International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Hydro-Magnetic Flow and Heat Transfer in an Inclined Composite Porous Medium Bounded by Parallel Plates

S.Nanda Kishore[A*] and S.Sreenadh[B]

[A]Department of Mathematics, N.B.K.R.I.S.T. Vidyanagar, Nellore, A.P. India.
[B]Department of Mathematics, S.V. University, Tirupathi, A.P.India.

Accepted 30 Nov 2014, Available online 01 Dec 2014, **Vol.4, No.6 (Dec 2014)**

Abstract

This paper deals with non-Darcian convective hydromagnetic flow in an inclined composite porous medium. It is assumed that the flow is steady, laminar fully developed and that fluid properties are constant. The flow in both phases is assumed to be driven by a common constant pressure gradient $\frac{-\partial p}{\partial x}$ *and temperature gradient* $\Delta T = T_{W1} - T_{W2}$ *where* T_{W1} *and* T_{W2} *are the temperatures of upper and lower plates. It is also assumed that at any given instant, the temperatures of fluid and the solid are the same. The viscous and Darcy dissipation terms and included in the energy equation. The governing equation is coupled and non-linear because of inclusion of dissipation terms and buoyancy force. The equations are solved using perturbation method. The effects of various parameters such as Hartmann number, porous parameter, inclination angle and Grashoff number on the flow quantities are discussed.*

Keywords: *Hydromagnetic flow, Darcy dissipation, buoyancy force, Hartmann number.*

1. Introduction

Convection in a porous medium has attracted a great deal of research attention because of the fundamental nature of the problem and a broad range of applications, including geothermal systems, thermal insulation, storage of nuclear waste materials, solidification of castings, direct contact heat exchangers, enhanced recovery of petroleum resources, and geothermal energy extraction. These applications together with the fact that the porous media occur naturally in many practical problems have motivated an increasing number of different types of studies in the last two decades. Extensive reviews of prior work on convective flows in porous media have been presented by Combrarnous and Bories (1975), Chenge (1978), Rudraiah (1984, 1988), Niedl (1984), Kariang (1991) and Neild and Bejan (1992). Most of the theoretical work has been based on Darcy's law and as noted by Prasad *et. al.*, (1985). But the experimental results did not agree with the theoretical results obtained with the Darcy model. This has led to inclusion of inertia and viscous effects in studies of convection in porous medium (Vafai and Tien 1981, 1982, Becker man *et al*., 1986, Geurgiadias and Cattan 1986, Lauriant and Prasad 1986, Rudraiah 1988 and Prasad 1990).

Based on our review of the current literature, it is evident that very few studies are available an conventional flow and heat transfer in inclined porous layer (Bories and Cambarnous 1973; Chaeng 1977; Rudraiah 1986; Oosthuizen and Paul, 1987) and further studies on composite porous layers with inclined geometry are rare. Malashetty *et al*., (2001) discussed convective flow and heat transfer in an inclined composite porous medium. Thus it is the objective of the present studies to investigate the effect of magnetic field on convection in composite porous layer with inclined geometry. As a first step towards introducing this complexity into the problem. We consider only the Brinkman extended Darcy-Lapwood model to obtain realistic predictions.

Mathematical Model

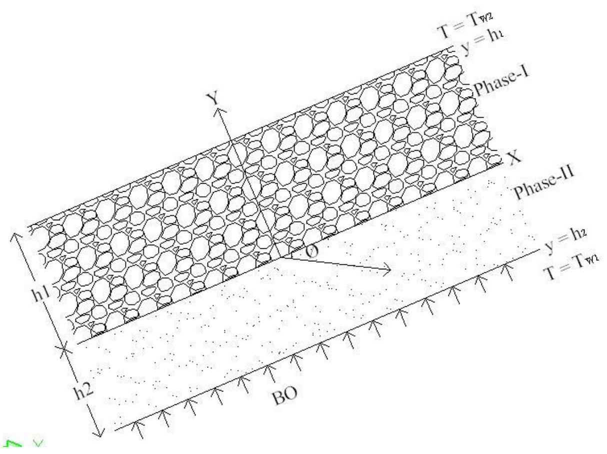

Fig. 1 Physical Model

Consider the steady laminar conducting flow of a viscous incompressible fluid through differentially permeable

*Corresponding author: **S.Nanda Kishore**

porous layers bounded two infinite inclined parallel plates maintained at different constant temperatures, extending in the Z and X directions making an angle α with the horizontal. (Fig. 3.1) The region $0 \leq= y \leq h_1 (Phase\ I)$ is filled with a homogeneous isotropic porous material having permeability K_1. This phase is saturated with a viscous fluid having density, P_1 viscosity μ_1 and thermal conductivity k_1. The region $-h_2 \leq y \leq 0 (Phase\ II)$ is filled with another homogeneous isotropic porous material having permeability K_2. This Phase is saturated with a different viscous fluid having density, ρ_2 Viscosity μ_2 and thermal conductivity k_2. A uniform transfer magnetic field of strength B_0 is applied perpendicular to the plates.

It is assumed that the flow is fully developed and that fluid properties are constant. The flow in the both phases is assumed to be driven by a common constant pressure gradient $\left(-\frac{\partial p}{\partial x}\right)$ and temperature gradient $\Delta T = T_{w1} - T_{w2}$ where T_{w1} is the temperature of the boundary at $y = h_1, and\ T_{w2}$ that at $y = -h_2$. It is also assumed that at any given instant, the temperatures of the fluid and the temperature of the solid are the same.

2. Nomenclature

Cp	-	Specific heat at constant pressure
Ec	-	Ecket number
G	-	Acceleration due to gravity
K	-	Permeability of the porous medium
K	-	Thermal conductivity of the fluid saturated porous medium
P	-	Non dimensional pressure gradient
Pr	-	Prandtl number
Re	-	Reynolds number
U	-	Velocity
$\overline{u_1}$	-	Average velocity
T	-	Temperature
Tw	-	Wall temperature
β	-	Coefficient of thermal expansion
σ	-	Porous parameter
α	-	Angle of inclination
ρ	-	Density of the fluid
V	-	Kinematic viscosity
μ	-	Viscosity
ε	-	Product of prandtl number and Ecket number (Pr.Ec)
ΔT	-	Difference of temperature $(T_{w1} - T_{w2})$
θ	-	Non dimensional temperatures $(T - T_{w2}) / \Delta T$

3. Mathematical formulation of the problem

The momentum and energy equations governing the flow in the two phases are given below

Phase I

$$\mu_1 \frac{d^2 u_1}{dy^2} + \rho_1 g \beta_1 (T_1 - T_{w2}) \sin\alpha - \left(\sigma_{e1} B_0^2 + \frac{\mu_1}{k_1}\right) u_1 = \frac{\partial p}{\partial x} \tag{1.1}$$

$$\frac{d^2 T_1}{dy^2} + \frac{\mu_1}{k_1}\left(\frac{du_1}{dy}\right)^2 + \frac{\mu_1}{K_1 k_1} u_1^2 = 0 \tag{1.2}$$

Phase I

$$\mu_2 \frac{d^2 u_2}{dy^2} + \rho_2 g \beta_2 (T_2 - T_{w2}) \sin\alpha - \left(\sigma_{e2} B_0^2 + \frac{\mu_2}{k_2}\right) u_2 = \frac{\partial p}{\partial x} \tag{1.3}$$

$$\frac{d^2 T_2}{dy^2} + \frac{\mu_2}{k_2}\left(\frac{du_2}{dy}\right)^2 + \frac{\mu_2}{K_2 k_2} u_2^2 = 0 \tag{1.4}$$

where u is the x component of fluid velocity. T is the fluid temperature, g is acceleration due to gravity and β is the coefficient of thermal expansion. The subscripts 1 and 2 denote the values of Phase I and Phase II respectively.

In reality by the experimental observations of Givler and Attobellie (1994), they are not equal. But it is assumed that the fluid viscosity and the Brinkman viscosity (i.e., effective viscosity) are same. This assumption has been made to restrict the number of parameters governing the system.

The boundary conditions an velocity are no-slip conditions requiring that the velocity must vanish at the wall. The boundary conditions on temperature are isothermal conditions. The two boundaries are held at constant different temperatures. In addition the continuity of velocity, shear stress, and temperature and heat flux at the interface between the two porous layers is assumed. The boundary conditions on velocity are

$$\begin{aligned} &u_1(h_1) = 0 \\ &u_1(0) = u_2(0) \\ &u_2(-h_2) = 0 \\ &\mu_1 \frac{du_1}{dy} = \mu_2 \frac{du_2}{dy} \quad at \quad y = 0 \end{aligned} \tag{1.5}$$

The boundary and interface conditions for temperature are

$$\begin{aligned} &T_1(h_1) = T_{w1} \\ &T_1(0) = T_2(0) \\ &T_2(h_2) = T_{w2} \\ &K_1 \frac{dT_1}{dy} = K_2 \frac{dT_2}{dy} \quad at \quad y = 0 \end{aligned} \tag{1.6}$$

4. Non-dimensionalization of the flow quantities

We introduce the following non dimensional quantities to make basic equations and boundary conditions dimensionless

$$u_1^* = \frac{u_1}{\overline{u_1}}, \quad u_2^* = \frac{u_2}{\overline{u_1}}, \quad y_1^* = \frac{y_1}{h_1}, \quad y_2^* = \frac{y_2}{h_2}, \quad \theta = (T - T_{w2}) / \Delta T$$

$m=\frac{\mu_1}{\mu_2}, \qquad K=\frac{K_1}{k_2},$

$h=\frac{h_2}{h_1}, \quad n=\frac{\rho_2}{\rho_1}, \quad b=\frac{\beta_2}{\beta_1}, \quad k=\frac{k_1}{k_2}$

$Da_1=\frac{k_1}{h_1^2}, \qquad Da_2=\frac{k_2}{h_2^2},$

$\frac{\sigma_{e2}}{\sigma_{e1}}=\alpha,$

In the view of the above non-dimensional quantities the equations (1.1) to (1.4) take the following form after dropping asterisks;

Phase I

$$\frac{d^2u_1}{dy^2}+\left(\frac{Gr}{\mathrm{Re}}\right)Sin\alpha\theta_1-\left(\frac{1}{Da_1}+M^2u_1\right)u_1=P \tag{1.8}$$

$$\frac{d^2\theta_1}{dy^2}+\Pr Ec\left(\frac{du_1}{dy}\right)^2+\frac{\Pr Ec}{Da}u_1^2=0 \tag{1.9}$$

Phase II

$$\frac{d^2u_2}{dy^2}+\frac{Gr}{\mathrm{Re}}Sin\alpha\, u_2-b^2u_2=mp \tag{1.10}$$

$$\frac{d^2\theta_2}{dy^2}+\Pr Ec\frac{k}{m}\left(\frac{du_2}{dy}\right)^2+\frac{\Pr EcK}{m.Da_2}u_2^2=0 \tag{1.11}$$

where

$b^2=\frac{k}{Da}+\alpha mM^2$

$Gr=\frac{g\beta_1h_1^3\Delta T}{v_1^2}$

$\Pr=\mu_1c_p/k_1$

$\mathrm{Re}=\overline{u}_1h_1/v_1$

$\sigma=\frac{h_1}{\sqrt{k_1}}$

$Ec=\left(\overline{u_1}\right)^2/c_p\Delta T$

$P=h_1^2\left(\frac{\partial p}{\partial x}\right)/\mu_1\overline{u_1}$

The non dimensional term of the velocity, temperature boundary and interface conditions (3.5) and (3.6) becomes (asterisks are neglected hereafter).

$$u(1)=0,u_1(0)=u_2(0),u_2(-1)=0$$

$$\frac{du_1}{dy}=1/mh\frac{du_2}{dy}\quad at\quad y=0 \tag{1.12}$$

and

$$\theta_1(1)=1,\theta_1(0)=\theta_2(0),\theta_2(-1)=0$$

$$\frac{d\theta_1}{dy}=\frac{1}{kh}\frac{d\theta_2}{dy}\quad at\quad y=0 \tag{1.13}$$

5. Solution of the problem

The governing equations of momentum (1.8) , (1.10) along with the energy equations (1.9) , (1.11) are solved subject to the boundary and interface conditions (1.12) and (1.13) from the velocity and temperature distributions. In this case the equations are coupled and nonlinear because of buoyancy force and the inclusion of the dissipation terms in the energy equation. In many practical problems the Eckert number is very small and is of order 10^{-5} so the product $\Pr.Ec=(\varepsilon)$ is very small and can be exploited to apply the regular perturbation method in view of this the solutions are assumed in the form

$$(u_i,\theta_i)=(u_{i0},\theta_{i0})+\varepsilon(u_{i1},\theta_{i1})+....... \tag{1.14}$$

Where $i=1,2\ldots.u_{i0},\theta_{i0}$ are solutions for the ε equal to zero. u_{i1},θ_{i1} are perturbed quantities to u_{i0},θ_{i0} respectively. Substituting the above identities in equations (1.8) – (1.11) are equating the coefficients of like powers of ε to zero we obtain the zeroth and first order equations as follows:

Phase I

Zeroth – order equations

$$\frac{d^2u_{10}}{dy^2}+\left(\frac{Gr}{\mathrm{Re}}Sin\alpha\right)\theta_{10}-a^2u_{10}=P \tag{1.15}$$

$$\frac{d^2\theta_{10}}{dy^2}=0 \tag{1.16}$$

First – order equations

$$\frac{d^2u_{11}}{dy^2}+\left(\frac{Gr}{\mathrm{Re}}Sin\alpha\right)\theta_{11}-a^2u_{11}=P \tag{1.17}$$

$$\frac{d^2\theta_{11}}{dy^2}+\left(\frac{du_{10}}{dy}\right)^2+\frac{1}{Da}u_{10}^2=0 \tag{1.18}$$

Phase II

Zeroth – order equations

$$\frac{d^2u_{20}}{dy^2}+\frac{Gr}{\mathrm{Re}}Sin\alpha\theta_{20}-b^2u_{20}=mp \tag{1.19}$$

$$\frac{d^2\theta_{20}}{dy^2}=0 \tag{1.20}$$

First order equations

$$\frac{d^2u_{21}}{dy^2}+\frac{Gr}{\mathrm{Re}}\theta_{21}Sin\alpha-b^2u_{21}=0 \tag{1.21}$$

$$\frac{d^2\theta_{21}}{dy^2}+\frac{k}{m}\left(\frac{du_{20}}{dy}\right)^2+\frac{k}{m}\frac{1}{Da_2}(u_{20})^2=0 \tag{1.22}$$

The corresponding boundary and interface conditions (1.12) and (1.13) reduce to

$$u_{10}(1)=0$$
$$u_{10}(0)=u_{20}(0)$$
$$u_{20}(-1)=0 \tag{1.23}$$
$$\frac{du_{10}}{dy}=\frac{1}{mh}\frac{du_{20}}{dy} \quad at \quad y=0$$
$$\theta_{10}(1)=1$$
$$\theta_{10}(0)=\theta_{20}(0)$$
$$\theta_{20}(-1)=0 \tag{1.24}$$
$$\frac{d\theta_{10}}{dy}=\frac{1}{kh}\frac{d\theta_{20}}{dy} \quad at \quad y=0$$
$$u_{11}(1)=0$$
$$u_{11}(0)=u_{21}(0)$$
$$u_{21}(-1)=0 \tag{1.25}$$
$$\frac{du_{11}}{dy}=\frac{1}{mh}\frac{du_{21}}{dy} \quad at \quad y=0$$
$$\theta_{11}(1)=0$$
$$\theta_{11}(0)=\theta_{21}(0)$$
$$\theta_{21}(-1)=0$$
$$\frac{d\theta_{11}}{dy}=\frac{1}{kh}\frac{d\theta_{21}}{dy} \quad at \quad y=0 \tag{1.26}$$

Solutions of the zero-order equations (1.15) , (1.16), (1.19) and (1.20) subject to the boundary conditions (1.23) and (1.24) are

$$\theta_{10}=\frac{y+kh}{kh+1} \tag{1.27}$$
$$\theta_{20}=\frac{kh(y+1)}{(kh+1)} \tag{1.28}$$
$$u_{10}=B_1\cosh ay+B_2 Sinhay+\frac{1}{a^2}(a_1y+a_2) \tag{1.29}$$
$$u_{20}=B_3 coshay+B_4\sinh ay-\frac{1}{b^2}(a_3y+a_4) \tag{1.30}$$

Solution of the first order perturbation equations (1.17), (1.18), (1.21) and (1.22) subject to the boundary conditions (1.25) and (1.26) are

$$\theta_{11}=a_{19}\cosh ay+a_{20}\sinh ay2ay+a_{21}y\sinh ay+a_{22}ycoshay$$
$$+a_{23}\cosh ay+a_{24}\sinh ay+a_{25}y^4+a_{26}y^3+a_{27}y^2+E_1y+E_2 \tag{1.31}$$
$$\theta_{21}=f_1\cosh 2by+f_2\sinh 2by+f_3y\cosh by+f_4y\sinh by+f_5\cosh by+$$
$$f_6\sinh by+f_7y^4+f_8y^3+f_9y^2+d_1y+d_2 \tag{1.32}$$
$$U_{11}=A_1\cosh ay+A_2\sinh ay+g_1\cosh 2ay+g_2\sinh 2ay+g_3y^2\cosh ay$$
$$+g_4y^2\sinh ay+g_5y\cosh ay+g_6y\sinh ay+g_7y^4+g_8y^3+g_9y^2+g_{10}y+g_{11} \tag{1.33}$$
$$U_{21}=A_3\cosh by+A_4\sinh by+e_1\cosh 2by+e_2\sinh 2by+e_3y^2\sinh by$$
$$+e_4y^2\cosh by+e_5y\cosh by+e_6y\sinh by+e_7y^4+e_8y^3+e_9y^2+e_{10}y+e_{11} \tag{1.34}$$

where

$$c_1=\frac{c_3}{kh},\ c_3=\frac{kh}{kh+1},\ c_1=c_3, c_2=c_4$$
$$a_1=-\frac{G_r}{\mathrm{Re}}Sin\phi\, c_1,\ a_2=p-\frac{G_r}{\mathrm{Re}}Sin\phi\, c_2$$
$$a_3=-\frac{G_r}{\mathrm{Re}}Sin\phi\, mn\beta h^2c_3,\ a_4=mph^2-\frac{G_r}{\mathrm{Re}}Sin\phi\, mn\beta h^2c_4$$
$$a_5=B_2Sinha+B_3Cosha,$$
$$a_6=B_2Sinha\,Coshb+B_4Sinhb\,Cosha$$
$$a_7=-\left(-\frac{a_3}{b^2}+\frac{ma_1h}{a^2}\right)Sinha\,Coshb+maha_6$$
$$a_8=\frac{1}{b\sinh a\cosh b+mah\sinh b\cosh a}$$
$$B_1=-\frac{Sinha}{Cosha}(B_2)+\frac{(a_1+a_2)}{a^2Cosha}$$
$$B_2=\frac{1}{mah}\left[bB_4-\frac{a_3}{b^2}+\frac{mha_1}{a^2}\right]$$
$$B_3=B_1+\frac{a_4}{b^2}-\frac{a_2}{a^2},\ B_4=a_7a_8$$
$$a_9=-\left(a^2B_1^2+\frac{B_2^2}{Da}\right),\ a_{10}=-\left(a^2B_2^2+\frac{B_1^2}{Da}\right)$$
$$a_{11}=-\left(a^2B_1B_2+\frac{B_1B_2}{Da}\right), a_{12}=-\left(2\frac{a_1}{a}B_1-\frac{2B_2a_2}{a^2}\right)$$
$$a_{13}=-\left(2\frac{a_1}{a}B_2-\frac{2B_1a_2}{a^2}\right),\ a_{14}=-\frac{a_1^2}{a^4(Da)}$$
$$a_{15}=-\frac{2a_1a_2}{a^4(Da)},\ a_{16}=\frac{2a_1B_2}{a^2(Da)}$$
$$a_{17}=\frac{2a_1B_1}{a^2(Da)},\ a_{18}=-\left[\frac{a_1^2}{a^4}+\frac{1}{Da}\frac{a_2^2}{a^4}\right]$$
$$a_{19}=\frac{a_9}{8a^2}+\frac{a_{10}}{8a^2},\ a_{20}=\frac{a_{11}}{4a^2},\ a_{21}=\frac{a_{12}}{a^2},$$
$$a_{22}=\frac{a_{13}}{a^2},\ a_{23}=\frac{a_{14}}{a^2}-\frac{2a_9}{a^3},\ a_{24}=\frac{a_9}{a^2}-\frac{2a_{11}}{a^3}$$
$$a_{25}=\frac{a_{14}}{12},\ a_{26}=\frac{a_{15}}{6}, a_{27}=-\frac{a_9}{4}+\frac{a_{10}}{4}+\frac{a_{11}}{2}$$
$$r_1=-\frac{k}{m}\left(b^2B_2^2+\frac{B_4^2}{Da}\right),\ r_2=-\frac{k}{m}\left(b^2B_4^2+\frac{B_3^2}{Da}\right)$$
$$r_3=-\frac{k}{m}\left(b^2+\frac{B_3B_4}{Da}\right),\ r_4=\frac{k}{m}\left(\frac{2a_3B_3}{b^2Da}\right)$$
$$r_5=-\frac{k}{m}\left(\frac{2a_3B_4}{b^2Da}\right),\ r_6=-\frac{k}{m}\left(-\frac{2a_3}{b}+\frac{2a_4B_3}{b^2Da}\right)$$
$$r_7=-\frac{k}{m}\left(-\frac{2a_3}{b}+\frac{2a_4B_4}{b^2Da}\right),\ r_8=-\frac{k}{m}\left(\frac{a_3^2}{b^4Da_2}\right)$$
$$r_9=-\frac{k}{m}\left(\frac{a_3^2}{b^4}+\frac{a_4^2}{b^4Da_2}\right),$$
$$f_1=\frac{r_1+r_2}{4b^2},\ f_2=\frac{r_3}{4b^2},\ f_3=\frac{r_4}{b^2}$$
$$f_4=\frac{r_5}{b^2},\ f_5=-\frac{2r_5}{b^3}+\frac{r_6}{b^2},$$
$$f_6=-\frac{2r_4}{b^3}+\frac{r_7}{b^2},\ f_7=\frac{r_8}{12}\cdot\ f_8=\frac{r_9}{6},\ f_9=-\frac{r_1}{2}+\frac{r_2}{2}+\frac{r_{10}}{2}$$

$$e_1 = \frac{sf_1}{3b^2}, e_2 = \frac{sf_2}{3b^2}, e_3 = \frac{sf_3}{4b}, e_4 = \frac{sf_4}{4b}$$

$$e_5 = \frac{sf_6}{2b} - \frac{sf_3}{4b^2}, e_6 = \frac{sf_5}{2b} - \frac{sf_4}{4b^2}$$

$$e_7 = -\frac{sf_7}{b^2}, e_8 = -\frac{sf_8}{b^2}, e_9 = -\frac{12 f_7 s}{b^4} - \frac{sf_9}{b^2}$$

$$j_1 = -\frac{6sf_8}{b^4} - \frac{sE_3}{b^2},\ j_2 = -\frac{24sf_7}{b^6} - \frac{2sf_9}{b^4} + \frac{se_4}{b^2}$$

$$g_1 = \frac{st_1}{3a^2}, g_2 = \frac{st_2}{3a^2}, g_3 = \frac{st_3}{4a}, g_4 = \frac{st_4}{4a}$$

$$g_5 = \frac{st_5}{2a} - \frac{st_3}{4a^2}, g_6 = \frac{st_6}{2a} - \frac{st_4}{4a^2}, g_7 = -\frac{st_7}{a^2}$$

$$g_8 = -\frac{st_8}{a^2}, g_9 = -\frac{12st_7}{a^4} - \frac{st_9}{a^2}$$

$$F_1 = mah\cosh a,\ F_2 = b\sinh a$$

$$F_3 = \cosh b,\ F_4 = -\sinh b$$

$$J_1 = mah\ I_5 - I_4\ Sinha$$

$$I_5 = I_1 - I_3 Cosha$$

$$A_3 = \frac{F_2 I_2 - F_4 J_1}{F_1 F_4 - F_2 F_3},\ A_4 = \frac{F_3 J_1 - F_1 I_2}{-F_2 F_3 + F_1 F_4}$$

$$A_1 = A_3 - I_3\ A_2 = -\frac{(I_1 + A_1 Cosha)}{Sinha}$$

6. Deductions and discussions

An analytic solution for convection flow and heat transfer for a composite fluid saturated inclined porous layer is obtained using the regular perturbation method. The flow is modeled with the Darcy – Lapwood - Brinkman equation. The viscous and Darcy dissipation terms are included in the energy equation. The product $\Pr.Ec(=\in)$ is used as a perturbation parameter.

The effect of the ratio of the heights of the two porous layers on velocity field is shown in fig. (1.2). for fixed K = 1, L = 5, $\theta = \pi/4, Da = 3, \alpha = 2, P = 0.5, m = 2, M = 2, K = 2, \in = 0.01, n = 0.1$. We observe that the larger the height of the upper phase compared to the lower phase the smaller the velocity of the fluid flow between the parallel plates.

The effect of the Grashoff number on velocity field is shown in fig. (1.3) for fixed K=2, Da=5, $\theta = \pi/4$, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1. The effect of increasing Grashoff number is to increase the convective motion. Physically an increase is the value of the Grashoff number means on increase of buoyancy for which supports the motion.

The effect of Darcy number on the velocity field is shown in figure (1.4) for fixed K=2, L=3, $\theta = \pi/4$, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1. increasing the Darcy number increases the velocity fields.

The velocity distribution for different inclination angles is shown in fig. (1.5) for fixed K=2, L=5, Da=5, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1. We observed that the increase in the inclination angle increase the flow.

In figure (1.6) for fixed K = 1, L = 5, $\theta = \pi/4, Da = 3, \alpha = 2, P = 0.5, m = 2, M = 2, K = 2, \in = 0.01, n = 0.1$, we find that an increase in the ratio of the permeabilities decreases the velocity fields.

The effect of Groshoff number on the velocity field is shown in fig.3. We observe that the effect of increasing Grashoff number is to increase the convective motion. An increase in the value of Grashoff number. Physically means an increase of buoyancy force which supports the motion.

The effect of Darcy Number on the temperature field as shown in fig. (1.7). for fixed K=1, L=5, $\theta = \pi/4$, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1. It is observe that an increase in the value of Darcy number increases the temperature field.

The effects of the ratio of the heights of the two porous layers on the temperature field is shown in fig (1.8) for fixed K=1, L=5, $\theta = \pi/4$, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1 ,Da=3. It is observed that an increase in the ratio of heights of the porous layers.

The effects of temperature profiles for different values of the ratio of the permeabilities is discussed in fig. (1.9) for fixed L=5, $\theta = \pi/4$, α =2, p=0.5, m=2, M=2, k=1, $\in = 0.01$, n=0.1, Da=3. Increasing the ratio of permeabilities increases an increasing in the temperature.

In fig (1.10) we observe that the temperature increases from the lower plate y=-1, to upper plate y=1. For fixed y, the temperature increases L i.e. increasing with the ratio of G_r and R_e .

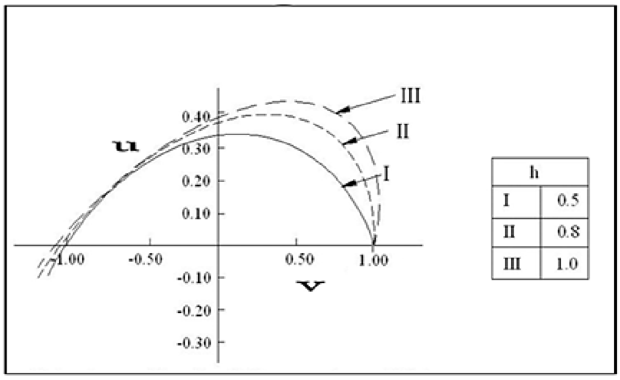

Fig.2

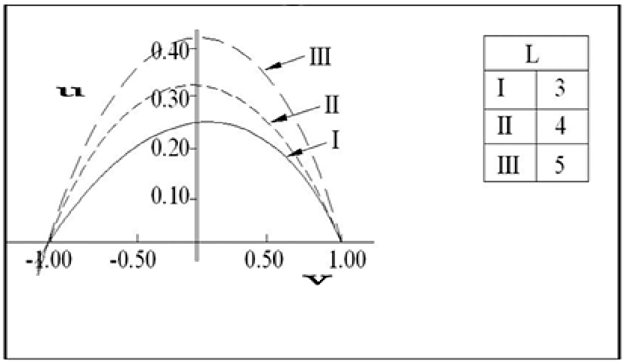

Fig.3

From in Fig. (1.11) we observe that the temperature increases with increasing θ for a given value of angle of inclination ϕ, for fixed y, temperature increases with increasing ϕ.

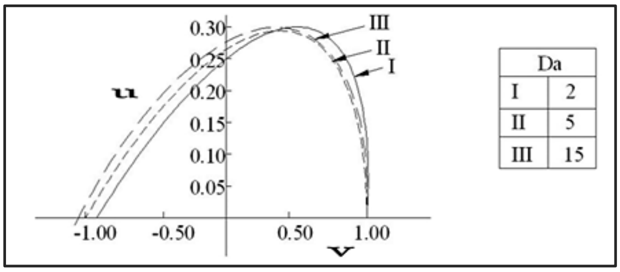

Fig.4

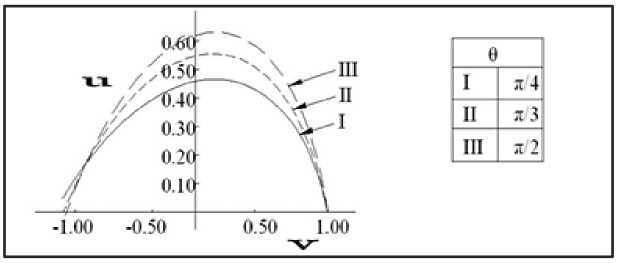

Fig.5

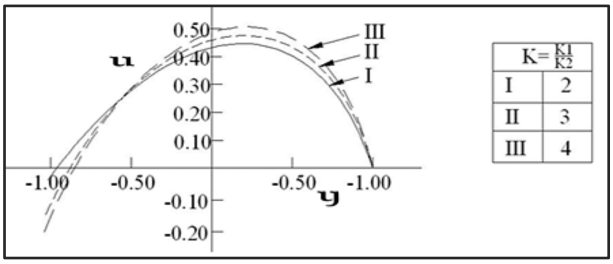

Fig.6

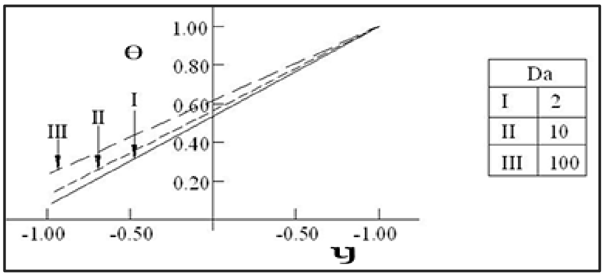

Fig. 7

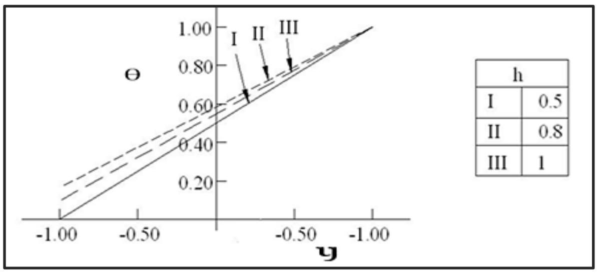

Fig.8

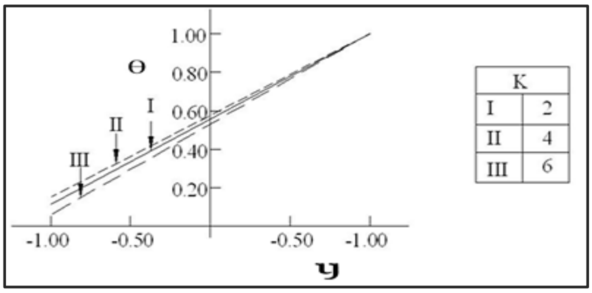

Fig.9

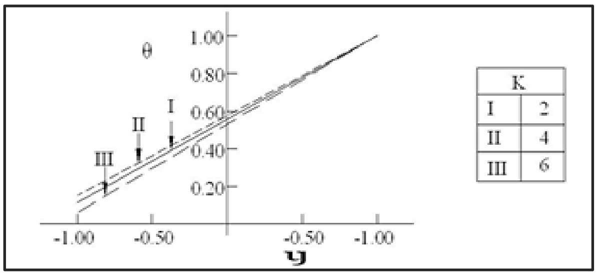

Fig. 10

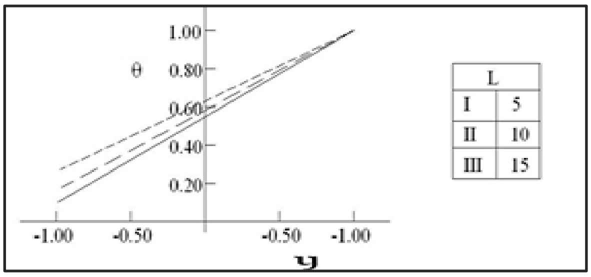

Fig. 11

References

Combarnous, M.A. and Bories, S.A. (1975), Hydrothermal convection in saturated porous media, Adv. Hydrosci.. vol. 10. pp. 231 – 307.

Cheng, P. (1978), Heat transfer in geothermal systems. Adv. Heat Transfer, vol.14, pp. 1-105.

Rudraiah, N. (1984), Non-liner convection in a porous medium with convective acceleration and viscous force, Arab, J. Sci. Engng., vol.9, pp.153-167.

Nield, D.A. (1984), Recent research on convection in a porous medium, Convection Flow in Porous Media, edited by Wooding and White, Proc. Seminar organized by OSIR and CSIRO Institute of Physical Science, W wairakei. New Zealand.

Prasad, V., Kulacki, F., and Keyhani, M. (1985), Natural convection in porous media, J.Fluid. Mech., vol. 150, pp. 89-119.

Beckermann, C., Viskanta, R., and Ramadhyani. A. (1986), Numerical study of non-Darcian natural convection in a vertical enclosure filled with a porous medium, Numer. Heat Transfer, vol.10, pp.557-570.

Georgiadis, J. and Catton, I. (1986), Prand number effect on Benard convection in porous media, ASME, J. Heat Transfer, vol. 108, pp. 284-290.

Lauriat, G. and Prasad, V**.,** Natural convection in a vertical porous cavity (1986), A numerical study for Brinkman – extended Darcy for mulation, Natual Convection in a Porous Media, edited by V. Prasad and N.A. Hussaian, pp.13-22, ASME, New York.

Malashetty. M.S, Umavathi. J.C, and Prathap Kumar. J (2001), Convective flow and heat transfer in an inclined composite porous medium, J. of porous medium 4 (1),pp 15-22.