International Journal of Engineering and Technology Volume 3 No. 1, January, 2013

Convective Laminar Radiating Flow over an Accelerated Vertical Plate Embedded in a Porous Medium with an External Magnetic Field

***Sahin Ahmed , **Abdul Batin**
*Heat Transfer and Fluid Mechanics Research, Department of Mathematics,
Goalpara College, Goalpara 783101, Assam, INDIA,
**Department of Mathematics, Indira Gandhi College, Boitamari,
Bongaigaon 783389, Assam, INDIA

ABSTRACT

In this paper we investigate the effects of conduction-radiation and porosity of the porous medium on laminar convective heat transfer flow of an incompressible, viscous, electrically conducting fluid over an impulsively started vertical plate embedded in a porous medium in presence of transverse magnetic field. The fluid considered here is a gray, absorbing/emitting radiation, but a non-scattering medium. The governing boundary layer equations have been solved analytically by using ***Laplace transform technique***. Numerical evaluation of the analytical results is performed and graphical results for velocity and temperature profiles within the boundary layer are discussed. The results show that increased cooling $(\boldsymbol{Gr} > 0)$ of the plate leads to a rise in the velocity profile. It is also observed that the velocity decreases with increasing magnetic field parameter $(\boldsymbol{M})$ or conduction-radiation parameter $(\boldsymbol{N_a})$ or porosity parameter $(\boldsymbol{K_r})$. Applications of the study arise in materials processing and solar energy collector systems.

Keywords: *Thermal radiation, porosity, MHD, shear stress, Nusselt number.*

2000 Mathematics Subject Classification: 76D05, 76W05, 76S05, 76R10, 44A10.

1. INTRODUCTION

In recent years, the problems of free convective and heat transfer flows through a porous medium under the influence of a magnetic field have been attracted the attention of a number of researchers because of their possible applications in many branches of science and technology, such as its applications in transportation cooling of re-entry vehicles and rocket boosters, cross-hatching on ablative surfaces and film vaporization in combustion chambers. On the other hand, flows through a porous medium have numerous engineering and geophysical applications, for example, in chemical engineering for filtration and purification technology to study the movement of natural gas, oil and water through the oil reservoirs. Stokes [1] was the first to derive an exact solution to be the Navier-Stokes Equation for the case of flow past an impulsively started infinite horizontal plate in a viscous incompressible fluid. Soundalgekar [2] later on presented an exact solution for the flow past an infinite vertical isothermal plate impulsively started in a viscous incompressible fluid. Effects of free convection currents on the flow were studied. However, these studies are confined to normal temperature of the surrounding medium. Many researchers have studied MHD free convective heat transfer flow in a porous medium; some of them are Raptis and Kafoussias [3], Sattar [4] and Kim [5]. Jaiswal and Soundalgekar [6] obtained an approximate solution to the problem of an unsteady flow past an infinite vertical plate with constant suction and embedded in a porous medium with oscillating plate temperature. The unsteady flow through a highly porous medium in the presence of radiation was studied by Raptis and Perdikis [7]. Ahmed [8] investigated the effect of transverse periodic permeability oscillating with time on the heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate, by means of series solution method. Ahmed [9] studied the effect of transverse periodic permeability oscillating with time on the free convective heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate subjected to a periodic suction velocity. Kumar and Verma [10] studied the problem of an unsteady flow past an infinite vertical permeable plate with constant suction and transverse magnetic field with oscillating plate temperature.

If the temperature of the surroundings fluid is rather high, radiation effects play an important role and this situation does exist in space technology. In such cases, one has to take into account the effects of radiation and free convection. The effects of radiation and viscous dissipation on the transient natural convection-radiation flow of viscous dissipation fluid along an infinite vertical surface embedded in a porous medium, by means of network simulation method, investigated by Zueco [11]. The effects of radiation on natural convection flows of a Newtonian fluid along a vertical surface embedded in a porous medium presented by Mahmud and Chamkha [12]. England and Emery [13] have studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Soundalgekar and Takhar [14] have considered the radiation free convection flow of an optically thin gray- gas past a semi- infinite vertical plate. Radiation effects on mixed convection along isothermal vertical plate were studied by Hossain and Takhar [15]. In all above studies, the stationary vertical plate is considered. Raptis and Perdikis [16] studied the effects of thermal radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Chandrakala and Raj [17] studied the effects of thermal radiation on flow past an impulsively started infinite isothermal vertical plate in the presence of magnetic field. Ahmed [18] investigated the effects of radiation and viscous dissipation heat on a magnetohydrodynamic steady mixed convective heat and mass transfer flow over an infinite vertical porous plate with constant suction taking into account the induced magnetic field.

The problem of unsteady natural convection flow past an impulsively started infinite vertical plate immersed in a porous medium in the presence of magnetic field and thermal radiation has not received much attention from contemporary researchers. hence, it is proposed to study the effects of ***thermal radiation*** and ***porosity of the medium*** on flow past an impulsively started infinite isothermal vertical plate in the presence of magnetic field. The dimensionless governing equations are solved using the Laplace transform technique.

2. MATHEMATICAL FORMULATION

Unsteady MHD laminar boundary-layer flow of a viscous incompressible fluid past along an accelerated vertical plate embedded in a saturated porous medium in the presence of transverse applied magnetic field and thermal radiation has been considered. It is also assumed that the radiation heat flux in the $\bar{x}$-direction is negligible as compared to that in the y-direction. The $\bar{x}$ axis is taken along the plate in the vertical upward direction and the $\bar{y}$ axis is taken normal to the plate. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate. The ***induced magnetic field*** and ***viscous dissipation*** is assumed to be negligible as the ***magnetic Reynolds number*** of the flow is taken to be very small. Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

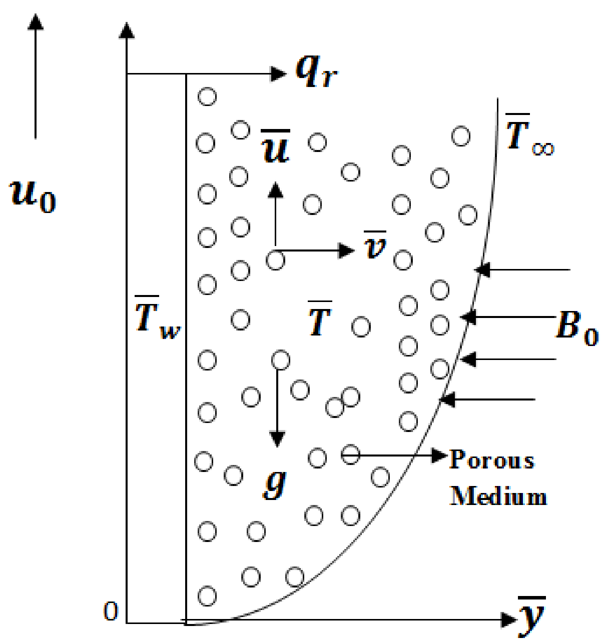

Figure 1: Physical configuration and coordinate system

$$\frac{\partial \bar{u}}{\partial \bar{t}} = g\beta(\bar{T} - \bar{T}_\infty) + \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \left(\frac{\sigma B_0^2}{\rho} + \frac{\nu}{\bar{K}}\right)\bar{u} \qquad (1)$$

$$\rho C_P \frac{\partial \bar{T}}{\partial \bar{t}} = \kappa \frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \frac{\partial q_r}{\partial \bar{y}} \qquad (2)$$

The initial and boundary conditions are:

$$\left.\begin{array}{l} \bar{t} \le 0: \ \bar{u} = 0, \bar{T} = \bar{T}_\infty \ \ \forall y \\ \bar{t} > 0: \ \bar{u} = u_0, \ \bar{T} = \bar{T}_\infty \ \text{at}\ y = 0 \\ \bar{t} > 0: \ \bar{u} \to 0, \ \bar{T} \to \bar{T}_\infty \ \ \text{as}\ y \to \infty \end{array}\right\} \qquad (3)$$

The local Rosseland approximation is used, which leads to

$$q_r = -\frac{4\bar{\sigma}}{3\bar{a}}\frac{\partial \bar{T}^4}{\partial \bar{y}} \qquad (4)$$

where $\bar{\sigma}$ and $\bar{a}$ are the ***Stefan-Boltzmann constant*** and the ***Mean absorption coefficient***, respectively. It is assumed that the temperature differences within the flow are sufficiently small so that $\bar{T}^4$ can be expressed as a linear function of $\bar{T}$ after using Taylor's series to expand $\bar{T}^4$ about the free stream temperature $\bar{T}_\infty$ and neglecting higher-order terms. This results in the following approximation:

$$\bar{T}^4 \cong 4\bar{T}_\infty^3 \bar{T} - 3\bar{T}_\infty^4 \qquad (5)$$

Using (4) and (5), the equation (2) takes the form

$$\rho C_P \frac{\partial \bar{T}}{\partial \bar{t}} = \left[\kappa + \frac{16\,\bar{\sigma}\,\bar{T}_\infty^3}{3\bar{a}}\right]\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} \qquad (6)$$

Introducing the following non-dimensional quantities:

$$\left.\begin{aligned} & y = \frac{v_0\bar{y}}{\nu}\,,\ u = \frac{\bar{u}}{u_0}\,,\ \theta = \frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}\,,\ Pr = \frac{\rho\nu C_P}{\kappa}, \\ & Gr = \frac{\nu g\beta(\bar{T}_w - \bar{T}_\infty)}{u_0^3}\,, t = \frac{u_0^2\bar{t}}{\nu}\,,\ M = \frac{\sigma B_0^2\nu}{\rho u_0^2}, \\ & N_a = \frac{\kappa\,\bar{a}}{4\bar{\sigma}\,\bar{T}_\infty^3}\,,\ K_r = \frac{u_0^2\bar{K}}{\nu^2} \end{aligned}\right\} \qquad (7)$$

Using the transformations (7), the non-dimensional forms of (1), and (6) are

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - (M + K_r^{-1})u + Gr\theta \qquad (8)$$

$$3N_a Pr\frac{\partial \theta}{\partial t} = (3N_a + 4)\frac{\partial^2 \theta}{\partial y^2} \qquad (9)$$

The corresponding initial and boundary conditions are:

$$\left.\begin{aligned} & u = 0\,,\ \theta = 0\,,\ \forall\, y\,, t \le 0 \\ & y > 0:\ u = 1\,,\ \theta = 1 \quad \text{at}\ \ y = 0 \\ & y > 0:\ u \to 0\,,\ \theta \to 0 \quad \text{as}\ y \to \infty \end{aligned}\right\} \qquad (10)$$

3. METHOD OF SOLUTION

The unsteady, non-linear, coupled partial differential equations (8) to (9) along with their boundary conditions (10) have been solved analytically using usual ***Laplace transform technique*** and the solutions for hydro magnetic flow in the presence of radiation and porosity of the medium are obtained as follows:

$$\theta(y,t) = erfc\left(\eta\sqrt{A}\right), \qquad (11)$$

$$\begin{aligned} u(y,t) = {} & f_1\left[e^{-2\eta\sqrt{N}}erfc\{\eta - \sqrt{Nt}\} + e^{2\eta\sqrt{N}}erfc\{\eta + \sqrt{Nt}\}\right] \\ & -f_2\left[e^{-2\eta\sqrt{Abt}}erfc\left(\eta - \sqrt{Abt}\right) + e^{2\eta\sqrt{Abt}}erfc\left(\eta + \sqrt{Abt}\right)\right] \\ & +f_2\left[e^{-2\eta\sqrt{Abt}}erfc\left(\eta\sqrt{A} - \sqrt{bt}\right) + e^{2\eta\sqrt{Abt}}erfc\left(\eta\sqrt{A} + \sqrt{bt}\right)\right] \\ & -f_2 erfc\left(\eta\sqrt{A}\right) \end{aligned} \qquad (12)$$

where $\eta = \frac{y}{2\sqrt{t}}\,,\ \ N = M + K_r^{-1}\,,$

$$f_1 = \frac{1}{2} + \frac{Gr}{2(1-A)b}\,,\ \ f_2 = \frac{Gre^{bt}}{2(1-A)b},$$

$$f_3 = \frac{Gr}{(1-A)}\,,\ \ A = \frac{3N_a Pr}{3N_a + 4}\,,\ \ b = \frac{N - N_a}{Pr - 1}$$

4. SKIN FRICTION

The boundary layer produces a ***drag force*** on the plate due to the ***viscous stresses*** which are developed at the wall. The ***viscous stress*** at the surface of the plate is given by

$$\tau = -\left[\frac{\partial u(y,t)}{\partial y}\right]_{y=0} = -\frac{1}{2\sqrt{t}}\left[\frac{\partial u(y,t)}{\partial \eta}\right]_{\eta=0}$$

$$= \frac{1}{\sqrt{t\pi}}\left[\left\{1 + \frac{Gr}{(1-A)b}\right\}\left(\sqrt{N\pi t}erf\sqrt{Nt} + 1\right) - \frac{Gr\sqrt{A}}{(1-A)b} - \frac{Gre^{bt}}{(1-A)b}\left\{1 - \sqrt{A} + \sqrt{Ab\pi}\left(erf\sqrt{Abt} - erf\sqrt{bt}\right)\right\}\right] \qquad (13)$$

5. RESULTS AND DISCUSSIONS

The purpose of the calculations given here is to study the effects of the parameters M; N_a; K_r; Pr and t upon the nature of the flow and transport. Selected computations have been depicted graphically in **figures 2 to 7**. All data corresponding to each figure is included therein. $Gr = 5$ imply ***strong thermal buoyancy force***; The Prandtl number Pr is taken for Liquid metal ($Pr = 0.025$), ***air*** at 20°C ($Pr = 0.71$), and ***water*** ($Pr = 7.0$). The current ***Laplace Transform Technique*** has been well-validated in previous studies by Chandrakala and Raj [17] and therefore comparisons with earlier studies are omitted here for brevity.

The effect of conduction-radiation parameter, N_a in presence of conducting air ($Pr = 0.71$) on the velocity variations along the vertical surface is depicted in **Fig. 2**. As N_a increases, considerable reduction is observed in velocity from the peak value at the wall (y = 0) across the boundary layer regime to the free stream, at which the velocity is negligible for any value of N_a. All profiles decay asymptotically to zero in the free stream. This is also in accordance with the results of Raptis and Perdikis [7] and Chandrakala [17].

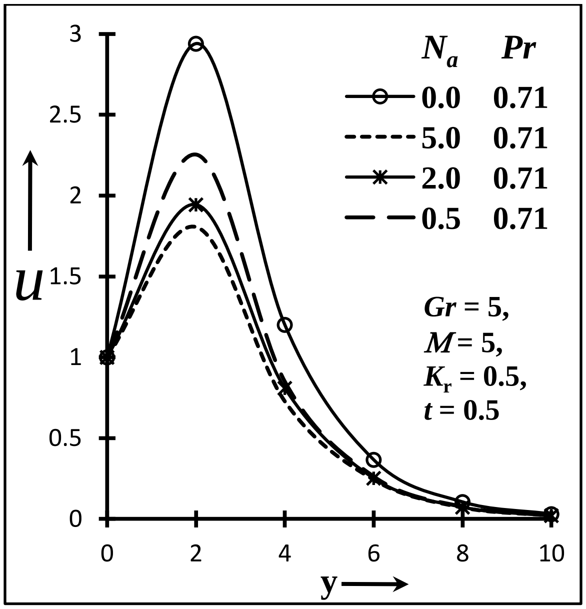

Fig. 2: Flow velocity for N_a

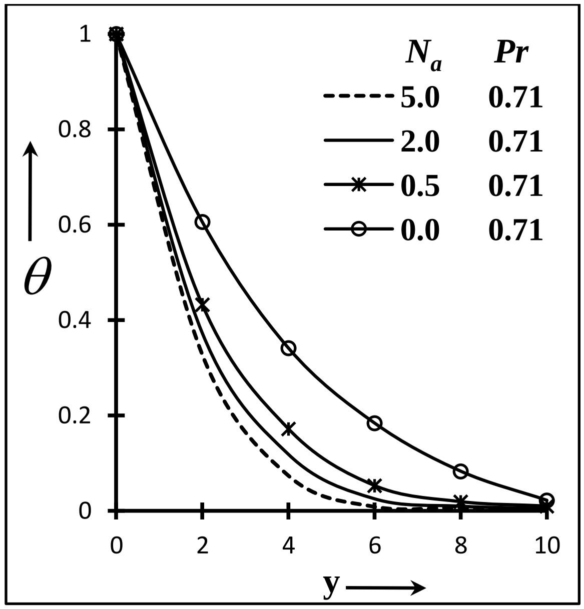

Fig. 3: Temperature distribution for N_a

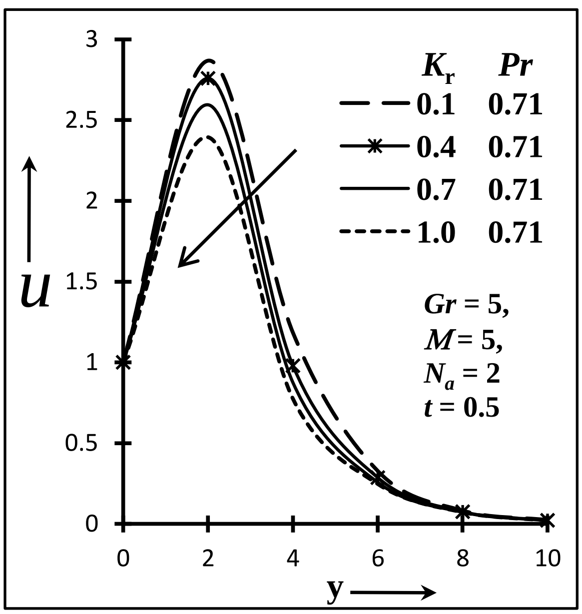

Fig. 4: Flow velocity for K_r

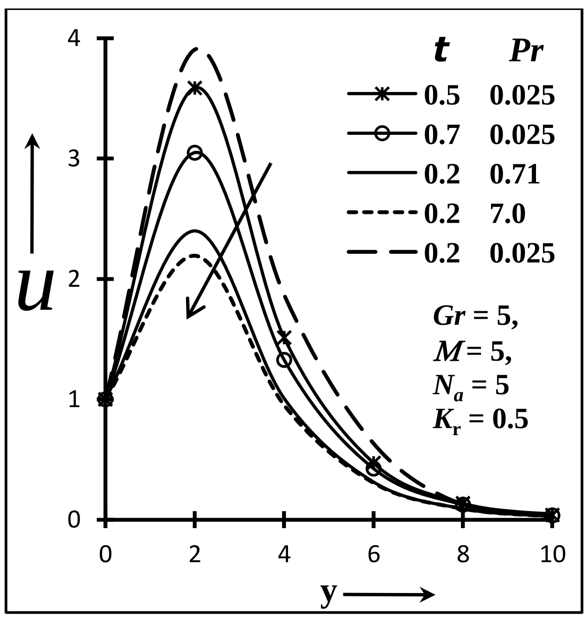

Fig. 5: Flow velocity for Pr and t

Figure 3 reveals the effects of N_a on the temperature profiles for the conducting air. It is evident from the figure that the temperature decreases with an increase in radiation-conduction for air. All pro files decay exponentially from maximum value $\theta = 1$ to zero in the free stream. These results agree with the earlier results of Soundalgekar and Takhar [14]; Hossain and Takhar [15].

Figure 4 reveals the effects of porosity, K_r, on the velocity profiles. The presence of a porous medium increases the resistance to flow resulting in decrease in the flow velocity. This behaviour is depicted by the decrease in the velocity as K_r decreases for ***air***.

Figure 5 illustrates the variation of transient velocity with various Prandtl numbers ($\boldsymbol{Pr}$) as well as time parameter($\boldsymbol{t}$). As Pr increased from **0.025** (liquid metal i.e. very high thermal conductivity), through **0.71** (air), to **7.0** (sea water), there is a clear decrease in flow velocity i.e. the flow is decelerated through the boundary layer transverse to the plate when the plate is cooled by the free convection currents ($Gr > 0$). Pr encapsulates the ratio of momentum diffusivity to thermal diffusivity for a given fluid. It is also the product of dynamic viscosity and specific heat capacity divided by thermal conductivity. Higher Pr fluids will therefore posses higher viscosities (and lower thermal conductivities) implying that such fluids will flow slower than lower Pr fluids. As a result the velocity will be decreased substantially with increasing Prandtl number. Also the flow velocity is decreased with time parameter.

In **Figure 6**, it is observed that the fluid temperature is reduced monotonically when the Prandtl number is increased. As the smaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore, heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Moreover, Figure 6 also shows that the effect of higher Pr results into the thinner thermal boundary layer as the higher Prandtl number fluid has a lower thermal conductivity. Also the flow velocity is decreased with time parameter. These results agree with the earlier results of Soundalgekar and Takhar [14]; Hossain and Takhar [15].

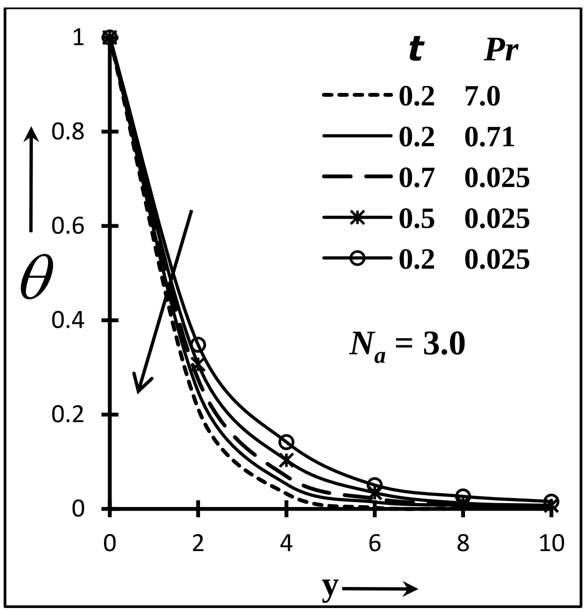

Fig. 6: Temperature distribution for $\boldsymbol{Pr}$, $\boldsymbol{t}$

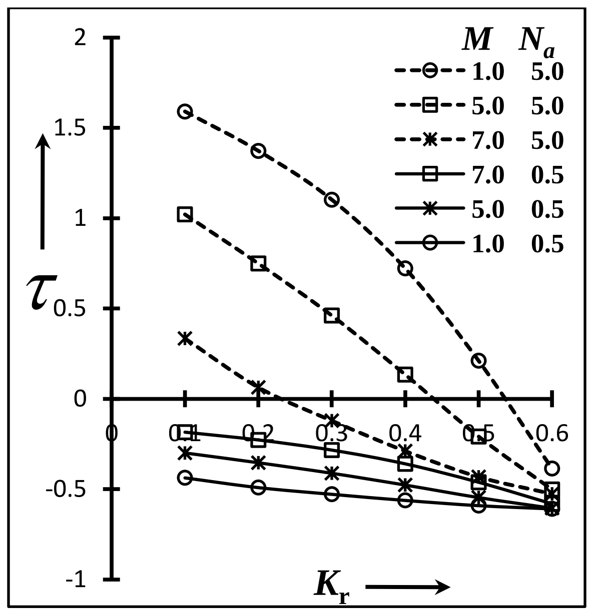

Fig. 7: Skin friction for $\boldsymbol{K_r}$, $\boldsymbol{N_a}$ and $\boldsymbol{M}$

Figure 7 reveals the skin-friction against porosity $\boldsymbol{K_r}$ for various values of parameters $\boldsymbol{M}$ and $\boldsymbol{N_a}$. It is observed that as porosity $\boldsymbol{K_r}$ increases from 0.1 through 0.2, 0.3, 0.4, 0.5 to 0.6, the skin deceases due to the presence of a porous medium which increases the resistance to flow resulting in decrease in the flow velocity. For $\boldsymbol{N_a} > 1$ thermal radiation is dominant over conduction and vice versa for $\boldsymbol{N_a} < 1$. The skin-friction increases with increasing radiation parameter $\boldsymbol{N_a}$. The magnitude of skin friction for $N_a = 5.0$ is much higher than that of $N_a = 0.5$. Moreover, the skin friction decreases with $\boldsymbol{M}$ due to the pull of ***Lorentz force***, this serves to decelerate the flow along the plate.

Figure 8 presents the transient velocity profiles in the boundary layer for various values of $\boldsymbol{Gr}$. The thermal Grashof number $\boldsymbol{Gr}$ signifies the relative effect of the thermal buoyancy (due to density differences) force to the viscous hydrodynamic force in the boundary layer flow. The positive values of $\boldsymbol{Gr}$ correspond to cooling of the plate by natural convection. Heat is therefore conducted away from the vertical plate into the fluid which increases temperature and thereby enhances the buoyancy force. It is observed that the transient velocity accelerates due to enhancement in the thermal buoyancy force, i.e., free convection effects. The maximum flow velocity occurs at the plate. However, as the buoyancy effects gets a relatively large, a distinctive peak in the velocity profiles, occurs in the fluid adjacent to the wall and this peak more distinctive as Gr increase further.

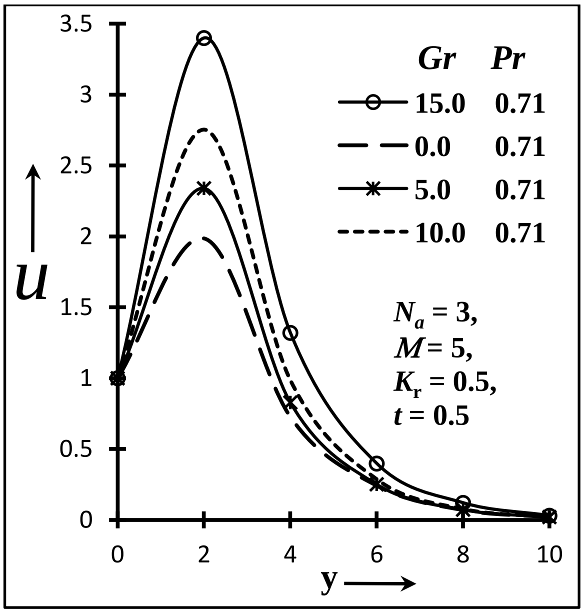

Fig. 8: Flow velocity for *Gr*

6. CONCLUSIONS

A theoretical analysis is performed to study the transient free convection-radiation magnetohydrodynamic viscous flow along an impulsively moving infinite vertical plane immersed in a porous medium under a transverse magnetic field. A flux model has been employed to ***simulate thermal radiation*** effects, valid for optically-thick gases. Analytical solutions through ***Laplace Technique*** have been obtained. Some of the important conclusions of the study are as follows:

- It is also observed that reduction in velocity and temperature are accompanied by simultaneous reductions in both velocity and thermal boundary layers.

- the flow is generally decelerated with the increase of porosity parameter ($\boldsymbol{K_r}$) for the conducting air.

- velocity and temperature were decreased with an increase in free convection-radiation ($\boldsymbol{N_a}$).

- increasing porosity contribution ($\boldsymbol{K_r}$) or magnetic field ($\boldsymbol{M}$) serves to depress shear stress significantly in the regime for the cases of air.

- with an increase in time parameter ($\boldsymbol{t}$), both the flow velocity and temperature is depressed.

- with an increase in free convection parameter ($\boldsymbol{Gr}$), the flow velocity is accelerated due to enhancement in the thermal buoyancy force.

The current study has employed a Newtonian viscous model.

NOMENCLATURE

u	Velocity component in x-direction (m. s^{-1}),
u_0	Dimensionless plate velocity (m. s^{-1}),
$\overline{C}$	Species concentration (kg. m^{-3}),
C_P	Specific heat at constant pressure (J. kg^{-1}. K),
$\overline{C}_\infty$	Species concentration in the free stream (kg.m^{-3}),
$\overline{C}_w$	Species concentration at the surface (kg. m^{-3}),
D	Chemical molecular diffusivity (m^2.s^{-1}),
g	Acceleration due to gravity (m.s^{-2}),
Gr	Thermal Grashof number,
Gr_m	Mass Grashof number,
M	Hartmann number parameter,
$\overline{a}$	Absorption coefficient,
Pr	Prandtl number,
$\overline{\sigma}$	Stefan-Boltzmann constant,
Sc	Schmidt number,
$\overline{T}$	Temperature (K),
$\overline{T}_w$	Fluid temperature at the plate (K),
$\overline{T}_\infty$	Fluid temperature in the free stream (K),
q_r	Radiative heat flux,
K_r	Porosity of the medium,
R_a	Thermal radiation,
t	Time parameter,
Nu	Nusselt number,
$erfc$	Complementary error function
erf	Error function

Greek Symbols

β	Coefficient of volume expansion for heat transfer (K^{-1}),
$\overline{\beta}$	Coefficient of volume expansion for mass transfer (K^{-1}),
μ	Viscosity of fluid,
θ	Dimensionless fluid temperature,
κ	Thermal conductivity (W. m^{-1}. K^{-1}),
ν	Kinematic viscosity (m^2.s^{-1}),
ρ	Density (kg. m^{-3}),

σ Electrical conductivity,
τ Shearing stress (N. m^{-2}),
ϕ Dimensionless species concentration

Subscripts

w Conditions on the wall
∞ Free stream conditions

ACKNOWLEDGMENT

The first author thanks the ***University Grants Commission*** of India for financial support for carrying out the Research via a Research project in the year **2010-11 of No. F.5/108/2009-10/5546**.

REFERENCES

[1] G. G. Stokes, Proc Camb. Phil. Soc, 9 (1951), 8.

[2] V. M. Soundalgekar, ASME Journal of Heat Transfer, 99 (1977), 499.

[3] A. Raptis and N.G. Kafoussias, "Magnetohydrodynamic free convection flow and mass transfer through porous medium bounded by an infinite vertical porous plate with constant heat flux," *Can. J. Phys*., vol. 60, No. 12, pp. 1725-1729 , 1982.

[4] M. A. Sattar, "Unsteady hydromagnetic free convection flow with Hall current mass transfer and variable suction through a porous medium near an infinite vertical porous plate with constant heat flux," *Int. J. Energy Research*, vol. 17, pp. 1-5, 1993.

[5] Y. J. Kim, Heat and mass transfer in MHD micropolar flow over a vertical moving porous plate in a porous medium, Transport in Porous Media, 56(1)(2004), 17-37.

[6] B. S. Jaiswal and V. M. Soundalgekar, "Oscillating plate temperature effects on a flow past an infinite vertical porous late with constant suction and embedded in a porous medium," *Heat and Mass Transfer*, vol. 37, pp. 125-131, 2001.

[7] A. Raptis and C. Perdikis, "Unsteady flow through a highly porous medium in the presence of radiation," *Transport in Porous Media*, vol. 57, pp. 171-179, 2004.

[8] S. Ahmed, "Transient three dimensional flow through a porous medium with transverse permeability oscillating with time," *Emirate Journal for Engineering research*, vol. 13, pp. 11-17, 2008.

[9] S. Ahmed, "Free convective transient three-dimensional flow through a porous medium oscillating with time in presence of periodic suction velocity," *International Journal of Applied Mathematics and Mechanics*, vol. 6, pp. 1-16, 2010.

[10] A. G. V. Kumar, S. V. K. Varma, "Thermal radiation and mass transfer effects on MHD flow past a vertical oscillating plate with variable temperature effects variable mass diffusion," *Int. Journal of Engineering*, vol. 3, pp. 493-499, 2011.

[11] J. Zueco, "Unsteady free convection-radiation flow over a vertical wall embedded in a porous medium," *Communications in Numerical Methods in Engineering*, vol. 24, pp. 1093-1105, 2008.

[12] A. A. Mahmoud and A. J. Chamkha, "Non-similar solutions for heat and mass transfer from a surface embedded in a porous medium for two prescribed thermal and solutal boundary conditions," *International Journal of Chemical Reactor Engineering*, vol. 8, pp. 1-24, 2010.

[13] W. G. England and A. F. Emery, "Thermal radiation effects on the laminar free convection boundary layer of an absorbing gas," *Journal of Heat transfer*, vol. 91, pp. 37-44, 1969.

[14] V. M. Soundalgekar and H. S. Takhar, "Radiation effects on free convection flow past a semi-infinite vertical plate," *Modeling, measurement and control*, vol. B. 51, pp. 31-40, 1993.

[15] M. A. Hossain and H. S. Takhar, "Radiation effect on mixed convection along a vertical plate with uniform surface temperature," *Heat and mass transfer*, vol. 31, pp. 243-248, 1996.

[16] A. Raptis and C. Perdikis, "Radiation and free convection flow past a moving plate," *Int. journal of Applied Mechanics and Engineering*, vol. 4, pp. 817-821, 1999.

[17] P. Chandrakala and S. A. Raj, "Radiation effects on MHD flow past an impulsively started infinite isothermal vertical plate," *Indian Journal of Chemical Technology*, vol. 15, pp. 63-67, 2008.

[18] S. Ahmed, "Mathematical model of induced magnetic field, with viscous/magnetic dissipation bounded by a porous vertical plate in presence of radiation," *Int. J. of Appl. Math and Mech.*, vol. 8, No. 1, pp. 86-104, 2012.