International Journal of Mathematical Archive-4(4), 2013, 94-103
Available online through www.ijma.info ISSN 2229 – 5046

HYDROMAGNETIC CONVECTIVE HEAT TRANSFER THROUGH A POROUS MEDIUM IN VERTICAL CHANNEL WITH QUADRATIC TEMPERATURE VARIATION

M. Ravindra[1*] & K. Radhika[2]
[1]Associate Professor, SSBN Degree & P.G. College, Anantapur, A.P, India
[2]Lecturer, SSBN Degree & P.G. College, Anantapur, A.P, India

(Received on: 22-02-13; Revised & Accepted on: 19-03-13)

ABSTRACT

In this paper an attempt has been made to study the free convective heat transfer of a viscous, electrically conducting fluid through a porous medium confined in a vertical channel under the influence of a uniform transverse magnetic field. The walls of the channel are maintained at non-uniform temperature and quadratic temperature distribution. The governing non-linear momentum equations are reduced to a single equation in terms of the Stokes stream function ψ, on eliminating pressure and using the equation of continuity .The temperature on the boundary is assumed to vary slowly in axial direction with slope δ(<<1).The stream function ψ and the temperature θ are given expansions in powers of δ,and the equations corresponding to the zeroth, first and second order are solved with the approximate boundary conditions. The velocity and temperature distributions have been analysed for variations in the governing parameters.

Key words: *Heat Transfer, Heat sources, Porous medium, Quadratic density, Temperature variation.*

INTRODUCTION

The hydro magnetic thermal convection has gained significance in the recent times owing to its abundant technological applications. With the advent of space technology the problem of controlling the skin friction and heat transfer around speed vehicles, has gained greater importance. It is well established that the primary use of electromagnetic fields in convection flows is to control the heat transfer and hence a detailed study of the influence of a magnetic field on that heat transfer of convection flows of an electrically conducting fluid is necessary. The heat transfer problems are generally solved for two types of configurations(1)Problems where the semi-infinite fluid is bounded by a non-porous(or porous)rigid boundary with a free stream which moves either with a uniform or time dependent fluctuation velocity(2) Problems where in the fluid is confined between non-porous(or porous) rigid boundaries. It is intuitively evident that the temperature distribution around a hot boundary in a fluid stream gives rise to a thermal boundary layer across which the temperature gradient is large. Hence apart from the velocity distribution in the flow the study of the thermal boundary layer and the influence of different forces (or kinematical factors) on the boundary layer is a major aspect of the heat transfer problem. When the buoyancy force is disregarded and the heat is transferred due to conduction alone the velocity field no longer depends on the temperature fields, although the dependence of the temperature field on the velocity field still persists, This happens at large Reynolds number and small temperature differences. Such flows being termed as forced flows while the temperature dependent buoyancy caused flows are known as free (or natural) convection flows.

Problems where the fluid is semi-infinite in extent bounded by a rigid wall and the free stream oscillations with time dependent velocity are often encountered in engineering applications viz., aerodynamics of a helicopter rotor or in fluttering aerofoil or in a variety of Bio-engineering problems. The analysis of the force oscillatory (with free stream oscillations)flow has been dealt by several authors. The flow and heat transfer characteristics have been found to depend on the heat source parameter, the Prandtl number and the Eckert number. In general the heat source parameter has been found to delay the fluid flow reversal and to act as catalyst (retarding) to the frequency parameter in augmenting(diminishing) the amplitude (phase) of the rate of heat transfer at the wall. The equations governing the flow and heat transfer have been solved numerically by the method of Runge-Kutta-Gill. It has been found that there are chances for the fluid velocity to exceed the free stream velocity although the plate velocity is smaller than the free stream. For the moving plate case, the presence of heat sources diminish the velocity in the fluid heating case and enhances in the fluid cooling case. The fluid temperature always decreases in the presence of heat sources and increases considerably with an increase in either the free stream parameter or the friction heating parameter. The presence of heat source has been found to diminish the rate of heat transfer coefficient at the plate considerably and this is true in the case of water. The governing equations of the problem, along with the boundary conditions, are integrated numerically for several sets of values of the parameters. It is found that the rate of heat transfer coefficient is a decreasing function of the heat source/sink parameter.

Corresponding author: *M. Ravindra[1*]*
[1]Associate Professor, SSBN Degree & P.G College, Anantapur, A.P, India

In all the above investigations, the variation of density is taken in the linear form

$$\Delta\rho = -\rho\beta(\Delta T) \tag{1.1}$$

where β is the coefficient of thermal expansion and is 2,07x10^{4}(0C)$^{-1+}$.This is valid for temperature variation near 20^{0}C.But this analysis is not applicable to the study of the flow of water at 4^{0}C past a vertical plate. This is because ,at 4^{0}C,the density of water is a maximum at atmospheric pressure and the above relations(1.1) dies not hold good. The modified form of (1.1) applicable to water at 40C is given by

$$\Delta\rho = -\rho\gamma(\Delta T)^2 \tag{1.2}$$

where $\gamma = 8x10^{-6}(0_C)^{-2}$ .Taking this fact into account, Goren showed in this case ,similarity solutions for the free convection flow of water at 4^{0}C past a semi-infinite vertical plate exist.

It is found that the flow and heat transfer both depend upon a new parameter $\gamma = \left(\dfrac{\beta_1}{\beta_0}\right)\Delta T$ in addition to the heat source parameter α and free convection parameter k.

Thermal convection problem in porous media occurs in a broad spectrum of the disciplines, ranging from Chemical Engineering to Geophysics. Applications include heat insulations by fibrous materials, spreading of pollutants, convection of Earth's mantle. A large cross section of fundamental research has been carried out by several authors in the recent times.A few other technological applications of a natural convection in a porous medium are cooling of nuclear fuel in shipping flasks and water filled storage bays, insulation of high temperature gas cooled reactor vessels, burrying of drums containing heart generating chemicals in the earth, thermal energy storage tanks, regenerative heat exchangers containing porous materials, petroleum reservoir and chemical catalytic reactions.

In all the above mentioned investigations the bounding walls are maintained at constant temperature. However, there are a few physical situations which warrant the boundary temperature to be maintained non-uniform. It is evident that in forced or free convection flow in a channel (pipe) a secondary flow can be created either by corrugating the boundaries or by maintaining non-uniform wall temperature. Such a secondary flow may be of interest in a few technological processes. For example, in drawing optical glass fibres of extremely low loss and wide width, the process of modified chemical vapour deposition (MCVD) has been suggested in recent times. In the MCVD process reactant flow through a rotating fused silica tube typically 1.5 to 3.0 cm in diameter, which is heated by an exterior torch. The torch slowly traverses (10 to 30 cm/min) in the same direction as the interior gas flows. As the cool reactant gases(Sicl)$_2$,O$_2$,various dopants) approach the hot zone of the traversing in the formation of particles typically 0,15 to 0,3 m in diameter. Some heterogeneous reaction occurs on the walls. Then the hot gas and suspended particles flow through the section of tube down stream of the hot zone, where the wall is at a lower temperature than the gas. Here apart of the particles will deposit thermophoretically due to the radial temperature gradients. Further down stream gas and wall temperature equilibrate and deposition ceases. As the torch transverses, the particulate deposit is consolidated into a thin various pore free layer by a viscous sintering mechanism, when the torch reaches the end of a traverses, it quickly returns to the entrance end of the tube and the process is repeated. A gradient index profile can be achieved by varying the dopant concentration for each pass. After 30 to 50 layers are deposited, the tube is collapsed into a solid rod, which is substantially drawn into a thin optical fibre, using a high temperature furnace. In commercialization of this product ,it is desirable to increase the efficiency of the thermophoretic deposition rate, since the cost of the fibre depends on the production of performs. Combined heat and mass transfer by free convection under boundary layer approximations has been studied by Bejan and Khair[2], Lai and Kulacki[4] and Murthy and Singh[5].Coupled heat and mass transfer by mixed convection in Darcian fluid-saturated porous media has been analysed by Lai [3].The free convection heat and mass transfer in a porous enclosure has been studied recently by Angirasa *et al* [1]. The combined effects of thermal and mass diffusion in channel flows has been studied in recent times by a few authors, notably Nelson and Wood [6, 7], and others [11, 12].

In this paper an attempt has been made to study the free convective heat transfer of a viscous, electrically conducting fluid through a porous medium confined in a vertical channel under the influence of a uniform transverse magnetic field. The walls of the channel are maintained at non-uniform temperature and quadratic temperature distribution. Important features of our analysis are (i) we take into account the axial dependence of the flow variables in accordance to the prescribed non-uniform temperature on the boundary (ii) the analysis is valid for all finite values of the parameters governing the flow viz., the Reynolds niumber R, The Grashof number G, the Peclect number Pe, the Darcy parameter D^{-1} and α the amplitude of the non-uniform boundary temperature. The governing non-linear momentum equations are reduced to a single equation in terms of the Stokes stream function ψ,on eliminating pressure and using the equation of continuity .The temperature on the boundary is assumed to vary slowly in axial direction with slope

δ(<<1).The stream function ψ and the temperature θ are given expansions in powers of δ,and the equations corresponding to the zeroth,

first and second order are solved with the approximate boundary conditions. The velocity and temperature distributions have been analysed for variations in the governing parameters in detail. The average Nusselt number has been evaluated for different values of G, D^{-1}, M, R and z.

FORMULATION OF THE PROBLEM

We consider the fully developed laminar steady flow of an incompressible, electrically conducting, viscous fluid confined in a vertical channel bounded by two flat walls, which are maintained at non-uniform temperature in the presence of a heat generating sources. The Boussinesq approximation is used so that the density variations will be considered only in the buoyancy force. The viscous dissipation is neglected in comparison to the transport of heat by conduction and convection. Also the kinetic viscosity ν, the thermal conductivity k are treated as constants. We choose the Cartesian coordinate system O(x, y) with x-axis in the vertical direction and y-axis normal to the walls. The walls of the channel are at y = ±L. The equations governing the steady flow and heat transfer are

$$\rho_e\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\rho g-(\sigma\mu_e^2H_o^2)u-\left(\frac{\mu}{k}\right)u \tag{2.1}$$

$$\rho_e\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\left(\frac{\mu}{k}\right)v \tag{2.2}$$

$$\rho_e\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-Q(T-T_e) \tag{2.3}$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{2.4}$$

$$\rho-\rho_e=-\gamma(T-T_e)^2 \tag{2.5}$$

where suffices x,y indicates differentiation with respect to variables,ρ_e,Te are density and temperature of the fluid in the equilibrium state,(u,v) are the velocity components along the O(x,y) directions, p is the pressure, T is the temperature in the flow region,ρ is the density,μe is the magnetic permeability ,σ is the electrical conductivity of the medium, Cp is the specific heat at constant pressure.λ is the coefficient of thermal conductivity and γ is coefficient of volume expansion.

In the equilibrium state

$$0=-\frac{\partial p_e}{\partial x}-\rho_e g \tag{2.6}$$

where p = p_D +pe, p_D being the hydrodynamaic pressure. The boundary conditions relevant to the problem are

$$u=0,v=0,T-Te=f(\delta x/L) \text{ on } y=\pm L \tag{2.7}$$

f is chosen twice differentiable function,δ is a small parameter proportional to the slope of the temperature variation on the boundary.

Also the flow is maintained by a constant imposed flux for which a characteristic velocity U is defined as

$$U=\frac{1}{L}\int_{-L}^{L}u\,dy \tag{2.8}$$

We introduce the non-dimensional variables as

$$(x',y')=(x,y)/L,(u',v')=(u,v)/U,\ p=\frac{1}{\rho_e U^2}p_D$$

$$\theta=\frac{T-T_e}{\Delta T_e},\ f'=f/\Delta T_e$$

$$\left(\Delta T_e = (T_e(-L) - T_e(L)\right) = \frac{QL^2}{\lambda}$$

Substituting these non-dimensional variables in equations (2.1)-(2,5) and eliminating the pressure, the momentum equations in terms of the the dimensionlesss stream function ψ redces to (after dropping the dashes)

$$R\left(\frac{\partial\psi}{\partial y}\frac{\partial(\nabla^2\psi)}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial(\nabla^2\psi)}{\partial y}\right) = \nabla^4\psi + 2\frac{G}{R}\theta\frac{\partial\theta}{\partial y} - M^2\frac{\partial^2\psi}{\partial y^2} - D^{-1}\nabla^2\psi \qquad (2.9)$$

$$\nabla^2\theta - \alpha\,\theta 1 = P_e\left(u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y}\right) \qquad (2.10)$$

where

$R = \frac{UL}{\nu}$ (Reynolds number) $\qquad G = \frac{\beta g \Delta T_e L^3}{\nu^2}$ (Grashof number)

$P_e = \frac{\rho_e C_p UL}{\lambda}$ (Peclet number) $\qquad D^{-1} = \frac{L^2}{k}$ (Darcy paramater)

$\alpha = \frac{QL^2}{\lambda C_p}$ (Heat source parameter)

The boundary conditions in the non-dimensional form for ψ and θ are

$$\psi(x,1) - \psi(x,-1) = 1 \;\; for \;\; all \;\; x$$

$$\frac{\partial\psi}{\partial x} = 0,\; \frac{\partial\psi}{\partial y} = 0,\; \theta(x,y) = f(\delta\, x) \;\; on \;\; y = \pm 1 \qquad (2.11)$$

$$\frac{\partial\theta}{\partial y} = 0 \qquad on \;\; y = 0$$

The value of ψ on the boundary assures the constant volumetric flow in consistent with the hypothesis (2.8).Also the wall temperature varies in the axial distance in accordance with the prescribed arbitrary function f.

ANALYSIS OF THE FLOW

The aim of this analysis is to discuss the perturbation created over a combined free and forced convection flow due to non-uniform slowly varying temperature imposed on the boundaries.

We introduce the temperature $\overline{x} = \delta x$ .With this transformation the equation (2.9) and (2.10) reduce to

$$\delta R\left(\frac{\partial\psi}{\partial y}\frac{\partial(F^2\psi)}{\partial\overline{x}} - \frac{\partial\psi}{\partial\overline{x}}\frac{\partial(F^2\psi)}{\partial y}\right) = F^4\psi + 2\frac{G}{R}\theta\frac{\partial\theta}{\partial y} - M^2\frac{\partial^2\psi}{\partial y^2} - D^{-1}F^2\psi \qquad (3.1)$$

$$F^2\theta - \alpha\,\theta = \delta\, P_e\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial\overline{x}}\frac{\partial\theta}{\partial y}\right) \qquad (3.2)$$

$$F^2 = \delta^2\frac{\partial^2}{\partial\overline{x}^2} + \frac{\partial^2}{\partial y^2}$$

We follow the perturbation scheme and analyse through first order as a regular perturbation problem at finite values of R, G, Pe and D^{-1}.

Introducing the formal asymptotic expansions

$$\psi = \psi_0 + \delta\psi_1 + \delta^2\psi_2. + \ldots\ldots\ldots\ldots$$
$$\theta = \theta_0 + \delta\,\theta_1 + \delta^2\theta_2 + \ldots\ldots \qquad (3.3)$$

and substituting them in (3.1) and (3.2) and separating the like powers of δ, the equations to the zeroth order are

$$\frac{\partial^4\psi_0}{\partial y^4}-M_1^2\frac{\partial^2\psi_0}{\partial y^2}=-\frac{G}{R}\theta_0\frac{\partial\theta_0}{\partial y} \tag{3.4}$$

$$\frac{\partial^2\theta_0}{\partial y^2}-\alpha\,\theta_0=0 \tag{3.5}$$

The corresponding boundary conditions on ψ_0 and θ_0 are

$$\psi_0(x,1)-\psi_0(x,-1)=1\ \ for\ all\ x$$

$$\frac{\partial\psi_0}{\partial x}=0,\ \frac{\partial\psi_0}{\partial y}=0\ \ on\ \ y=\pm1$$

$$\theta_0(x,y)=f(\delta x)\ on\ \ y=\pm1 \tag{3.6}$$

$$\frac{\partial\theta_0}{\partial y}=0\qquad on\ \ y=0$$

The equations to the first order are

$$\frac{\partial^4\psi_1}{\partial y^4}-M_1^2\frac{\partial^2\psi_1}{\partial y^2}=-\left(\frac{2G}{R}\right)\left(\theta_0\frac{\partial\theta_1}{\partial y}+\theta_1\frac{\partial\theta_0}{\partial y}\right)+R\left(\frac{\partial\psi_0}{\partial y}\frac{\partial^2\psi_0}{\partial x\partial y^2}+\frac{\partial\psi_0}{\partial x}\frac{\partial^2\psi_0}{\partial y^3}\right) \tag{3.7}$$

$$\frac{\partial^2\theta_1}{\partial y^2}-\alpha\,\theta_1=P_e\left(\frac{\partial\psi_0}{\partial y}\frac{\partial\theta_0}{\partial x}+\frac{\partial\psi_0}{\partial x}\frac{\partial\theta_0}{\partial y}\right) \tag{3.8}$$

The corresponding boundary conditions are

$$\psi_1(x,1)-\psi_1(x,-1)=0\ \ for\ all\ x$$

$$\frac{\partial\psi_1}{\partial x}=0,\ \frac{\partial\psi_1}{\partial y}=0\ \ on\ \ y=\pm1 \tag{3.9}$$

$$\theta_1(x,y)=0)\quad on\ \ y=\pm1$$

$$\frac{\partial\theta_1}{\partial y}=0\quad on\ \ y=0 \tag{3.10}$$

SOLUTION OF THE PROBLEM

The zeroth order and first order solutions for the stream function and temperature satisfying the corresponding boundary conditions are

$$\psi_0=a_4Sh(M_1y)+a_5y+a_6+a_2Sh(\beta_1y)$$

$$\theta_0=\gamma\frac{Ch(\beta_1y)}{Ch(\beta_1)}$$

The solutions for ψ_1 and θ_1 corresponding to the first order perturbations are

$$\psi_1 = a_{88}Ch(M_1 y) + a_{89}Sh(M_1 y) + a_{90}y + a_{91} + \phi(y)$$

$$\begin{aligned}\varphi(y) = {} & a_{70}Sh(2M_1 y) + a_{71}Sh(\beta_1 y) + a_{72}Sh(\beta_5 y) + a_{73}Sh(4\beta_1 y) - a_{74}yCh(M_1 y) \\ & -a_{75}Sh(2\beta_1 y) - a_{76}y^2 Sh(M_1 y) + a_{77}ySh(2\beta_1 y) + a_{78}Sh(\beta_8 y) + a_{78}Sh(\beta_9 y) \\ & -a_{80}Ch(\beta_8 y) + a_{81}Ch(\beta_9 y) - a_{82}Sh(\beta_1 y) - a_{83}Ch(2\beta_1 y) + a_{84}y^2 Ch(2\beta_1 y) \\ & +a_{85}y^3 Sh(2\beta_1 y) - a_{86}y^2 - a_{87}\end{aligned}$$

$$\theta_1 = a_{21}Ch(\beta_1 y) + a_{16}Ch(\beta_2 y) - a_{17}Ch(\beta_3 y) + a_{18}Ch(3\beta_1 y) - a_{19}ySh(\beta_1 y) + a_{20}y^2 Ch(\beta_1 y)$$

AVERAGE NUSSELT NUMBER

The average Nusselt number on the channel walls are given by

$$(Nu)_{y=\pm 1} = \frac{1}{(\theta_m - f)}\left(\frac{\partial \theta}{\partial y}\right)_{y=\pm 1}$$

and the corresponding expressions are

$$(Nu)_{y=+1} = \frac{(b_1 + \delta\, b_3)}{\theta_m - \gamma}$$

$$(Nu)_{y=-1} = \frac{(b_2 + \delta\ b_4)}{\theta_m - \gamma}$$

where

$$\theta_m = \frac{1}{L}\int_{-L}^{L} \theta\, dy$$

DISCUSSION OF THE NUMERICAL RESULTS

The velocity and temperature distributions in an electrically conducting viscous fluid through a porous medium in a vertical channel with quadratic density temperature variation are shown in fig 1 - * for different values of G,D^{-1}, R,α,α, and x. Fig (1) represents the axial velocity u for a different G. It is found that no reverse flow occurs for any value of the governing parameters. The magnitude of u enhances with increasing G>0 and depreciates with │G│ (<0), with maximum occurring at y = 0. From fig (2) we find that lesser the permeability of the porous medium higher the magnitude of u in the fluid region. Also │u│ enhances with R ≤ 50 and depreciates for higher R ≥ 60. An increase in the strength of heat generating sources reduces │u│in the fluid region. As amplitude α_1 of the non-uniform boundary temperature increases we notice an enhancement in u in the entire fluid region [fig (3)]. From fig (4) we notice that as we move along the axial direction x we observe an enhancement in │u│ for x ≤ Π/2 and depreciates with higher x ≥ Π.

The secondary velocity (v) which is due to the non-uniformity of the boundary temperature is shown in fig (5) – (8) for different values of G,D^{-1}, R, α,α_1 and x. It is found that for different variations of parameters the secondary velocity changes from negative to positive as we move from the left boundary to right boundary Fig (5) represents v with G. It is noticed that the magnitude of v experiences an enhancement with increase in │G│. For G>0, v shifts from towards the mid region to the towards the boundary while for G<0 v changes from towards the boundary to towards the mid region as we move from left region to right region. From fig (6) we find that lesser the permeability of the porous medium larger │v│. Also is depreciates with increase in R. The variation of v with heat source parameter α shows that │v│depreciates with increase in the strength of heat generating source. Also │v│ enhances with increase in the amplitude α_1 of the boundary temperature. Moving along the axial direction the secondary velocity reduces in magnitude with x ≥ Π.

The non-dimensional temperature (θ) in shown in figs 9-12 for different values of G, D^{-1}, R, α, α_1, and x. for different variations of parameters, we find that the temperature is negative. For variations in G, the temperature attains the maximum at y = 0.6 for all an increasing in G < 2 x 10^3 the temperature enhances and for higher G ≥ 3 x 10^3 the actual temperature depreciates in the left region while in the right region it enhances except in the vicinity of the boundaries y=±1.From fig (9), we find that lesser the permeability of porous medium larger the actual temperature everywhere in the region. Also the temperature enhances with R. From fig (11) we noticed that an increase in the heat source parameter α results in a depreciates in the actual temperature. Also an increase in the amplitude α_1 of the boundary temperature results in a deprecation in the actual temperature. The variation of θ with axial distance x exhibits an oscillating nature in view of the boundary temperature.

The average Nusselt number (Nu) which measures the rate of heat transfer at y = ± 1 is shown in tables 1 – 4 for different G,D^{-1}, R, α, α and x. It is found that an increase in G > 0 reduces the rate of heat transfer at y = 1 and enhances at y = -1 and a reversed effect is observed with increase in │G│ (<0). An increase in the Reynolds number R depreciates │Nu│ at both the walls. Lesser the permeability of the porous medium smaller │Nu│ at y = ± 1. Also the presence of the heat sources enhances │Nu│ for all G at y = ± 1 (Table 1 & 2). As the amplitude of the non-uniform temperature enhances we notice an increment in │Nu│ ay y = 1 for G > 0 and depreciation at y = 1 for G > 0 while for G < 0 we find a reversed effect. As we move along the axial distance the rate of heat transfer reduces with x ≤ Π and enhances at higher axial distances (Table 3 & 4).

CONCLUSIONS

1) An increasing amplitude α_1 of the non-uniform boundary temperature increases we notice an enhancement in u in the entire fluid region.
2) │v│depreciates with increase in the strength of heat generating source.
3) │v│ enhances with increase in the amplitude α_1 of the boundary temperature.
4) An increase in the heat source parameter α results in a depreciates in the actual temperature.
5) An increase in the amplitude α_1 of the boundary temperature results in a deprecation in the actual temperature.
6) The presence of the heat sources enhances │Nu│ for all G at y = ± 1.
7) As the amplitude of the non-uniform temperature enhances we notice an increment in │Nu│ ay y = 1 for G > 0 and depreciation at y = 1 for G > 0 while for G < 0 we find a reversed effect.

REFERENCES

[1] Angirasaa,D,Peterson,G.P and Pop, I :Combined heat and mass transfer by natural convection with opposing buoyancy effects in a fluid saturated porous medium, Int. J. Heat Mass Transfer (1997), V.40, pp. 2755-2773.

[2] Bejan,A and Khair,K.R: Heat and Mass transfer by natural convection in a porous medium, Int. J. Heat Mass transfer, (1985)V.28,pp.908-918

[3] Lai,F.C: Cpupled heat and mass transfer by mixed convection from a vertical plate in a saturated porous medium., Int. Commn. heat mass transfer(1971),,V.18,pp.93-106

[4] Lai,F.C and Kulacki,F.A : Coupled heat and mass transfer by natural convection from vertical surfaces in porous medium., Int. J. Heat Mass Transfer, (1991),V.34, pp.1189- 1194

[5] Murthy,P.V.S.N and Singh,P: Heat and Mass transfer by natural convection in a Non-Darcy porous medium, Acta Mech, (1990),V.26,pp.567

[6] Nelson,D.J and Wood,B.D: Combined heat and mass transfer by natural convection between vertical plates with uniform flux boundary conditions, Heat transfer(1986),V.4,pp.1587-1952

[7] Nelson,D.J and Wood,B.D: Combined heat and mass transfer by natural convection between vertical plates ,Int. J., Heat Mass transfer, (1989),V.82, pp.1789-1792

[8] Prasad,V,Kulacku,F.A and Keyhani,M: Natural convection in a porous medium, J. Fluid Mech. (1985),V.150,pp.89-119

[9] Raptis, A.A and Perdikis, C Radiation and free convection flow past a moving plate, Appl. Mech. Eng, (1999), Vol.4, pp 817-821.

[10] Sudha Mathew: Hydro magnetic mixed convective heat and mass transfer through a porous medium in a vertical channel with thermo-diffusion effect. Ph.D thesis, S, K. University, Anantapur, India(2009).

[11] Trevison ,D.V and Bejan,A: Combined heat and mass transfer by natural convection in vertical enclosure, Trans. ASME (1987),V.109,pp.104-111

[12] Wei-Mon Yan:Combined buoyancy effects of thermal and mass diffusion on laminar forced convection in horizontal rectangular ducts, Int, J, Heat Mass transfer, (1996),V.39, pp.1479-1488

Figures:

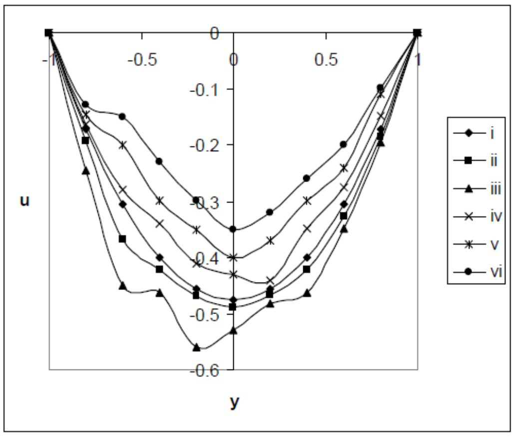

Fig. 1 : Primary velocity (u) with G

$D^{-1} = 10^2$, R = 35, $\alpha = 2$, $\alpha_1 = 0.5$

	I	II	III	IV	V	VI
G	10^3	$3x10^3$	$5x10^3$	-10^3	$-3x10^3$	$-5x10^3$

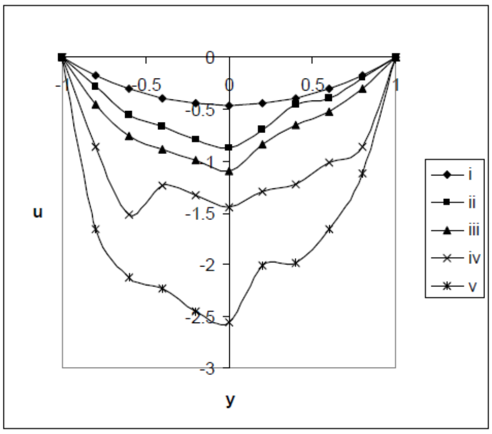

Fig. 2 : u with R & D^{-1}

$G = 10^3$, $\alpha = 2$

	I	II	III	IV	V
R	35	70	140	35	35
D^{-1}	10^2	10^2	10^2	$2x10^2$	$3x10^2$

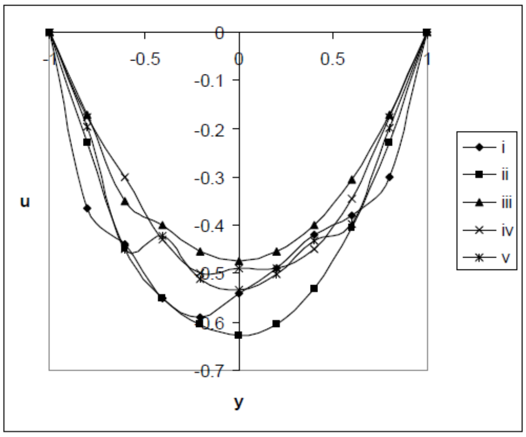

Fig. 3 : u with α & α_1

$G = 10^3$, $D^{-1} = 10^2$, R = 35

	I	II	III	IV	V
α	2	4	2	2	2
α_1	0.5	0.5	0.1	0.3	0.4

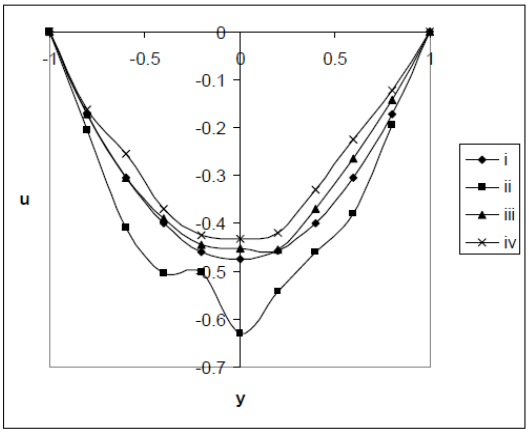

Fig. 4 : u with x

$\alpha = 2$, α_1 0.5

	I	II	III	IV
x	$\pi/4$	$\pi/2$	π	2π

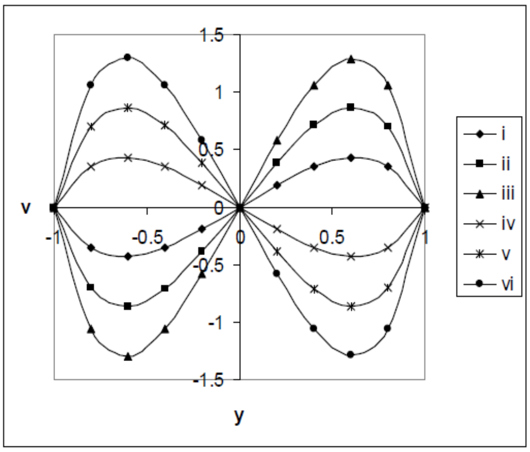

Fig. 5 : Secondary velocity (v) with G

$D^{-1} = 10^2$, R = 35, $\alpha = 2$, $\alpha_1 = 0.5$

	I	II	III	IV	V	VI
G	10^3	$3x10^3$	$5x10^3$	-10^3	$-3x10^3$	$-5x10^3$

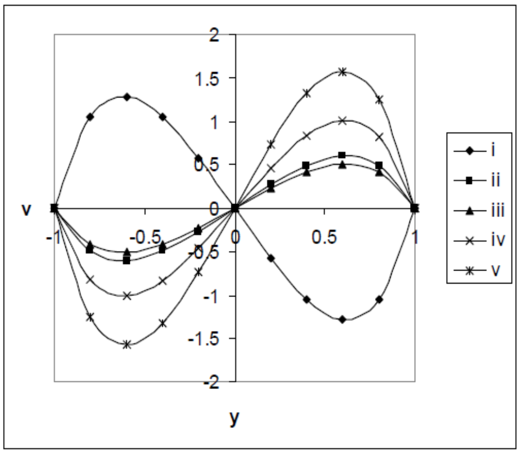

Fig. 6 : v with R & D^{-1}

$G = 10^3$, $\alpha = 2$

	I	II	III	IV	V
R	35	70	140	35	35
D^{-1}	10^2	10^2	10^2	$2x10^2$	$3x10^2$

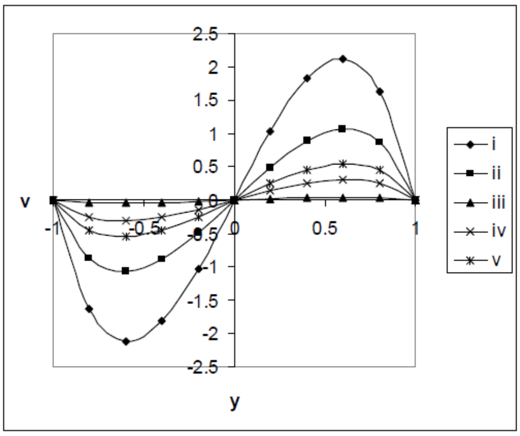

Fig. 7 : v with α & α_1

$G = 10^3$, $D^{-1} = 10^2$, $R = 35$

	I	II	III	IV	V
α	2	4	2	2	2
α_1	0.5	0.5	0.1	0.3	0.4

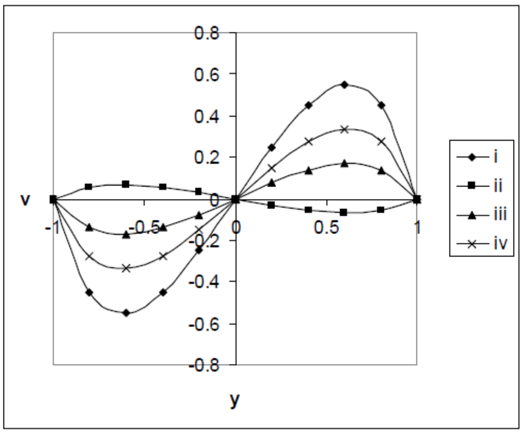

Fig. 8 : v with x

$\alpha = 2$, α_1 0.5

	I	II	III	IV
x	$\pi/4$	$\pi/2$	π	2π

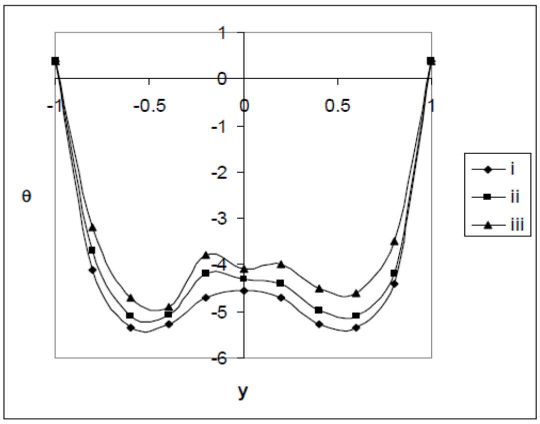

Fig. 9 : Temperature (θ) with G

$D^{-1} = 10^2$, $R = 35$, $\alpha = 2$, $\alpha_1 = 0.5$

	I	II	III	IV	V	VI
G	10^3	$3\text{x}10^3$	$5\text{x}10^3$	-10^3	$-3\text{x}10^3$	$-5\text{x}10^3$

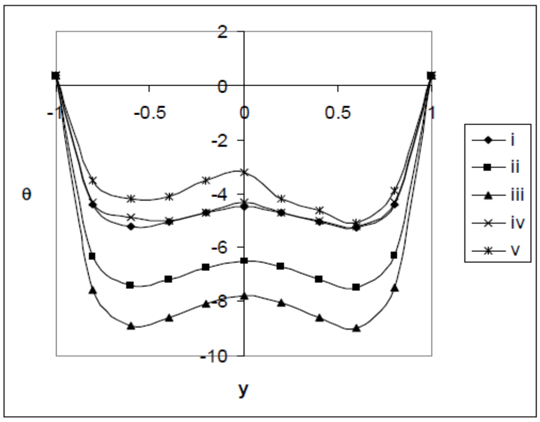

Fig. 10 : θ with R & D^{-1}

$G = 10^3$, $\alpha = 2$

	I	II	III	IV	V
R	35	70	140	35	35
D^{-1}	10^2	10^2	10^2	$2\text{x}10^2$	$3\text{x}10^2$

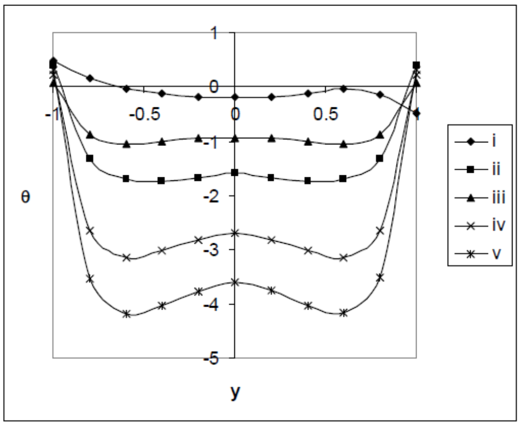

Fig. 11 : θ with α & α_1

$G = 10^3$, $D^{-1} = 10^2$, $R = 35$

	I	II	III	IV	V
α	2	4	2	2	2

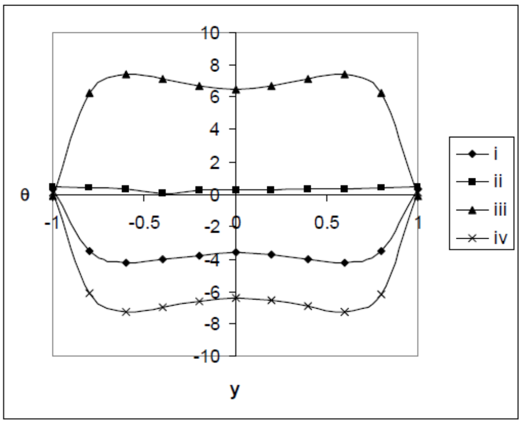

Fig. 12 : θ with x

$\alpha = 2$, α_1 0.5

	I	II	III	IV
x	$\pi/4$	$\pi/2$	π	2π

Tables:

Table.1

Average Nusselt Number(Nu) at y= 1, P=0.71, α1=0.5,x=π/4

G/Nu	I	II	III	IV	V	VI
10^3	-0.5577	-0.5428	-0.5634	-0.5428	-0.6002	-0.6683
$3x10^3$	-0.5276	-0.5030	-0.5437	-0.5231	-0.5987	-0.6483
-10^3	-0.5578	-0.5429	-0.5532	-0.5426	-0.6101	-0.6582
$-3x10^3$	-0.5876	-0.5629	-0.5828	-0.5624	-0.6202	-0.6985

Table.2

Average Nusselt Number(Nu) at y= -1, P=0.71, α1=0.5,x=π/4

G/Nu	I	II	III	IV	V	VI
10^3	0.5578	0.5429	0.5231	0.5626	0.6002	0.6683
$3x10^3$	0.5779	0.5530	0.5328	0.5824	0.6402	0.6583
-10^3	0.5577	0.5428	0.5335	0.5528	0.6101	0.6482
$-3x10^3$	0.5476	0.5327	0.5238	0.5331	0.5602	0.6282
	I	II	III	IV	V	VI
R	35	70	35	35	35	35
D^{-1}	10^2	10^2	$2x10^2$	$3x10^2$	10^2	10^2
α	2	2	2	2	4	6

Table.3

Average Nusselt Number(Nu) at y=1, P=0.71, α_1=0.5,x=π/4

G/Nu	I	II	III	IV	V	VI
10^3	-0.5654	-0.5454	-0.5253	4.3912	-0.5344	-0.5679
$3x10^3$	-0.5454	-0.5253	-0.5152	4.3912	-0.5402	-0.5478
-10^3	-0.5656	-0.5458	-0.5255	4.3909	-0.5340	-0.5579
$-3x10^3$	-0.5955	-0.5655	-0.5357	4.3876	-0.5321	-0.5879

Table.4

Average Nusselt Number(Nu) at y= -1, P=0.71, α_1=0.5,x=π/4

G/Nu	I	II	III	IV	V	VI
10^3	0.5654	0.5828	0.6034	-4.3912	0.5342	0.5583
$3x10^3$	0.5678	0.6230	0.6437	-4.3811	0.5278	0.5781
-10^3	0.5652	0.5829	0.6232	-4.3914	0.5267	0.5682
$-3x10^3$	0.5435	0.5629	0.6028	-4.3945	0.5321	0.5585
	I	II	III	IV	V	VI
α_1	0.1	0.3	0.7	0.5	0.5	0.5
x	π/4	π/4	π/4	π/2	π	2π

Source of support: Nil, Conflict of interest: None Declared