ISSN 2229-5518

OSCILLATORY HYDROMAGNETIC FREE CONVECTIVE FLOW OF A VISCO-ELASTIC FLUID PAST AN INFINITE VERTICAL POROUS FLAT PLATE WITH HALL EFFECT

A.P. Mishra[1], G.S. Roy[2] and S.Biswal[3] , S.S.S. Mishra[4] and A.Mishra[5]

1 **Research Scholar, Institute of Mathematics and Applications, Bhubaneswar, India**
2 **Former Professor of Physics, Plot. 6, Bhudeswari Colony, BBSR, India**
3 **Former Professor of Physics, SERC, BBSR, India**
4 **Department of Physics, UGS Mahvidyalaya, Sakhigopal, Puri, India**
5 **Dept. Physics, A.D. Mohavidyalaya, Brahmagiri, Puri, India**

ABSTRACT:

Hall effect on Oscillatory hydromagentic free convective flow of a visco-elastic fluid past an infinite vertical porous flat plate has been studied with numerical and computational analysis. The constitutive equations of continuity, velocity components and temperature of the visco-elastic fluid under consideration are obtained in Cartesian co-ordinates pertaining to the physical situations of the problem. These equations have been solved by using complex variable technique. Expressions for velocity, temperature, shear stress and the rate of heat transfer are obtained. Velocity and temperature profiles are shown in graphs where as the values of the skin-friction and the Nusselt number are entered in tables for variour values of the fluid parameters R_c, m, G, P_r and Ω. It is observed that the Hartmann number, Hall parameter, Grashof number, Prandtl number, Elastic parameter and the frequency parameter influence the flow field to a great extent. Temperature of the field is measurably affected by the heat absorbing sink. The permeability parameter produces a reverse effect as regards to that of the magnetic parameter.

1. INTRODUCTION

Hydromagnetic free convection problems have a wide range of applications such as relevancy in a global general circulation with convection in equatorial zones. Further, the study of effects of Hall currents on fluid flow and heat transfer has a lot of applications in cooling of nuclear reactor, MHD power generation and in several astrophysical studies.

The problem of unsteady free convection flow along a vertical flat plate in the presence of an applied magnetic field is of general interest from the view point of many applications such as in space flight and nuclear fusion research. The literature is replete with many examples of such studies. A few of them are the works of Gupta[1], Singh2, Chawla[3], Pop[4], Hassain[5], Hossain and Mohammed[6] and Hossain and Rashid[7]. Hall effect on oscillatory hydromagnetic free convective flow past an infinite vertical porous flat plate has been analysed by Mohapatra and Tripathy[8].

When the magnetic field is very strong, one can not neglect the effect of Hall current. In the hydromagnetic flow, the Hall effect rotates the current vector away from the direction of the electric field and generally reduces the effect of the force that the magnetic field exerts on the flow. All the works mentioned above are only based upon the studies of the effects of Hall current on MHD free convective viscous flow. But the effect of Hall current on the unsteady hydromagnetic visco-elastic flow has wide applications in the problems of the MHD generators and the Hall accelerators as with the case of Newtonian fluid. Consequently recent studies on the magnetohydrodynamic unsteady visco-elastic flow with the Hall current attracted many research scholars to investigate various such problems with different physical situations. Dash and Ojha[9] have studied the hydromagnetic flow and heat transfer of an elastico-viscous fluid over a porous plate in the slip flow regime. Soundalgekar[10] has investigated the free convection effect on the Stokes problem for a vertical plate in elastico-viscous fluid without imposition of an external magnetic field. Dash and Biswal[11] have studied the free convection effect of the flow of an elastico-viscous fluid past an exponentially accelerated vertical plate in the absence of magnetic field. In all these papers, the effect of Hall current has not been taken into account though the presence of external magnetic field and the Hall current produce enormous physical situations to be analysed. As the flow characteristics of both Newtonian and non-Newtonian fluids are changed with the application of magnetic field as well as the effect of Hall current on it, Biswal and Pattnaik[12] have analysed the effect of Hall current on oscillatory hydromagnetic free convective flow of a visco-elastic fluid past an infinite vertical porous flat plate. But, they have not taken the permeability of the porous medium into consideration, though the porosity affects the flow field to a great extent. The object of the present paper is to study the oscillatory hydromagnetic free convective flow of a viscoelastic fluid past an infinite vertical porous flat plate with Hall effect including the permeability of the porous medium.

2. FORMULATION OF THE PROBLEM

The vertical porous flat plate is considered to be perpendicular to the plane of this paper. The X-axix is chosen along the vertical plate while the Y-axis is normal to it. The Z-axis lies on the plate perpendicular to both x and y axis.

Under such a physical situation, we write the equation of continuity as

$$\frac{\partial V}{\partial Y} = 0 \tag{2.1}$$

Which yields V = –V_0 (constant), $V_0 > 0$, where V is the fluid velocity along Y-axis. Since the electrically conducting fluid taken here for consideration is assumed to be incompressible and an external uniform transverse magnetic field is applied to it, we write

$$\text{div } \vec{H} = 0 \text{ and div } \vec{J} = 0 \tag{2.2}$$

which implies $\frac{\partial H_y}{\partial Y} = 0$ and $\frac{\partial J_y}{\partial y} = 0$ respectively.

Neglecting the polarization effect and the induced magnetic field, we have

$$\vec{E} = 0$$

and $H_x = H_z = 0$, respectively

while H_Y = Constant = H_0

Thus, $\vec{J} = (J_x, 0, J_z)$

$$\vec{H} = (0, H_0, 0)$$

$$\vec{V} = (u, -V_0, w) \tag{2.3}$$

As the effect of Hall current is taken into the purview of discussion, the Ohm's law is modified and is represented as

$$\vec{J} + \frac{\omega_e \tau_e}{B_0}\left(\vec{J} \times \vec{B}\right) = \sigma\left(\vec{E} + \vec{V} \times \vec{B} + \frac{1}{en_e}\nabla P_e\right) = \sigma\left(\vec{E} + \vec{V} \times \vec{B} + \frac{1}{en_e}\nabla P_e\right) \tag{2.4}$$

Where ω_e is the cyclotron frequency,

τ_e is the electron collision time,

σ is the electrical conductivity of the fluid e is the charge of an electron

n_e is the number density of electrons

P_e is the electron pressure

$B_0(=\mu_e H_0)$ is the magnetic field induction

μ_e is the magnetic permeability

$\vec{J}$ is the current density vector

$\vec{E}$ is the electric field

And $\vec{B}$ is the induced magnetic field

Equations (2.3) and (2.4) yield

$$\left.\begin{aligned} J_x &= \frac{\sigma B_0}{1+m^2}(mu - w) \\ J_z &= \frac{\sigma B_0}{1+m^2}(u - mw) \end{aligned}\right\} \tag{2.5}$$

Where m = $\omega_e \tau_e$, is the Hall parameter.

The governing equations are now obtained as follows:

Equation of motion along X-axis is

$$\frac{\partial u}{\partial t} - V_0 \frac{\partial u}{\partial y} = v\frac{\partial^2 u}{\partial y^2} - K_0 \frac{\partial^3 u}{\partial y^2 \partial t} - \frac{\sigma B_0^2 (u + mw)}{\rho\left(1+m^2\right)} + g\beta\theta + \frac{v}{K'}u \tag{2.6}$$

Equation of motion along z-axis is

$$\frac{\partial w}{\partial t} - V_0 \frac{\partial w}{\partial y} = v\frac{\partial^2 w}{\partial y^2} - K_0 \frac{\partial^3 w}{\partial y^2 \partial t} + \frac{\sigma B_0^2 (mu - w)}{\rho\left(1+m^2\right)} \tag{2.7}$$

and equation of energy is

$$\frac{\partial \theta}{\partial t} - V_0 \frac{\partial \theta}{\partial y} = \frac{K}{\rho C}\frac{\partial^2 \theta}{\partial y^2} \tag{2.8}$$

where u is the x-component of flow velocity

w is the z-component of flow velocity

v is the kinematic viscosity (μ/ρ)

μ is the co-efficient of viscosity of the fluid

ρ is the density of the fluid

g is the acceleration due to gravity

K_0 is the Bulk modulus of elasticity of the fluid

K is the thermal conductivity of the fluid

β is the free convection term

ISSN 2229-5518

C is the specific heat at constant pressure

K' is the permeability of porous medium

And θ is the nondimensional temperature defined as

θ (y, t) = T (y, t) – T_∞, T_∞ being the temperature of the fluid far away from the plate while T being the reference temperature.

In equation (2.8) the viscous dissipation term has been neglected because small velocities are usually encountered in free convection flows. The Joulean dissipation being of the same order has also been neglected. Introducing the following non-dimensional variables.

$$\left.\begin{aligned} &\eta=\frac{V_0 y}{v},\ t'=\frac{V_0^2 t}{4v},\ u'=\frac{u}{V_0},\ w'=\frac{w}{V_0}, \\ &\theta'=\frac{\theta}{a}\ (a,\text{ to be defined later}) \\ &G=\frac{4g\beta v a}{V_0^3},\ M=\frac{4B_0^2\sigma v}{\rho V_0^3},\ P_r=\frac{v\rho C}{K},\ R_c=K_0\frac{V_0^2}{v^2},\ K^*=K'V_0^2/v^2 \end{aligned}\right\} \quad (2.9)$$

Where η, G, M, P_r, R_c K^* are the modified y-co-ordinate, Grashof number, Hartmann number. Prandtl number, elastic parameter and permeability factor respectively. The equations (2.6) to (2.8) are transformed to their corresponding non-dimensional forms (dropping the dashes) as

$$\frac{\partial u}{\partial t}-4\frac{\partial u}{\partial \eta}=4\frac{\partial^2 u}{\partial \eta^2}-R_c\frac{\partial^3 u}{\partial \eta^2 \partial t}-\frac{\left(M+1/K^*\right)}{\rho\left(1+m^2\right)}(mw+u)+G\theta \quad (2.10)$$

$$\frac{\partial w}{\partial t}-4\frac{\partial w}{\partial \eta}=4\frac{\partial^2 w}{\partial \eta^2}-R_c\frac{\partial^3 w}{\partial \eta^2 \partial t}-\frac{\left(M+1/K^*\right)(mu-w)}{\left(1+m^2\right)} \quad (2.11)$$

$$\frac{\partial \theta}{\partial t}-4\frac{\partial \theta}{\partial \eta}=\frac{4}{P_r}\frac{\partial^2 \theta}{\partial \eta^2} \quad (2.12)$$

Which are to be solved under the boundary conditions given below

$$\left.\begin{aligned} &u(0,t)=w(0,t)=0 \\ &u(\infty,t)=w(\infty,t)=0 \\ &\theta(0,t)=a\,e^{i\omega t} \\ \text{and}\quad &\theta(\infty,t)=0 \end{aligned}\right\} \quad (2.13)$$

ISSN 2229-5518

3. Method of solution

Since, each of the governing equations of motion (2.10) and (2.11) includes both the components of velocity u and w, we assume a velocity function Ψ defined as

$$\Psi = u + iw \tag{3.1}$$

Where $i = \sqrt{-1}$, the imaginary term and then combining equations (2.10) and (2.11) we get,

$$\frac{\partial \psi}{\partial t} - 4\frac{\partial \psi}{\partial \eta} = 4\frac{\partial^2 \psi}{\partial \eta^2} - R_c \frac{\partial^3 \psi}{\partial \eta^2 \partial t} - \frac{\left(M + 1/K^*\right)}{1+m^2}(1-im)\psi + G\theta \tag{3.2}$$

Introducing the non-dimensional parameter $\Omega = \frac{4\nu\omega}{V_0^2}$, the frequency parameter and using equations (2.9) and (3.1), the boundary conditions (2.13) are transformed to (dropping the dashes)

$$\left.\begin{aligned} &\Psi(0, t) = \Psi(\infty, t) = 0 \\ &\theta(0, t) = \exp(i\Omega t) \\ &\theta(\infty, t) = 0 \end{aligned}\right\} \tag{3.3}$$

Solution of Energy Equn.

Substituting $\theta(\eta, t) = e^{i\Omega t} f(\eta)$ in equation (2.12), we obtained

$$f''(\eta) + P_r f'(\eta) - \frac{i\Omega P_r}{4} f(\eta) = 0 \tag{3.4}$$

Where the prime (/) denotes differentiation with respect to η. Equation (3.4) is a second order homogeneous differential equation which is to be solved under the boundary condition

$$\left.\begin{aligned} &f(0) = 1 \\ &f(\infty) = 0 \end{aligned}\right\} \tag{3.5}$$

Therefore, equation (3.4) with the help of equation (3.5) provides

$$f(\eta) = e^{\left[\frac{1}{2}\left(-P_r - \left(P_r^2 + i\Omega P_r\right)^{1/2}\right)\right]\eta} \tag{3.6}$$

and hence θ (η, t) becomes

$$\theta(\eta, t) = e^{\left\{i\Omega t - \eta/2\left[P_r + \left(P_r^2 + i\Omega P_r\right)^{1/2}\right]\right\}} \tag{3.7}$$

Separating the real and imaginary parts of θ (η, t), the real parts (θ_r) is given by

$$\theta_r(\eta,t) = e^{\left\{-\left(\eta/2\right)\left[P_r + R_1 Cos\left(\gamma/2\right)\right]\right\}} \text{ Cos}\left[\Omega t - \left(\frac{\eta}{2}\right) R_1 Sin\left(\frac{\gamma}{2}\right)\right] \tag{3.8}$$

Where $R_1 = P_r^{1/2}\left(P_r^2 + \Omega^2\right)^{1/4}$

$$\gamma = \tan^{-1}\left(\frac{\Omega}{P_r}\right)$$

Solution of Equation of Motion

In order to solve equation (3.2), we make the substitution $\Psi = e^{i\Omega t}F(\eta)$ here and the equation can be written as

$$\left[1 - \frac{iR_c\Omega}{4}\right]F''(\eta) + F'(\eta) - \frac{1}{4}\left[\frac{\left(M + 1/K^*\right)}{1+m^2} - i\left(\frac{\left(M + 1/K^*\right)m}{1+m^2} - \Omega\right)\right]F(\eta)$$

$$= -\frac{G}{4}\exp(-a_1\eta) \tag{3.9}$$

Where the prime (′) denotes differentiation with respect to η and

$$a_1 = \frac{1}{2}\left\{P_r + \left(P_r^2 + i\Omega P_r\right)^{1/2}\right\}$$

The corresponding boundary condition to solve the above equation is

$$\left.\begin{aligned} F(0) &= 0 \\ F(\infty) &= 0 \end{aligned}\right\} \tag{3.10}$$

Equation (3.9) is a second order inhomogeneous differential equation can be solved after evaluating its complementary function (C.F.) and particular integral parts (P.I.)

$$\text{C.F.} = C_1 e^{-a_2\eta} + C_2 e^{-a_3\eta}$$

Where $a_2 = \frac{1}{2}\left[\frac{1}{1-iA} + \sqrt{\frac{1}{(1-iA)^2} + \frac{B-iC}{(1-iA)}}\right]$

$$a_3 = \frac{1}{2}\left[\frac{1}{1-iA} - \sqrt{\frac{1}{(1-iA)^2} + \frac{B-iC}{(1-iA)}}\right]$$

$$\text{P.I.} = \frac{-Ge^{-a_1\eta}}{4(1-iA)a_1^2 - 4a_1 - (B-iC)}$$

Hence the complete solution (C.S.) of equation (3.9) is given by

C.S. = C.F. + P.I.

The constants C_1 and C_2 are evaluated with the help of the boundary conditions (3.10) and are given by

$$C_1 = \frac{G}{4(1-iA)a_1^2 - 4a_1 - (B-iC)}$$

and $C_2 = 0$

Thus F (η) is given by

$$F(\eta) = \frac{G\left(e^{-a_2\eta} - e^{-a_1\eta}\right)}{4(1-iA)a_1^2 - 4a_1 - (B-iC)} \qquad (3.11)$$

And

$$\Psi(\eta, t) = e^{i\Omega t} F(\eta) = \frac{Ge^{i\Omega t}\left(e^{-a_2\eta} - e^{-a_1\eta}\right)}{4(1-iA)a_1^2 - 4a_1 - (B-iC)} \qquad (3.12)$$

Where $A = \frac{R_c\Omega}{4}$

$$B = \frac{\left(M + \frac{1}{K^*}\right)}{1+m^2}$$

And $C = \frac{\left(M + \frac{1}{K^*}\right)}{1+m^2} - \Omega$

Applying the method of separation of real and imaginary parts in equation (3.12), it can now be put in the following from.

$$(\eta, t) = \frac{G}{A_r^2 + A_i^2}\Bigg[A_r\left(e^{\left(-\eta/2\right)a_{2r}} Cos\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{\left(-\eta/2\right)2a_{1r}} Cos\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)$$

$$+ A_i\left(e^{-\left(\eta/2\right)a_{2r}} Sin\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{-\left(\eta/2\right)2a_{1r}} Sin\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\Bigg\}$$

$$+ i\Bigg\{A_r\left(e^{-\left(\eta/2\right)a_{2r}} Sin\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{-\left(\eta/2\right)2a_{1r}} Sin\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)$$

$$- A_i\left(e^{-\left(\eta/2\right)a_{2r}} Sin\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{-\left(\eta/2\right)2a_{1r}} Sin\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\Bigg\}\Bigg] \qquad (3.13)$$

Where $a_{1r} = \frac{1}{2} R_1 \, Sin \, \frac{\gamma}{2}$

$$a_{1r} = \frac{1}{2}\left[P_r + R_1 Cos\left(\frac{\gamma}{2}\right)\right]$$

$$a_{2i} = \frac{A + AR_2 Cos\left(\delta/2\right) + R_2 Sin\left(\delta/2\right)}{1 + A^2}$$

$$a_{2r} = \frac{1 + R_2 Cos\left(\delta/2\right) + AR_2 Sin\left(\delta/2\right)}{1 + A^2}$$

$$R_2 = \left[(a + B - AC)^2 + (AB + C)^2\right]^{1/4}$$

$$\delta = \tan^{-1}\left[\frac{-(AB + C)}{(1 + B - AC)}\right]$$

$$A_i = \left(8a_{1r}a_{1i} + 4Aa_{1i}^2 - 4Aa_{1i}^2 - 4a_{1i} + C\right)$$

$$A_r = \left(8Aa_{1r}a_{1i} + 4Aa_{1i}^2 - 4Aa_{1i}^2 - 4a_{1i} - B\right)$$

Equation (3.1) and (3.13) on comparison lead to

$$u = \frac{G}{A_r^2 + A_i^2}\left[A_r\left(e^{\left(-\eta/2\right)a_{2r}} Cos\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{\left(-\eta/2\right)2a_{1r}} Cos\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\right.$$
$$\left. + A_i\left(e^{-\left(\eta/2\right)a_{2r}} Sin\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{-\left(\eta/2\right)2a_{1r}} Sin\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\right\} \quad (3.14)$$

$$w = \frac{G}{A_r^2 + A_i^2}\left[A_r\left(e^{\left(-\eta/2\right)a_{2r}} Cos\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{\left(-\eta/2\right)2a_{1r}} Cos\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\right.$$
$$\left. + A_i\left(e^{-\left(\eta/2\right)a_{2r}} Sin\left[\Omega t - \left(\eta/2\right)a_{2i}\right] - e^{-\left(\eta/2\right)2a_{1r}} Sin\left[\Omega t - \left(\eta/2\right)2a_{1i}\right]\right)\right\} \quad (3.15)$$

Once the velocity field is known, it becomes important from practical point of view to know the effect of physical parameters R_c, m, G, Ω and Ωt on the shearing stress.

The stearing stress at the wall along X-axis is given by $\tau_{xy} = \mu \frac{\partial u}{\delta y}\Big|_{y=0}$

Which can be non-dimensionalised to $\tau_1 = \frac{\partial u}{\partial \eta}\Big|_{\eta=0}$ dropping dashes. Consequently,

$$\tau_1 = \frac{G}{A_r^2 + A_i^2}\left[\frac{A_r}{2}\left\{\frac{1}{(1 + A^2)}[A \text{ Sin } \Omega t - \text{Cos } \Omega t + AR_2 \text{Sin}\left(\Omega t + \frac{\delta}{2}\right)\right.\right.$$
$$\left. - R_2 \text{ Cos}\left(\Omega t + \frac{\delta}{2}\right)\right]$$
$$+ P_r \text{ Cos } \Omega t + R_1 \text{ Cos}\left(\Omega t + \frac{\gamma}{2}\right)\Big\} + \frac{A_i}{2}\left\{-\frac{1}{(1 + A^2)}[A \text{ Cos } \Omega t + \text{Sin } \Omega t\right.$$

$$+ AR_2 \text{ Cos } \left(\Omega t + \frac{\delta}{2}\right)$$

$$+ R_2 \text{ Sin } \left(\Omega t + \frac{\delta}{2}\right)\Bigg] + P_r \text{ Sin } \Omega t + R_1 \text{ Sin } \left(\Omega t + \frac{\gamma}{2}\right)\Bigg\}\Bigg] \quad (3.16)$$

Similarly the shear stress at the wall along z-axis is given by

$$\tau_{zy} = \mu \frac{\partial w}{\partial y}\bigg|_{y=0}$$ which can be non-dimensionalised to

$$\tau_2 = \frac{\partial w}{\partial \eta}\bigg|_{\eta=0}$$ dropping dashes, Thus,

$$\tau_2 = \frac{G}{A_r^2 + A_i^2}\left[\frac{A_r}{2}\left\{-\frac{1}{(1+A^2)}\right.\right.[A \text{ Cos } \Omega t + \text{Sin } \Omega t$$

$$+ AR_2 \text{ Cos } \left(\Omega t + \frac{\delta}{2}\right) + R_2 \text{ Sin } \left(\Omega t + \frac{\delta}{2}\right)\Bigg]$$

$$+ P_r \text{ Sin } \Omega t + R_1 \text{ Sin } \left(\Omega t + \frac{\gamma}{2}\right)\Bigg\} + \frac{A_i}{2}\left\{-\frac{1}{(1+A^2)}\right.[A \text{ Sin } \Omega t$$

$$- \text{Cos } \Omega t + AR_2 \text{ Sin } \left(\Omega t + \frac{\delta}{2}\right)$$

$$- R_2 \text{ Cos } \left(\Omega t + \frac{\delta}{2}\right)\Bigg] + P_r \text{ Cos } \Omega t + R_1 \text{ Cos } \left(\Omega t + \frac{\gamma}{2}\right)\Bigg\}\Bigg] \quad (3.17)$$

Finally, the rate of heat transfer is given by

$$Q(t) = \frac{-\partial \theta_r}{\partial \eta}\bigg|_{\eta=0}$$

$$= \frac{1}{2}\,[P_r \text{ Cos } \Omega t + R_1 \text{ Cos } (\Omega t + \gamma/2)] \quad (3.18)$$

4. Results and discussion

The present investigation accounts for the variation of fluid velocities along x and z axes and the temperature filed caused due to change of various physical parameters involved here. The velocity and temperature profiles are shown graphically while the values of shear stresses and the surface heat flux are entered in the tables. All these numerical calculation are carried out with the help of the software facilities available at the computer centre of Utkal University, Bhubaneswar.

Fig. 1 shows the effects of elastic parameter R_c, Grashof number G, Hartmann number M, the Hall parameter m and the permeability factor K^* on the velocity u keeping Prandtl number P_r and frequency parameter Ω constant. It is observed that as the elastic property of the fluid increases the value of u decreases first and then starts increasing. This remarkable change occurs at the transition point η=3.5, as evident from the curves I, II and III. Grashof number influences the flow behaviour to a considerable extent since an increase in G causes the fluid velocity u to increase. Curves IV and V reveal that an increase in M has a retarding effect on u. However, Hall parameter m fully controls the flow field as enunciated from the curves V, VI and VII. The increase in m causes the primary flow velocity u to decrease and interestingly an effect opposite to it is noticed at a considerable distance from the plate. It is also marked that decrease in the permeability factor K^* produces the same effect on the velocity field as an increase in the magnetic parameter M.

Fig 2 illustrates the dependence of the z-component of velocity profile (w) on R_c, G, M and m. The elastic parameter-change causes w to vary slowly. However, a small change is noticed near the plate (η=2.0) with a sign of fall in the value of w with the rise of R_c which is reversed with the increase of η. All these results are followed from curves I, II and III. When Grashof number increases, keeping all other variables fixed, there is a sharp rise in w near the plate (curves II and IV). Rise in Hartmann number reduces the z-component of velocity but increasing the Hall parameter increases the value of w significantly (curves IV, V and VI). The above analysis are made for P_r=0.1 and Ω=1.0.

The effects of P_r and Ω on the real part of the temperature field are shown in Fig 3. It is worthy to mention here that the real part of temperature (θ_r) rises with the rise of the frequency parameter Ω and a reverse effect is observed for increasing the Prandtl number P_r. Further, the temperature falls more rapidly at distances far away from the plate with higher value of Ω.

Table 1 establishes the variation of the skin-friction at the wall along x-axis, i.e., τ_1 for various values of R_c, m, G, Ω and Ωt. The value of τ_1 decreases when the elastic parameter increases. A similar effect is also observed for the rise of Ωt. However, a reversal effect is noticed in the case of G. The τ_1 value goes on increasing with the increase in Grashof number and an exception to this arises for Ωt =2.0, where τ_1 starts reducing even though G increases. The most interesting observation from this table is that the increase in Hall parameter m, enhances the value of τ_1 for Ωt lying between 0.0 and 0.1 while the effect is opposite for Ωt > 1.0. It is further seen that when the frequency parameter Ω increases, the value of skin friction along X-axis increases with an exception occurring at Ωt = 0.0, where τ_1 reduces.

Table 1 : Effects of R_c, m, G, Ωt and Ω on the skin friction at the wall along x-axis for P_r = 0.1 and M = 3.0, K^* = 1.0

R_c	m	$G/\Omega t$	5.0	7.0	9.0	Ω
		0.0	1.7944	2.5122	3.2300	
		0.5	1.6074	2.2503	2.8933	
0.05	0.5	1.0	1.0267	1.4374	1.8481	1.0
		1.5	.1947	.2726	.3505	
		2.0	-.6849	-.9589	-1.2329	
		0.0	1.7716	2.4802	3.1889	
		0.5	1.5103	2.1144	2.7186	
0.5	0.5	1.0	.8793	1.2310	1.5827	1.0
		1.5	.0329	.0461	.0593	
		2.0	-.8215	-1.1501	-1.4787	
		0.0	2.2163	3.1029	3.9894	
		0.5	1.7609	2.4653	3.1697	
0.5	1.0	1.0	.8744	1.2242	1.5740	1.0
		1.5	-.2262	-.3167	-.4071	
		2.0	-1.2714	-1.7800	-2.2886	
		0.0	2.0127	2.8178	3.6229	
		0.5	1.8119	2.5366	3.2614	
0.5	1.0	1.0	1.1674	1.6344	2.1014	2.0
		1.5	.2372	.3320	.4269	
		2.0	-.7512	-1.0516	-1.3521	

The numerical values of skin friction at the wall along z-axis, i.e., τ_2 are entered in table 2 which shows the effects of R_c, G, m, Ω and Ωt on τ_2. The value of τ_2 first rises and then starts falling at Ωt = 1.5 with the rise of R_c as evident from the readings of this table. It is observed that the value of τ_2 starts rising with the rise of Ωt

ISSN 2229-5518

from 0.0 to 1.5 and shows a tendency to fall from Ωt = 2.0. The frequency parameter has got a reverse effect on τ_2 as compared to Ωt. From the readings of this table it is also observed that τ_2 increases with an increase in any one of the parameters m and G. However, for the negative value of τ_2, it tends to decrease with the rise of G. All these results are obtained considering other variables constant.

Table 3 exhibits the relation of the surface heat flux with P_r, Ω and Ωt. It is to note here that the surface heat flux decreases with an increase in any one of the parameters P_r, Ω and Ωt as evident from the table.

Table 2 :Effects of R_c, G, m, Ωt and Ω on skin friction at the wall along z-axis for P_r = 0.1 and M = 3.0, K^* = 1.0

R_c	m	$G/\Omega t$	5.0	7.0	9.0	Ω
		0.0	-.0680	-.0952	-.1224	
		0.5	-8007	1.1209	1.4412	
0.05	0.5	1.0	1.4732	2.0625	2.6518	1.0
		1.5	1.7851	2.4992	3.2133	
		2.0	1.6600	2.3240	2.9879	
		0.0	0.0926	.1297	.1667	
		0.5	.9306	1.3029	1.6752	
0.5	0.5	1.0	1.5408	2.1571	2.7734	1.0
		1.5	1.7737	2.4832	3.1927	
		2.0	1.5724	2.2013	2.8303	
		0.0	.3839	.5375	.6911	
		0.5	1.3995	1.9593	2.5191	
0.5	1.0	1.0	2.0724	2.9014	3.7303	1.0
		1.5	2.2379	3.1331	4.0283	
		2.0	1.8555	2.5977	3.3399	
		0.0	-.0950	-.1331	-.1711	
		0.5	.8815	1.2341	1.5868	
0.5	1.0	1.0	1.6423	2.2992	2.9561	2.0
		1.5	2.0009	2.8013	3.6017	
		2.0	1.8697	2.6167	3.3654	

Table 3 : Effects of P_r, Ω and Ωt on the rate of heat transfer for R_c = 0.5, G = 5.0, M=3.0, m = 0.5, K^* = 1.0

P_r	Ω	Ωt	Q(t)
0.1	1.0	0.0	.1675
0.1	1.0	1.0	0.0010
0.1	1.0	2.0	-.1664
0.1	2.0	2.0	-.2285
0.1	3.0	2.0	-.2759
0.2	3.0	2.0	-.4003
0.3	3.0	2.0	-.4993

5 CONCLUSIONS

Thus the systematic study of the present problem enables us to arrive at the following conclusions.

i) The Hall Parameter controls the flow field to a great extent. The velocity profile along X-axis decreases while that along z-axis increases with the increase in Hall parameter.

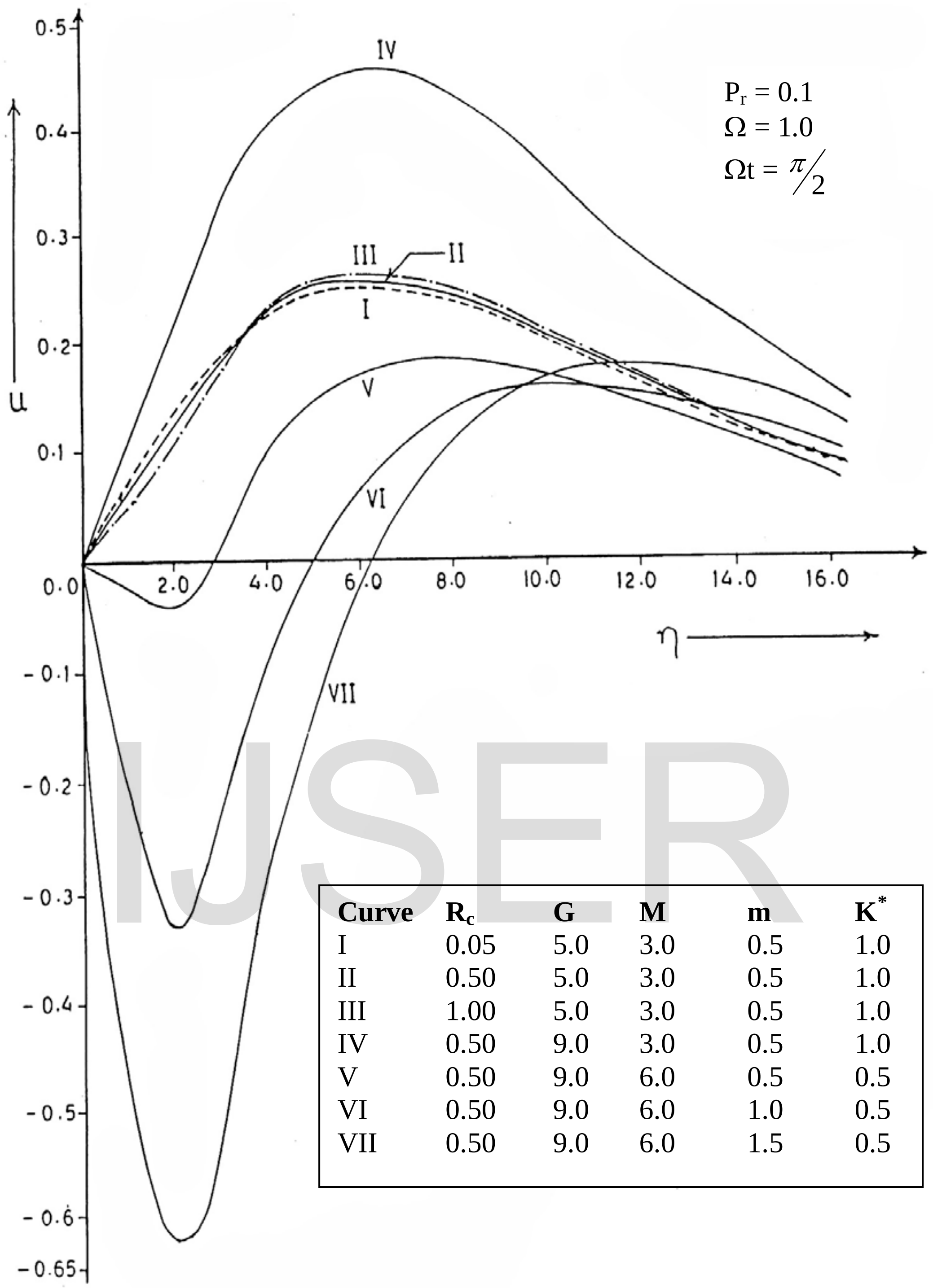
ii) An increase in Grashof number enhances u and w both while the increase in Hartmann number reduces the values of both the components of velocity profile.

iii) An increase in elastic property of the fluid decelerates the flow slowly near the plate.

iv) The temperature profile rises with the rise of frequency parameter and falls with the rise of Prandtl number.

v) Decrease in the value of permeability factor reduces the values of both the velocity components u and w.

ISSN 2229-5518



Curve	R_c	G	M	m	K^*
I	0.05	5.0	3.0	0.5	1.0
II	0.50	5.0	3.0	0.5	1.0
III	1.00	5.0	3.0	0.5	1.0
IV	0.50	9.0	3.0	0.5	1.0
V	0.50	9.0	6.0	0.5	0.5
VI	0.50	9.0	6.0	1.0	0.5
VII	0.50	9.0	6.0	1.5	0.5

Fig. 1 :Effects of R_c, G, M, K^* and m on u.

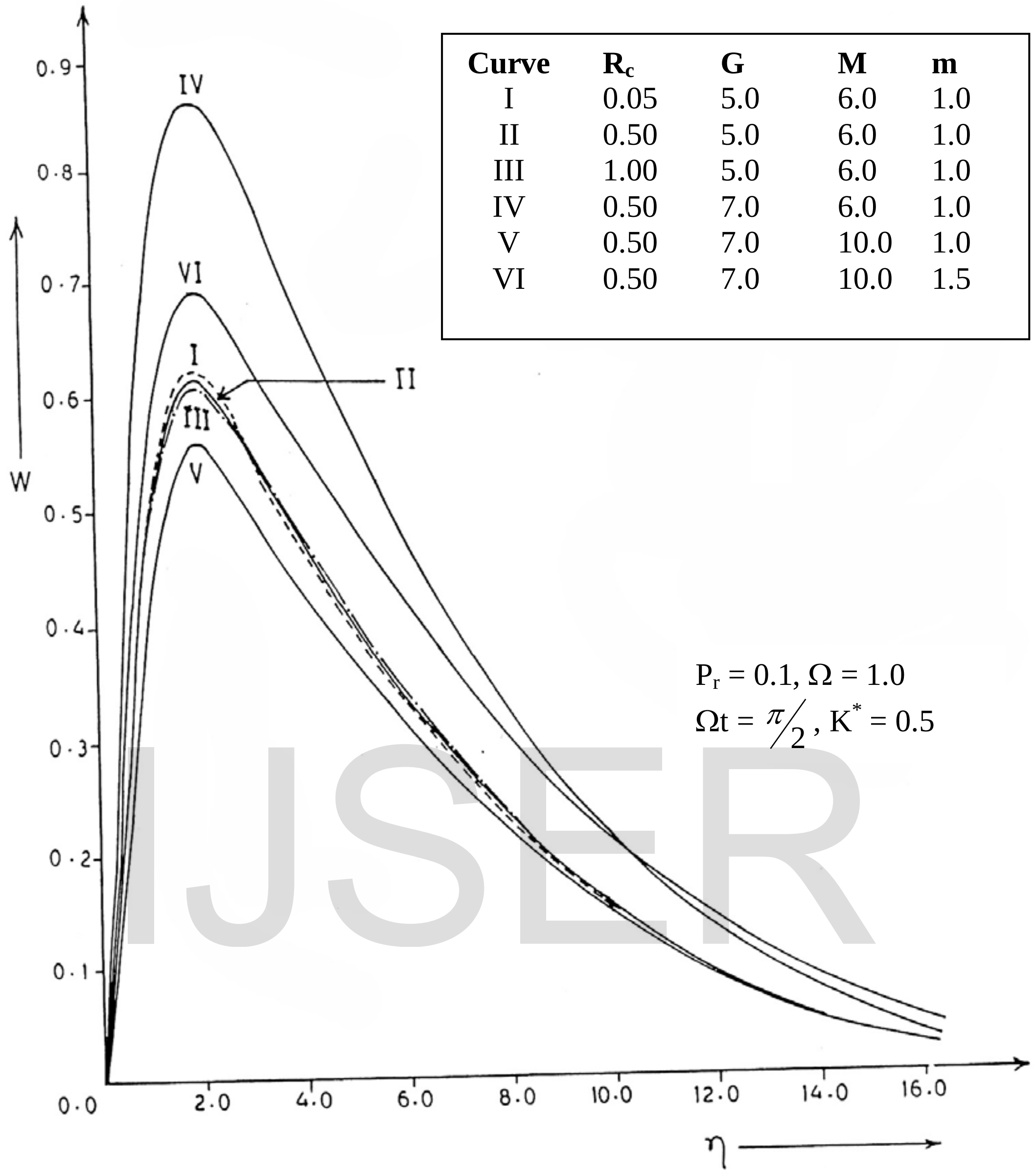


Fig. 2 : Effects of R_c, G, M and m on w.

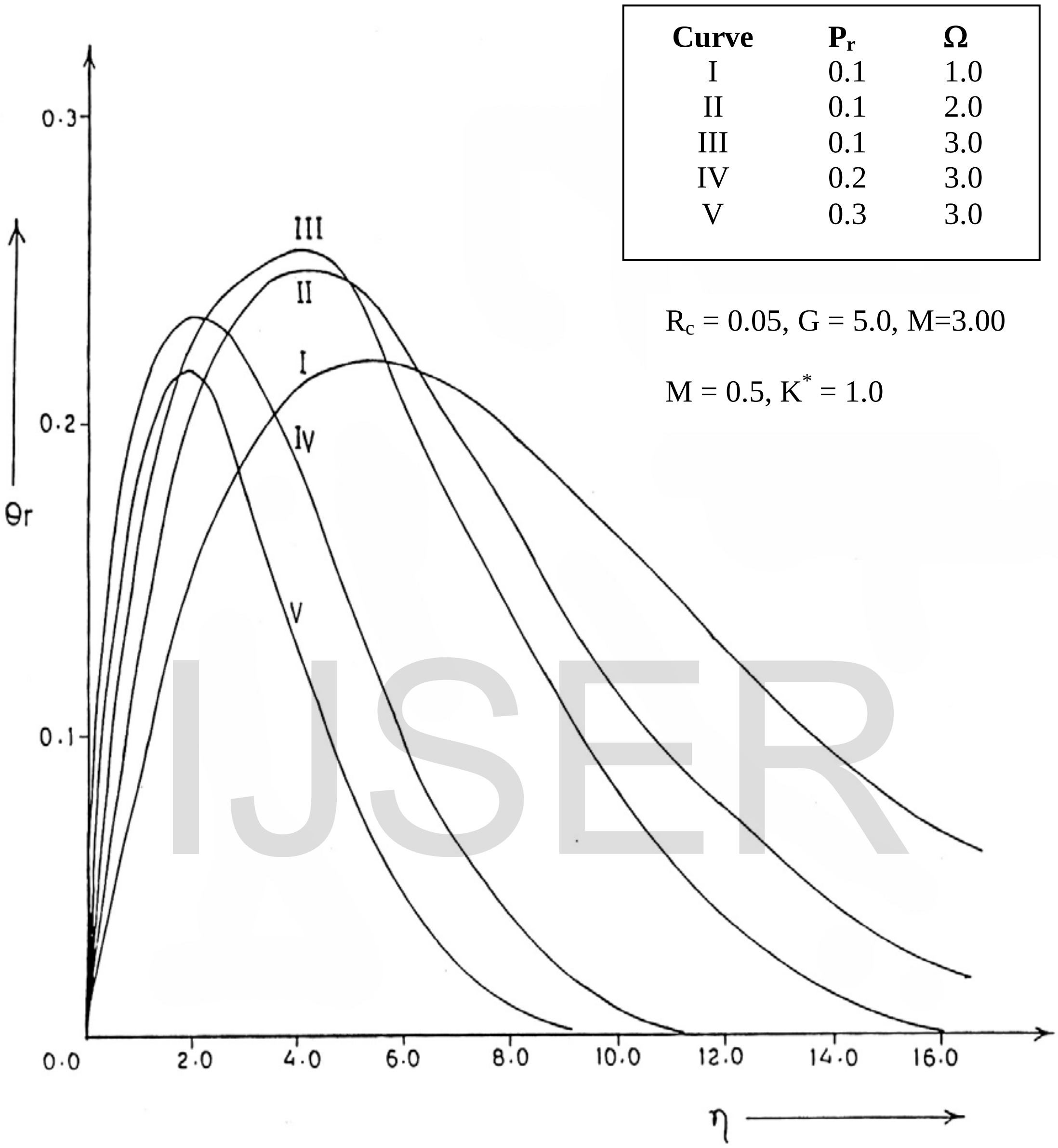


Fig. 3 : Effects of P_r and Ω on θr.

References :

1. A.S. Gupta, *Acta. Mechanica* **22**, 281 (1975)
2. D.Singh, *J.Phys. Soc. Japan* **19**, 75.1 (1964)
3. S.S. Chawla, and Angew, Z. *Math. Mech*. **47**, 499 (1967)
4. I. Pop. and Angew, Z. *Math. Mech*. **49**, 756 (1969)
5. M.A. Hossain, *J. Phys. Soc Jpn* **55**, 2183 (1986)
6. M.A. Hossain, and K. Mohammed, *Japanese Journ. Appl. Physics*. **27**, 8, 1531 (1988)
7. M.A. Hossain, and R.I.M.A. Rashid, *J. Phys. Soc. Japan* **56**, 1, 97-104 (1987)
8. P. Mohapatra, and A. Tripathy, *J. Or. Math. Soc* **7**, 1, 49-63 (1988)
9. G.C. Dash, and B.K. Ojha, *AMSE Model*, *Simu. Contr.* B, **20**, 39-53 (1989)
10. V.M. Soundalgekar, *Czeeh.J.Phys*. B**28**, 721-727 (1978)
11. G.C. Dash, and S. Biswal, *Model*, *Simu. Contr*, B., AMSE Press, **21**, 4, 13 (1989)
12. S. Biswal, and B.K. Pattnaik, *Bull. Orissa Phy. Soc*., Vol. **7**, pp. 47 (1999)