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Research Article

UNSTEADY FREE AND FORCED CONVECTIVE MHD FLOW THROUGH A POROUS VERTICAL CHANNELS WITH THERMAL WAVES

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ABSTRACT
In this paper, we study the unsteady free and forced convective flow of a viscous incompressible electrically conducting fluid through a porous medium of variable permeability between two long vertical non-conducting wavy channels is by using Galerkin Method. The effect of various physical parameters on the stream function and temperature of fluid are calculated numerically and are shown through graph. The numerical values of the skin friction and Nusselt number are calculated for various parameters.

Key Words: *Unsteady Convective Flow, Hartmann Number, Prandtl Number, Grashof Number, Source / Sink Parameter and Skin-friction*

INTRODUCTION
This topic has been discussed by many researchers because of their application to transpiration cooling of reentry vehicles, racket boosters, cross – hatching on ablative surface and film vaporization in combustion chambers. Probably Benjamin (1959) was the first to study the problem of a flow over a wavy wall. Lyne (1971) investigated the steady steaming generated by an oscillatory viscous flow over a wavy wall under the assumption that the amplitude of the wave is smaller than the stokes layer thickness by the method of conformal transformation. The problem of free convection in an incompressible viscous fluid bounded by long vertical wavy wall and a parallel flat wall has been investigated by Vajravelu and Sastri (1978). Vajravelu and Sastri (1980) studied the problem of natural convection heat transfer in a wavy channel. The problem of non – linear convection heat transfer and fluid flow, induced by traveling thermal waves with the different configuration of channel has been investigated by Vajravelu and Debnath (1986). Vajravelu (1989) studied the combined free and forced convection in hydro magnetic flow in a vertical wavy channel with the traveling thermal waves. Purohit and Patidar (1998) studied the problem of viscous incompressible fluid in porous medium confined between two long vertical wavy walls. The problem of unsteady free convective MHD flow of a viscous in compressible fluid in porous medium between two long vertical wavy walls was discussed by Sarangi and Jose (2004). Sarangi and Sharma (2007) studied the unsteady free and forced convective flow of a viscous incompressible electrically conducting fluid through a porous medium of variable permeability bounded by vertical channels by using multi – parameter perturbation technique.

The aim of the present paper is to investigate the combined free and forced convection unsteady convection in MHD flows through porous medium of variable permeability bounded by vertical wavy channels with thermal waves using Galerkin method.

Formulation of the Problem
Consider the two dimensional unsteady combined convective heat transfers and MHD flow of a viscous incompressible fluid through a porous medium of variable permeability between long vertical wavy walls with travelling thermal waves. Let X1-axis be in the vertical upward direction and Y1-axis be perpendicular to it. The walls are parallel to the direction of buoyancy and the wall surfaces are represented by $y1 = (d{=}a \cos \lambda 1\ x1)$ and $y1 = [-d{=}a \cos (\lambda 1\ x1{+}Ø)]$ .The permeability of the porous medium is considered to be the form $K' = K1\ [1+ \varepsilon \cos (\lambda 1\ x1 + \omega 1\ t1)]$, where K1 is the mean permeability of the porous medium, $\varepsilon(<< 1)$ the amplitude of permeability variation, ω1 and λ1 the

perturbation parameters. The fluid properties are assumed to be constant. On neglecting the viscous dissipation, the work done by pressure and induced magnetic field and on applying the Boussinesq approximation the equation governing motion and heat transfer are

$$\frac{\partial u1}{\partial x1}+\frac{\partial v1}{\partial y1}=0 \tag{1}$$

$$\rho\left(\frac{\partial u1}{\partial t1}+u1\frac{\partial u1}{\partial x1}+v1\frac{\partial u1}{\partial y1}\right)=-\frac{\partial p1}{\partial x1}+\mu\left(\frac{\partial^2 u1}{\partial x1^2}+\frac{\partial^2 u1}{\partial y1^2}\right)-\sigma B_o^2 u1+\rho g\beta\left(T1-\hat{T}1\right)-\frac{\mu u1}{K'} \tag{2}$$

$$\rho\left(\frac{\partial v1}{\partial t1}+u1\frac{\partial v1}{\partial x1}+v1\frac{\partial v1}{\partial y1}\right)=-\frac{\partial p1}{\partial y1}+\mu\left(\frac{\partial^2 v1}{\partial x1^2}+\frac{\partial^2 v1}{\partial y1^2}\right)-\frac{\mu u1}{K'} \tag{3}$$

$$\rho C_p\left(\frac{\partial T1}{\partial t1}+u1\frac{\partial T1}{\partial x1}+v1\frac{\partial T1}{\partial y1}\right)=\kappa\left(\frac{\partial^2 T1}{\partial x1^2}+\frac{\partial^2 T1}{\partial y1^2}\right)+Q \tag{4}$$

where u1, v1 are velocity components along X1 and Y1 axis, T1 is the fluid temperature,
p1, Q, K1, t1 B_0, C_p, g, σ, ρ, μ, β, $\hat{T}1$ are pressure, constant heat addition / absorption, mean permeability parameter, time, applied magnetic field, specific heat at constant pressure, acceleration due to gravity, coefficient of electric conductivity, density, viscosity, volume expansion, wall temperature respectively.
The boundary conditions are

$$u1=v1=0, T1=T11\left[1+\varepsilon\cos\left(\lambda 1x1+\omega 1t1\right)\right]=\hat{T}1 \quad \text{at} \quad y=d+a\cos\left(\lambda 1x1\right)$$

$$u1=v1=0, T1=T12\left[1+\varepsilon\cos\left(\lambda 1x1+\omega 1t1\right)\right]=\hat{T}2 \quad \text{at} \quad y=-d+a\cos\left(\lambda 1x1+\theta\right) \tag{5}$$

The boundary conditions indicate that there are traveling thermal waves moving in the negative X1-direction.
Introducing non-dimensional quantities

$$x=\frac{x1}{d}, y=\frac{y1}{d}, t=\frac{t1\nu}{d^2}, u=\frac{u1d}{\nu}, v=\frac{v1d}{\nu}, p=\frac{p1d^2}{\rho\nu^2}$$

$$T=\frac{\left(T1-\hat{T}1\right)}{\left(\hat{T}2-\hat{T}1\right)}, K=\frac{K1}{d^2}, \lambda=\lambda 1d, \omega=\frac{\omega 1d^2}{\nu}, Pr=\frac{\mu C_p}{\kappa}$$

$$\alpha=\frac{Qd^2}{\kappa\left(\hat{T}2-\hat{T}1\right)}, M^2=\frac{\sigma B_0^2\nu}{\rho d}, G=\frac{g\beta d^3\left(\hat{T}2-\hat{T}1\right)}{\nu^2}, \varepsilon=\frac{a}{d}$$

in to the equations (1) to (5), we get

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-M^2u+GT-\frac{u}{K\left(1+\varepsilon\cos\left(\lambda x+\omega t\right)\right)} \tag{6}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{v}{K\left(1+\varepsilon\cos\left(\lambda x+\omega t\right)\right)} \tag{7}$$

$$Pr\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\alpha \tag{8}$$

Where ν, Pr, α, M, G, ε, $\hat{T}2$ are kinematic viscosity, Prandtl number, heat source / sink parameter, Hartmann number, Grashof number, dimensionless amplitude parameter, wall temperature.
The corresponding boundary conditions are

$$u = v = 0,\ T = 0 \quad \text{at} \quad y = 1+\varepsilon\cos(\lambda x)$$
$$u = v = 0,\ T = 1 \quad \text{at} \quad y = -1+\varepsilon\cos(\lambda x+\theta) \tag{9}$$

Introducing the stream function U = ψ defined as $u = -\left(\frac{\partial\psi}{\partial y}\right)$ and $v = \left(\frac{\partial\psi}{\partial x}\right)$ in to the equations (6) to (9), we get

$$\psi_{yyt} + \psi_{xxt} - \psi_y\psi_{xyy} - \psi_y\psi_{xxx} + \psi_x\psi_{yyy} + \psi_x\psi_{xxy} = \psi_{xxxx} + 2\psi_{xxyy} + \psi_{yyyy}$$
$$+M^2\psi_{yy} - GT_y - \frac{\psi_{xx}}{K}\left(1-\varepsilon e^{i(\lambda x+\omega t)}\right) + \frac{\psi_x}{K}\left(\varepsilon i\lambda e^{i(\lambda x+\omega t)}\right) - \frac{\psi_{yy}}{K}\left(1-\varepsilon e^{i(\lambda x+\omega t)}\right) \tag{10}$$
$$\Pr\left(T_t - \psi_y T_x + \psi_x T_y\right) = T_{xx} + T_{yy} + \alpha \tag{11}$$

The corresponding boundary conditions are

$$\psi_x = \psi_y = 0,\ T = 0 \quad \text{at} \quad y = 1+\varepsilon\cos(\lambda x)$$
$$\psi_x = \psi_y = 0,\ T = 1 \quad \text{at} \quad y = -1+\varepsilon\cos(\lambda x+\theta) \tag{12}$$

Assume

$$\psi(x,y,t) = \psi_0(y) + \left(\varepsilon e^{i(\lambda x+\omega t)}\right)\psi_1(y)$$
$$T(x,y,t) = T_0(y) + \left(\varepsilon e^{i(\lambda x+\omega t)}\right)T_1(y) \tag{13}$$

On substituting the equation (13) in to the equations (10) to (12) and equating the coefficient of like powers of ε, we get
Zeroth order equations

$$\psi_0^{iv} - M^2\psi_0'' - GT_0' - \frac{\psi_0''}{K} = 0 \tag{14}$$
$$T_0'' + \alpha = 0 \tag{15}$$

The corresponding boundary conditions are

$$\psi_0' = 0,\ \psi_0 = 0,\ T_0 = 0 \quad \text{at} \quad y = 1$$
$$\psi_0' = 0,\ \psi_0 = 0,\ T_0 = 1 \quad \text{at} \quad y = -1 \tag{16}$$

The equations (14) and (15) are ordinary differential equations and are solved by using Galerkin method under boundary conditions (16). The solutions are given by

$$T_0 = \frac{\alpha}{2}\left(1-y^2\right) \tag{17}$$
$$\psi_0 = b_0\left(2y^2 - y^4 - 1\right) \tag{18}$$

First order equations

$$\psi_1^{iv} - i\omega\left(\psi_1'' - \lambda^2\psi_1\right) + i\lambda\psi_0'\left(\psi_1'' - \lambda^2\psi_1\right) - i\lambda\psi_1\psi_0''' - 2\lambda^2\psi_1'' + \lambda^4\psi_1$$

$$-M^2\psi_1'' - GT_1' + \frac{\lambda^2\psi_1}{K} - \frac{\psi_1''}{K} + \frac{\psi_0''}{K} = 0 \tag{19}$$

$$T_1'' - Pr\,i\omega T_1' + Pr\,i\lambda\left(\psi_0' T_1 - \psi_1 T_0'\right) - \lambda^2 T_1 = 0 \tag{20}$$

The corresponding boundary conditions are

$$\psi_1' = -\psi_0'' e^{-i\omega t}, \psi_1 = 0, T_1 = -T_0' e^{-i\omega t} \quad \text{at} \quad y = 1$$

$$\psi_1' = -\psi_0'' e^{i(\theta-\omega t)}, \psi_1 = 0, T_1 = -T_0' e^{i(\theta-\omega t)} \quad \text{at} \quad y = -1 \tag{21}$$

Assume

$$\psi_1(y) = \psi_{10} + \lambda\psi_{11}$$
$$T_1(y) = T_{10} + \lambda T_{11} \tag{22}$$

On substituting the equation (22) in to the equations (19) to (21) and equating the coefficient of like powers of λ, we get

Zeroth order equations

$$\psi_{10}^{iv} - i\omega\psi_{10}'' - M^2\psi_{10}'' - GT_{10}' - \frac{\psi_{10}''}{K} + \frac{\psi_0''}{K} = 0 \tag{23}$$

$$T_{10}'' - Pr\,i\omega T_{10} = 0 \tag{24}$$

The corresponding boundary conditions are

$$\psi_{10}' = -\psi_0'' e^{-i\omega t}, \psi_{10} = 0, T_{10} = -T_0' e^{-i\omega t} \quad \text{at} \quad y = 1$$

$$\psi_{10}' = -\psi_0'' e^{i(\theta-\omega t)}, \psi_{10} = 0, T_{10} = -T_0' e^{i(\theta-\omega t)} \quad \text{at} \quad y = -1 \tag{25}$$

First order equations

$$\psi_{11}^{iv} - i\omega\psi_{11}'' + i\psi_0'\psi_{10}'' - i\psi_{10}\psi_0''' - M^2\psi_{11}'' - GT_{11}' - \frac{\psi_{11}''}{K} = 0 \tag{26}$$

$$T_{11}'' - Pr\,i\omega T_{11} + Pr\,i\left(\psi_0' T_{10} - \psi_{10} T_0'\right) = 0 \tag{27}$$

The corresponding boundary conditions are

$$\psi_{11}' = 0,\ \psi_{11} = 0,\ T_{11} = 0 \quad \text{at} \quad y = 1$$

$$\psi_{11}' = 0,\ \psi_{11} = 0,\ T_{11} = 1 \quad \text{at} \quad y = -1 \tag{28}$$

The equations (23), (24) and (26),(27) are ordinary differential equations and are solved by using Galerkin method under boundary conditions (25),(28). The solutions are given by

$$T_{10}(y) = \left(\alpha y t_{105} + \frac{\alpha y^2}{2} t_{1011}\right) + i\left(\alpha y t_{106} + \frac{\alpha y^2}{2} t_{1012}\right) \tag{29}$$

$$\psi_{10}(y) = \left[l_{19}\left(3y^5 - 4y^3 + y\right) + l_{17}\left(y^4 - 2y^2 + 1\right) + l_{20}\left(3y^4 - 4y^2 + 1\right)\right]$$
$$+ i\left[l_{21}\left(-3y^5 + 4y^3 - y\right) + l_{18}\left(y^4 - 2y^2 + 1\right) + l_{22}\left(-3y^4 + 4y^2 - 1\right)\right] \tag{30}$$

$$T_{11}(y) = \left(t_{118} + it_{119}\right)\left(y^2 - 1\right) \tag{31}$$

$$\psi_{11}(y) = (l_{31} + il_{32})(1 - 2y^2 + y^4) \tag{32}$$

Substituting the equations (29) to (32) in to the equation (22), we get

$$\psi_1(y) = \left[l_{19}(3y^5 - 4y^3 + y) + l_{17}(y^4 - 2y^2 + 1) + l_{20}(3y^4 - 4y^2 + 1) + \lambda l_{31}(1 - 2y^2 + y^4)\right] + i\left[l_{21}(-3y^5 + 4y^3 - y) + l_{18}(y^4 - 2y^2 + 1) + l_{22}(-3y^4 + 4y^2 - 1) + \lambda l_{32}(1 - 2y^2 + y^4)\right] \tag{33}$$

$$T_1(y) = \left(\alpha y t_{105} + \frac{\alpha y^2}{2} t_{1011} + \lambda t_{118}(y^2 - 1)\right) + i\left(\alpha y t_{106} + \frac{\alpha y^2}{2} t_{1012} + \lambda t_{119}(y^2 - 1)\right) \tag{34}$$

Substituting the equations (33) & (34) in to the equation (13), we get Stream function U = ψ(y) and Temperature T(y)

$$\psi(y) = b_0(2y^2 - y^4 - 1) + \varepsilon\left[\cos(\lambda x + \omega t) + i\sin(\lambda x + \omega t)\right] \left\{\begin{array}{l}\left[l_{19}(3y^5 - 4y^3 + y) + l_{17}(y^4 - 2y^2 + 1) + l_{20}(3y^4 - 4y^2 + 1) + \lambda l_{31}(1 - 2y^2 + y^4)\right] \\ + i\left[l_{21}(-3y^5 + 4y^3 - y) + l_{18}(y^4 - 2y^2 + 1) + l_{22}(-3y^4 + 4y^2 - 1) + \lambda l_{32}(1 - 2y^2 + y^4)\right]\end{array}\right\} \tag{35}$$

$$T(y) = \frac{\alpha}{2}(1 - y^2) + \varepsilon\left[\cos(\lambda x + \omega t) + i\sin(\lambda x + \omega t)\right] \left\{\left(\alpha y t_{105} + \frac{\alpha y^2}{2} t_{1011} + \lambda t_{118}(y^2 - 1)\right) + i\left(\alpha y t_{106} + \frac{\alpha y^2}{2} t_{1012} + \lambda t_{119}(y^2 - 1)\right)\right\} \tag{36}$$

Constants expressions are not presented here for sake of brevity.

Skin Friction. The skin friction coefficients at the walls are

$$T11 = 8b_0 + 24b_0\varepsilon\cos(\lambda x) – \varepsilon\cos(\lambda x + \omega t))(36l_{19} + 8l_{17} + 28l_{20} + 8\lambda l_{31}) – \varepsilon\sin(\lambda x + \omega t))(36l_{21} - 8l_{18} + 28l_{22} - 8\lambda l_{32}) \tag{37}$$

$$T22 = 8b_0 + 24b_0\varepsilon\cos(\lambda x + \theta) – \varepsilon\cos(\lambda x + \omega t))(-36l_{19} + 8l_{17} + 28l_{20} + 8\lambda l_{31}) + \varepsilon\sin(\lambda x + \omega t))(36l_{21} + 8l_{18} - 28l_{22} - 8\lambda l_{32}) \tag{38}$$

Nusselt number. The Nusselt number at the walls are

$$N11 = - \alpha – \alpha\varepsilon\cos(\lambda x) + \varepsilon\cos(\lambda x + \omega t)(\alpha t_{101} + 2\lambda t_{18}) - \varepsilon\sin(\lambda x + \omega t)(\alpha t_{102} + 2\lambda t_{19}) \tag{39}$$

$$N22 = \alpha – \alpha\varepsilon\cos(\lambda x + \theta) + \varepsilon\cos(\lambda x + \omega t)(\alpha t_{101} + 2\lambda t_{18}) - \varepsilon\sin(\lambda x + \omega t)(\alpha t_{102} + 2\lambda t_{19}) \tag{40}$$

RESULTS AND DISCUSSION

Figure 1: In the presence of heat source: The Stream function decreases due to increase in Prandtl number, Heat source parameter. The Stream function increases due to decrease in Grashof number and increase in Hartmann number, frequency parameter. The behaviour of Stream function is reversed when y ≥ 0.

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Figure 2: In the presence of heat sink: The Stream function increases due to increase in Prandtl number and decrease in Heat sink parameter. The Stream function decreases due to decrease in Grashof number and increase in Hartmann number, frequency parameter. The behaviour of Stream function is reversed when y ≥ 0.

Figure 3: In the presence of heat source: The Temperature of fluid decreases due to increase in Heat source parameter. The Temperature of fluid increases due to increase in Prandtl number, frequency parameter. The Grashof number, Permeability parameter and Hartmann number have negligible effect on Temperature of fluid. The behaviour of Temperature of fluid is reversed when y ≥ 0.

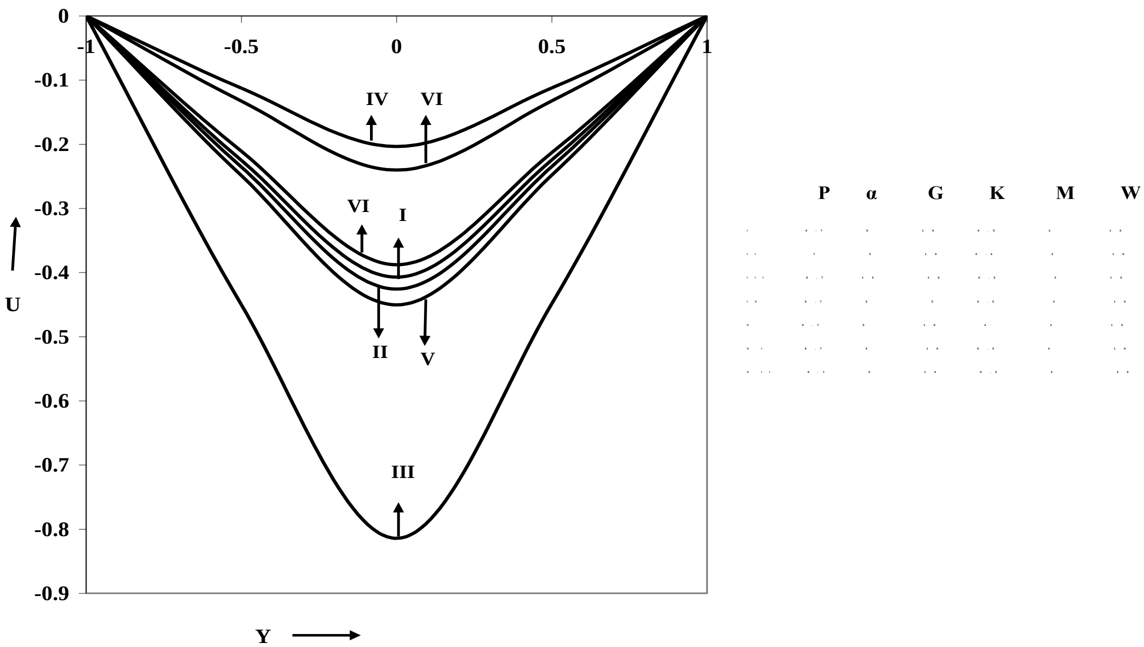

Figure 1: Stream function distribution U versus Y

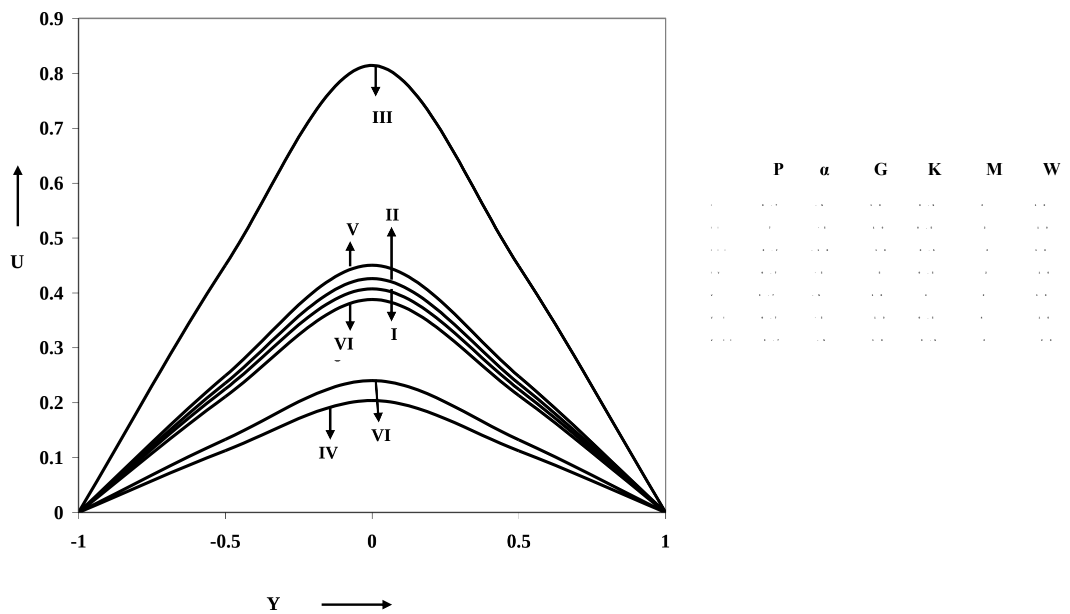

Figure 2: Stream function distribution U versus Y

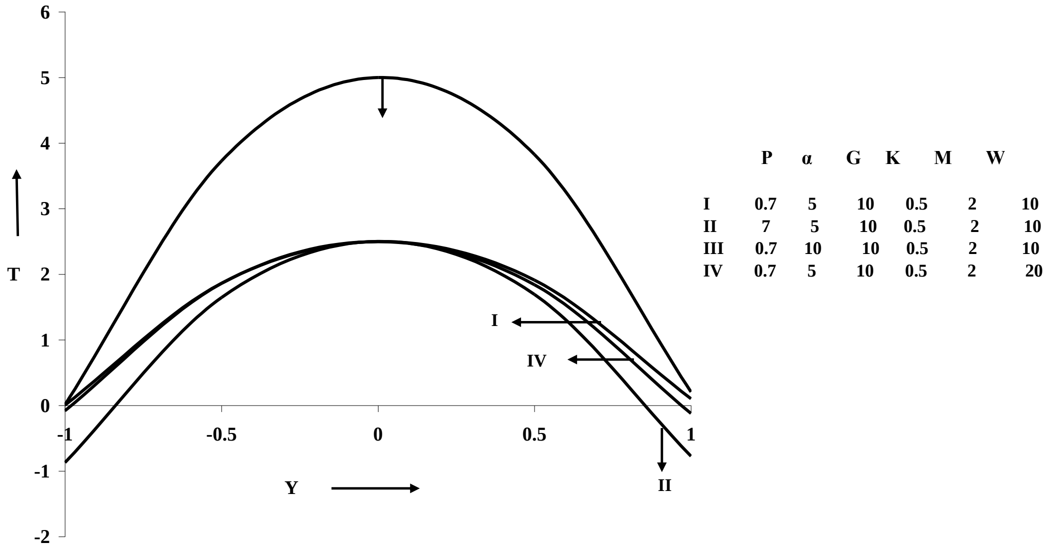

Figure 3: Temperature distribution T versus Y

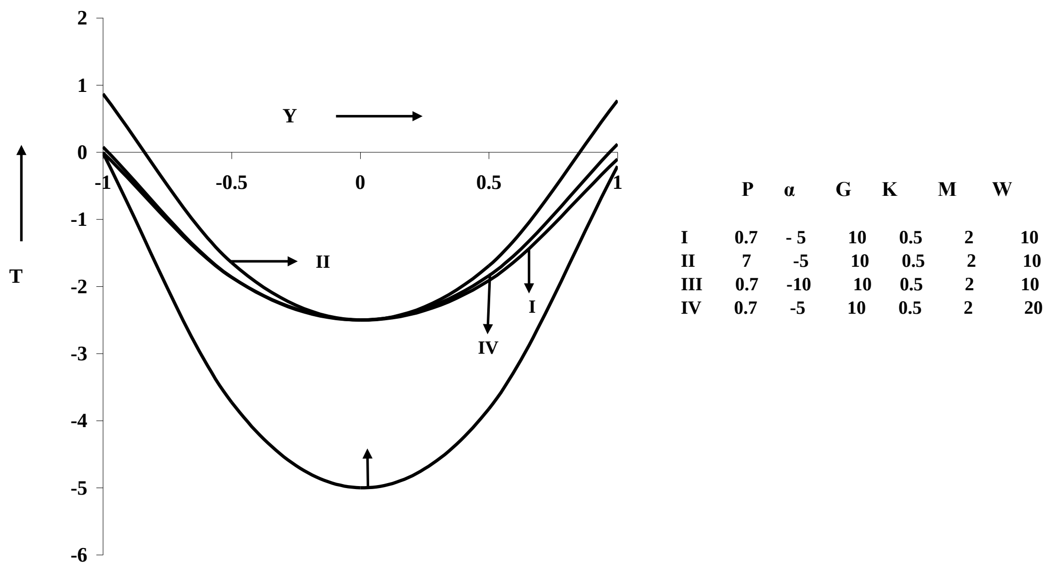

Figure 4: Temperature distribution T versus Y

Table 1: Values of Skin Friction coefficient and Nusselt number at the walls in the presence of heat source

Pr	α	G	M	K	ω	T11	T22	N11	N22
0.7	5	10	2	0.5	10	3.335083	3.644414	-4.845712	5.154288
7	5	10	2	0.5	10	3.483986	3.793316	-6.598349	3.401651
0.7	10	10	2	0.5	10	6.66909	7.28775	-9.690201	10.309799
0.7	5	5	2	0.5	10	1.667676	1.822341	-4.846018	5.153982
0.7	5	10	4	0.5	10	1.966239	2.14478	-4.846114	5.153886
0.7	5	10	2	4	10	3.689394	4.03579	-4.845477	5.154523
0.7	5	10	2	0.5	20	3.368543	3.259071	-5.155736	4.844264

Table 2: Values of Skin Friction coefficient and Nusselt number at the walls in the presence of heat sink

Pr	α	G	M	K	ω	T11	T22	N11	N22
0.7	-5	10	2	0.5	10	-3.33616	-3.645491	4.846935	-5.153065
7	-5	10	2	0.5	10	-3.484212	-3.793543	6.598132	-3.401868
0.7	-10	10	2	0.5	10	-6.673398	-7.292058	9.695094	-10.304906
0.7	-5	5	2	0.5	10	-1.667946	-1.822611	4.846629	-5.153371
0.7	-5	10	4	0.5	10	-1.96646	-2.145009	4.846533	-5.153467
0.7	-5	10	2	4	10	-3.69095	-4.037275	4.844717	-5.15283
0.7	-5	10	2	0.5	20	-3.368782	-3.25931	5.156579	-4.843421

Figure 4: In the presence of heat sink: The Temperature of fluid increases due to decrease in Heat sink parameter. The Temperature of fluid decreases due to increase in Prandtl number, frequency parameter. The Grashof number, Permeability parameter and Hartmann number have negligible effect on Temperature of fluid. The behaviour of Temperature of fluid is reversed when $y \geq 0$.

Table 1: In the presence of heat source: The Skin Friction coefficient at the wall $y = 1 + \varepsilon \cos(\lambda x)$ increases due to increase in Prandtl number, Heat source parameter, Permeability parameter, Frequency parameter. The Skin Friction coefficient at the wall $y = 1 + \varepsilon \cos(\lambda x)$ decreases due to decrease in Grashof number and increase in Hartmann number. The Skin Friction coefficient at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ increases due to increase in Prandtl number, Heat source parameter, Permeability parameter. The Skin Friction coefficient at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ decreases due to decrease in Grashof number and increase in Hartmann number, Frequency parameter.

The Nusselt number at the wall $y = 1 + \varepsilon \cos(\lambda x)$ decreases due to increase in Prandtl number, Heat source parameter, Hartmann number Frequency parameter and decrease in Grashof number. The Nusselt number at the wall $y = 1 + \varepsilon \cos(\lambda x)$ increases due to increase in Permeability parameter. The Nusselt number at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ decreases due to increase in Prandtl number, Hartmann number, Frequency parameter and decrease in Grashof number. The Nusselt number at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ increases due to increase in Heat source parameter, Permeability parameter.

Table 2: In the presence of heat sink: The Skin Friction coefficient at the wall $y = 1 + \varepsilon \cos(\lambda x)$ decreases due to increase in Prandtl number, Permeability parameter, Frequency parameter and decrease in Heat sink parameter. The Skin Friction coefficient at the wall $y = 1 + \varepsilon \cos(\lambda x)$ increases due to decrease in Grashof number and increase in Hartmann number. The Skin Friction coefficient at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ decreases due to increase in Prandtl number, Permeability parameter and decrease in Heat sink parameter. The Skin Friction coefficient at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ increases due to decrease in Grashof number and increase in Hartmann number, Frequency parameter.

The Nusselt number at the wall $y = 1 + \varepsilon \cos(\lambda x)$ increases due to increase in Prandtl number, Permeability parameter, Frequency parameter and decrease in Heat sink parameter. The Nusselt number at the wall $y = 1 + \varepsilon \cos(\lambda x)$ decreases due to decrease in Grashof number and increase in Hartmann number. The Nusselt number at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ increases due to increase in Prandtl number, Permeability parameter, Frequency parameter. The Nusselt number at the wall $y = -1 + \varepsilon \cos(\lambda x + \theta)$ decreases due to increase in Hartmann number and decrease in Heat source parameter, Grashof number.

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