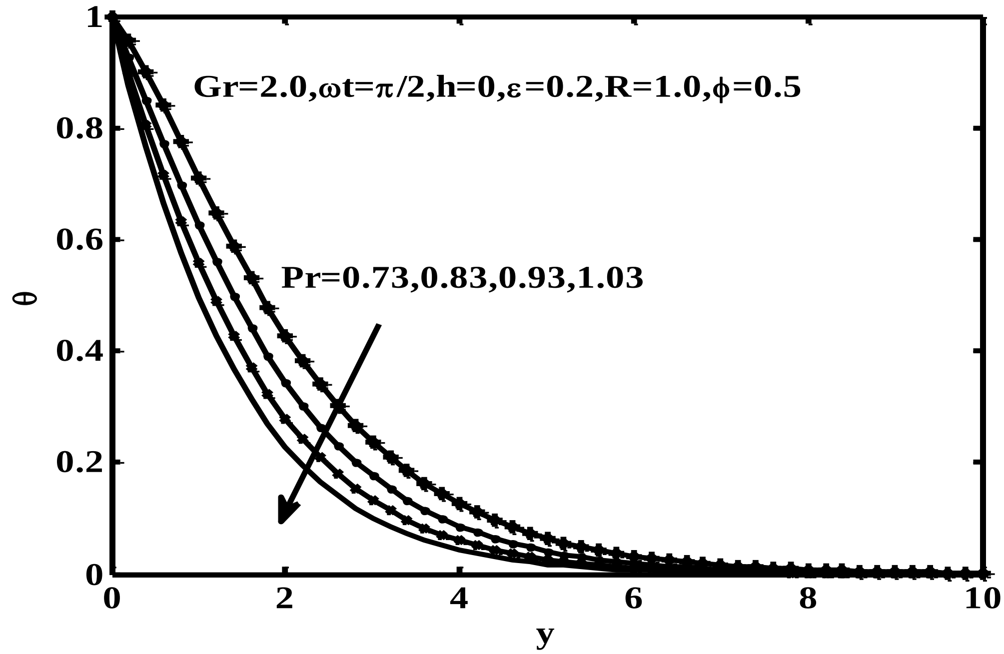

Figure 7. The transient temperature profiles

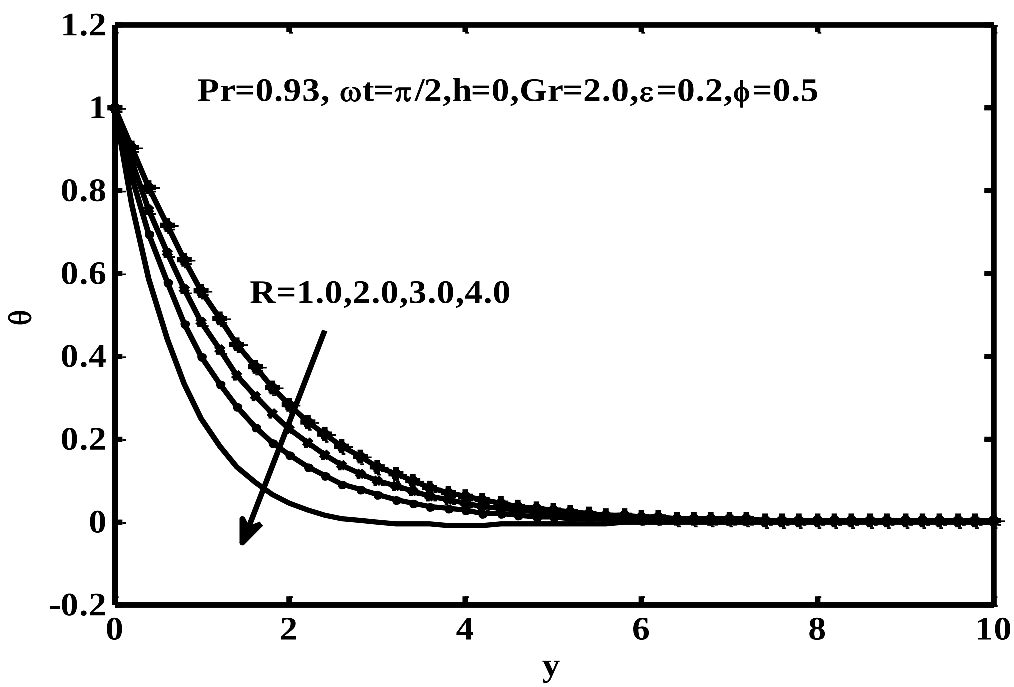

Figure 8. The transient temperature profiles